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ABSTRACT

The purpose of this water treatment field study training program is to: (1) develop new qualified water treatment plant operators; (2) expand the abilities of existing operators, permitting better service both to employers and public; and (3) prepare operators for civil service and certification examinations (examinations administered by state/professional associations which operators take to indicate a level of professional competence). Volume 2 is a continuation of volume 1, in which the emphasis was on the knowledge and skills needed by operators of conventional surface water treatment plants. This 12-chapter volume contains information on: iron and manganese control; fluoridation; softening; trihalomethanes; demineralization; handling and disposal of processed wastes; maintenance; instrumentation; safety; advanced laboratory procedures; drinking water regulations; and administration. Objectives, glossary, lessons, questions (with suggested answers), and a test are provided for each chapter. A final examination (with answers), how to solve water treatment plant arithmetic problems, water abbreviations, complete glossary, and subject index are provided in an appendix. Information on objectives, scope, and uses of this manual and instructions to participants in home-study courses are found in volume 1. (TW)

Environmental Protection Agency Review Notice

This training manual has been reviewed by the Office of Drinking Water, U.S. Environmental Protection Agency and the California Department of Health Services. Both agencies have approved this manual for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency nor the California Department of Health Services. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Environmental Protection Agency; California Department of Health Services; California State University, Sacramento; National Environmental Training Association; authors of the chapters or project reviewers, consultants, and directors.

WATER TREATMENT PLANT OPERATION

Volume II

A Field Study Training Program

prepared by

California State University, Sacramento
School of Engineering
Applied Research and Design Center

in cooperation with the
National Environmental Training Association

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Kenneth D. Kerri, Project Director

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for the

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OPERATOR TRAINING MANUALS

OPERATOR TRAINING MANUALS IN THIS SERIES are available from Ken Kerri, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819-2654, phone (916) 278-6142.

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NOTICE

This manual is revised and updated before each printing based on comments from persons using the manual.

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PREFACE

VOLUME II

Volume II is a continuation of Volume I. In Volume I, the emphasis was on the knowledge and skills needed by operators of conventional surface water treatment plants. Volume II stresses information needed by those operators but also includes information on specialized water treatment processes for iron and manganese control, fluoridation, softening, trihalomethanes, demineralization and the handling and disposal of process wastes. Topics of importance to the operators of all water treatment plants include maintenance, instrumentation, safety, advanced laboratory procedures, water quality regulations, administration, and how to solve water treatment plant arithmetic problems.

You may wish to concentrate your studies on those chapters that apply to your water treatment plant. Upon successful completion of this entire volume, you will have gained a broad and comprehensive knowledge of the entire water treatment field.

For information on:

1. Objectives of this manual,
2. Scope of this manual,
3. Uses of this manual,
4. Instructions to participants in the home-study course, and
5. Summary of procedure,

please refer to Volume I.

The Project Director is indebted to the many operators and other persons who contributed to this manual. Every effort was made to acknowledge material from the many excellent references in the water treatment field. Reviewers Leonard Ainsworth, Jack Rossum, and Joe Monscvitz deserve special recognition for their extremely thorough review and helpful suggestions. John Trax, Chet Pauls, and Ken Hay, Office of Drinking Water, U.S. Environmental Protection Agency, and John Gaston, Bill MacPherson, Bert Ellsworth, Clarence Young, Ted Bakker, and Beverlie Vandre, Sanitary Engineering Branch, California Department of Health Services, all performed outstanding jobs as resource persons, consultants and advisors. Larry Hannah served as Education Consultant. Illustrations were drawn by Martin Garrity. Charlene Arora helped type the field test and final manuscript for printing. Special thanks are well deserved by the Program Administrator, Gay Kornweibel, who typed, administered the field test, managed the office, administered the budget, and did everything else that had to be done to complete this project successfully.

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WATER TREATMENT PLANT OPERATION, VOLUME I

COURSE OUTLINE

WATER TREATMENT PLANT OPERATION, VOLUME II

CHAPTER 12

IRON AND MANGANESE CONTROL

by

Jack Rossum

with a special section by

Gerald Davidson

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Chapter 12. Iron and Manganese Control

OBJECTIVES

Chapter 12. IRON AND MANGANESE CONTROL

Following completion of Chapter 12, you should be able to:

1. Identify and describe the various processes used to control iron and manganese,
2. Collect samples for analysis of iron and manganese,
3. Safely operate and maintain the following iron and manganese control processes:
   a. Phosphate treatment,
   b. Ion exchange,
   c. Oxidation by aeration,
   d. Oxidation with chlorine,
   e. Oxidation with permanganate,
   f. Greensand,
   g. Proprietary processes, and
4. Troubleshoot red water problems.

GLOSSARY

Chapter 12. IRON AND MANGANESE CONTROL

ACIDIFIED (uh-SID-uh-FIE-d)
ACIDIFIED

The addition of an acid (usually nitric or sulfuric) to a sample to lower the pH below 2.0. The purpose of acidification is to "fix" a sample so it won't change until it is analyzed.

AQUIFER (ACK-wi-fer)
AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

BACKFLOW
BACKFLOW

A reverse flow condition, created by a difference in water pressures, which causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source. Also see BACKSIPHONAGE.

BACKSIPHONAGE
BACKSIPHONAGE

A form of backflow caused by a negative or below atmospheric pressure within a water system. Also see BACKFLOW.

BENCH SCALE TESTS
BENCH SCALE TESTS

A method of studying different ways or chemical doses for treating water on a small scale in a laboratory.

BREAKPOINT CHLORINATION
BREAKPOINT CHLORINATION

Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

CHELATION (key-LAY-shun)
CHELATION

A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of metals (copper). Also see SEQUESTRATION.

COLLOIDS (CALL-loids)
COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

DIVALENT (die-VAY-lent)
DIVALENT

Having a valence of two, such as the ferrous ion, Fe^{2+}. Also called BIVALENT.

GREENSAND
GREENSAND

A sand which looks like ordinary filter sand except that it is green in color. The sand is a natural ion exchange material which is capable of softening water and removing iron and manganese.

INSOLUBLE (in-SAWL-you-bull)
INSOLUBLE

Something that cannot be dissolved.

ION EXCHANGE
ION EXCHANGE

A water treatment process involving the reversible interchange (switching) of ions between the water being treated and the solid resin. Undesirable ions in the water are switched with acceptable ions on the resin.

ION EXCHANGE RESINS
ION EXCHANGE RESINS

Insoluble polymers, used in water treatment, that are capable of exchanging (switching or giving) acceptable cations or anions to the water being treated for less desirable ions.

RESINS RESINS

See ION EXCHANGE RESINS.

SEQUESTRATION (SEE-kwes-TRAY-shun) SEQUESTRATION

A chemical complexing (forming or joining together) of matallic cations (such as iron) with certain inorganic compounds, such as phosphate Sequestration prevents the precipitation of the metals (iron). Also see CHELATION.

ZEOLITE ZEOLITE

A type of ion exchange material used to soften water. Natural zeolites are siliceous compounds (made of silica) which remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials which remove calcium or magnesium and replace them with either sodium or hydrogen. Manganese zeolites are used to remove manganese.

CHAPTER 12. IRON AND MANGANESE CONTROL

12.0 NEED TO CONTROL IRON AND MANGANESE

Like the cities of Minneapolis and St. Paul, iron and manganese are referred to as a pair. They are, in fact, two distinct elements and are often found in water separately. Neither of them has any direct adverse health effects. Indeed, both are essential to the growth of many plants and animals, including humans.

However, the iron and manganese found in drinking water have no nutrient value for humans. Even if they were available in beneficial amounts, the presence of iron and manganese in drinking water would still be objectionable.

Clothes laundered in water containing iron and manganese above certain levels come out stained. When bleach is added to remove the stains, they are only intensified and become fixed so that no amount of further washing with iron-free water will remove the stains. They can be removed by treatment with oxalic acid, but this is rather hard on fabrics or by the use of commercial rust removers. Excessive amounts of iron and manganese are also objectionable because they impart stains on plumbing fixtures, bath tubs and sinks.

Perhaps the most troublesome consequence of iron and manganese in the water is that they promote the growth of a group of microorganisms known as iron bacteria. These organisms obtain energy for their growth from the chemical reaction that spontaneously occurs between iron and manganese and dissolved oxygen. These bacteria form thick slimes on the walls of the distribution system mains. Such slimes are rust colored from iron and black from manganese. Variations in flow cause these slimes to come loose which result in dirty water (a big source of consumer complaints). Furthermore, these slimes will cause foul tastes and odors in the water.

The growth of iron bacteria is controlled by chlorination. However, when water containing iron is chlorinated, the iron is converted into rust particles, and manganese is converted into a jet black compound called manganese dioxide. These materials form a loosely adherent coating on the pipe walls. Pieces of this coating will break loose from the pipe walls when there are changes or reversals of flow in the distribution system.

Iron and manganese in water can be easily detected by observing the color of the inside walls of filters and the filter media. If the raw water is prechlorinated, there will be black stains on the walls below the water level and a black coating over the top portion of the sand filter bed. This black color will usually indicate a high level of manganese in the raw water while a brownish-black stain indicates the presence of both iron and manganese.

The generally acceptable limit for iron in drinking water is 0.3 mg/*L* and that for manganese is 0.05 mg/*L*. However, if the water contains more than 0.02 mg/*L* of manganese, the operator should initiate an effective flushing program to avoid complaints. By regularly flushing the water mains, the buildup of black manganese dioxide can be prevented.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 22.

12.0A What problems are caused by iron and manganese in drinking water?

12.0B How can the growth of iron bacteria be controlled?

12.0C What are the generally acceptable limits for iron and manganese in drinking water?

12.1 MEASUREMENT OF IRON AND MANGANESE

12.10 Occurrence of Iron and Manganese

Because both iron and manganese react with dissolved oxygen to form *INSOLUBLE COMPOUNDS*,[1] they are not found in high concentrations in waters containing dissolved oxygen except as *COLLOIDAL SUSPENSIONS*[2] of the oxides. Accordingly, surface waters are generally free from both iron and manganese. One exception to this rule is that manganese up to one mg/*L* or higher may be found in shallow reservoirs and may come and go several times a year.

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[1] *Insoluble Compounds (in-SAWL-you-bull). Compounds that cannot be dissolved.*

[2] *Colloidal Suspensions (CALL-loid-al) Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.*

Iron or manganese is most frequently found in water systems supplied by wells and springs. Horizontal wells under rivers are notoriously prone to produce water containing iron. Bacteria will reduce iron oxides in soil to the soluble, *DIVALENT*[3] form of iron (Fe^{2+}) which will produce groundwater with a high iron content.

Iron bacteria can make use of the ferrous ion (Fe^{2+}). These bacteria will oxidize the iron and use the energy for reducing carbon dioxide to organic forms (slimes). The manganous ion (Mn^{2+}) is used in a similar fashion by certain bacteria. Very small concentrations of iron and manganese in water can cause problems, because bacteria obtain the nutrients (iron and manganese) from water in order to grow even when the concentrations are very low.

Iron bacteria are found nearly everywhere. They are frequently found in iron water pipes and everywhere else that a combination of dissolved oxygen and dissolved iron is usually or frequently present. Only one cell of iron bacteria is needed to start an infestation of iron bacteria in a well or a distribution system. Unfortunately it is almost impossible to drill a well and maintain sterile conditions to prevent the introduction of iron bacteria.

12.11 Collection of Iron and Manganese Samples

The best way to determine if there is an iron and manganese problem in a water supply is to look at the plumbing fixtures in a couple of houses. If the fixtures are stained, then there is a problem. Determination of the concentrations of iron and manganese in water is useful when evaluating well waters for use and treated waters for effectiveness of treatment processes.

The results of tests for iron and manganese are wrong more often than they are right. This is because samples for these substances are difficult to collect. Both iron and manganese form loosely adherent (not firmly attached) scales on pipe walls, including the sample lines. When the sample tap is opened, particles of scale may be dislodged and enter the sample bottle. If many of these particles enter the sample bottle, the error can become very large. Furthermore, unless the sample is acidified (enough nitric acid added to drop the pH to less than 2), both iron and manganese tend to form an adherent scale on the walls of the sample bottle in the few days that sometimes elapse before the analysis is started. When the sample is poured from the bottle for testing, most of the iiron and manganese will then remain inside the sample bottle.

To avoid this situation, samples should be taken from a plastic sample line located as close to the well or other source as possible. Open the sampling tap slowly so that the flow rate is suitable for filling the sample bottle. Allow the sample water to flow for at least one minute for each 10 feet (3 m) of sample line before the sample is collected.

Samples for iron and manganese should be tested within 48 hours unless they have been acidified. If the sample contains any clay or if any particles of rust are picked up from a steel pipe or fitting, an acidified sample will dissolve the iron in these substances and the results will be too high. If clay or rust particles are observed in a sample, do not acidify and request lab to analyze sample immediately. Furthermore, many laboratories fail to be sure that iron and manganese are in the divalent form (Fe^{2+} or Mn^{2+}) by adding enough nitric acid prior to the tests to lower the pH to less than two, so laboratory errors may be even greater than sampling errors.

12.12 Analysis for Iron and Manganese

The preferred method of testing for iron and manganese is atomic absorption, but for the small plant the equipment is too expensive. With careful attention to laboratory procedures, colorimetric methods (comparing colors of unknowns with known standards) can provide sufficient accuracy in most instances. These colorimetric methods use either a spectrophotometer, a filter photometer, or the less satisfactory set of matched Nessler tubes with standards. Good results have been obtained by the use of properly calibrated colorimeters (Figure 12.1). For detailed procedures on how to use a spectrophotometer to measure iron and manganese, see Chapter 21, "Advanced Laboratory Procedures."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 22.

12.1A How do iron and manganese form insoluble compounds?

12.1B Why must iron and manganese samples be acidified when they are collected?

12.1C Where should a sample for iron and manganese testing be collected?

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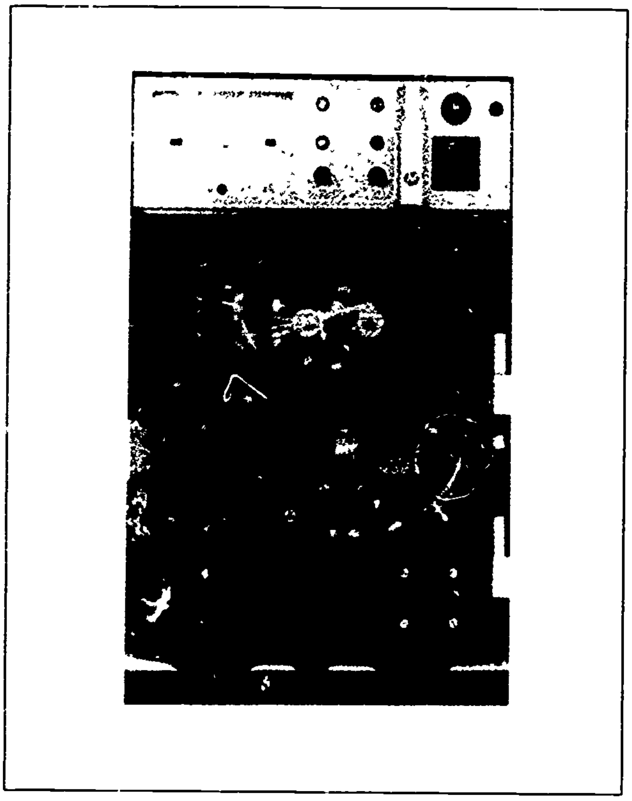
[3] *Divalent (die-VAY-lent). Having a valence of two, such as the ferrous ion, Fe^{2+}. Also called BIVALENT.*



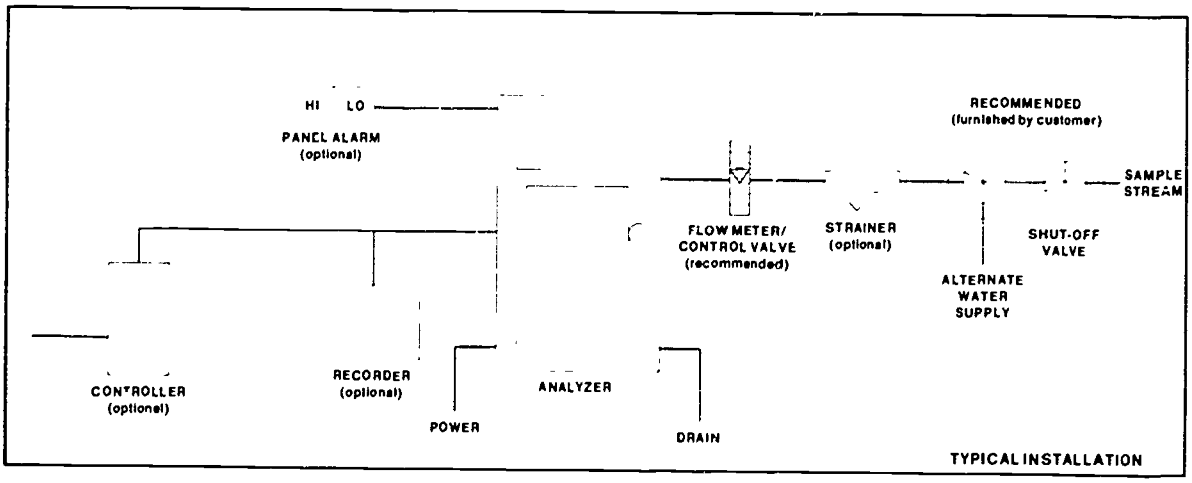


Fig. 12.1 Typical continuous on-line pump-colorimeter analyzer for iron, manganese or permanganate

(Permission of Hach)

12.2 REMEDIAL ACTION

Several methods are available to control iron and manganese in water. This section discusses how to operate the most common treatment processes.

12.20 Alternate Source

The construction of a plant to remove iron and manganese will cost as much as or more than a new well so it pays to investigate the possibility of obtaining an alternate supply of water that is free from iron and manganese. This investigation should include samples from nearby private wells, discussions with well drillers who have been active in the locality and discussions with engineers in the state agency responsible for the regulation of well drilling.

If the water produced by the well contains dissolved oxygen along with iron and manganese, this is an indication that water is being drawn from more than one *AQUIFER*.[4] One or more, of the aquifers must be producing water containing dissolved oxygen but is free of iron and manganese since oxygen reacts with both elements to form insoluble compounds. Furthermore, it is highly probable that the iron- or manganese-bearing water is from deeper aquifers so that it may be possible to cure the problem simply by sealing off these deeper aquifers.

12.21 Phosphate Treatment

If the water contains manganese up to 0.3 mg/*L* and less than 0.1 mg/*L* of iron, an inexpensive and reasonably effective control can be achieved by feeding the water with one of the polyphosphates listed below. Chlorine usually must be fed along with the polyphosphate to prevent the growth of iron bacteria. The effect of the polyphosphate is to delay the precipitation of oxidized manganese for a few days so that the scale that builds on the pipe walls is greatly reduced.

The chlorine dose for phosphate treatment should be sufficient to produce a free chlorine residual of approximately 0.25 mg/*L* after a five-minute contact time (a higher chlorine dose may be required with some water to maintain a free chlorine residual of at least 0.2 mg/*L* throughout the distribution system).

Any of the three polyphosphates (pyrophosphate, tripolyphosphate, and metaphosphate) can be used, but sodium metaphosphate is effective in lower concentrations than the others. The proper phosphate dose is determined by laboratory *BENCH SCALE TESTS*[5] in the following manner

1. Treat a series of samples with a standard chlorine solution to determine the chlorine dose required to produce the desired chlorine residual.
2. Prepare a standard polyphosphate solution by dissolving 1.0 gram of polyphosphate in a liter of distilled water.
3. Treat another series of samples with varying amounts of polyphosphate solution. One m*L* of the standard polyphosphate solution (0.1% solution) in a liter sample is equivalent to 8.34 pounds of polyphosphate per million gallons (see Examples 2 and 3 on pages 15 and 16). Stir to assure that the polyphosphate has been well mixed; and continue stirring while adding the previously determined chlorine dose so as to minimize the creation of high concentrations of chlorine.
4. Observe the samples daily against a white background, noting the amount of discoloration. The proper polyphosphate dose is the lowest dose that delays noticeable discoloration for a period of four days.

Samples for the above bench test should be as fresh as possible and should be kept away from direct sunlight to avoid heating.

Polyphosphate treatment to control iron and manganese is usually most effective when the polyphosphate is added upstream from the chlorine, but satisfactory results may be obtained by feeding them together. The chlorine should never be fed ahead of the polyphosphate because the chlorine will oxidize the iron and manganese (cause insoluble precipitates to form too soon).

If you are able to install a one-half inch (12 mm) polyethylene hose in the well so that it discharges a few inches below the suction screen, you can construct a very satisfactory semi-automatic feed system. Use a gas-feed chlorinator whose water supply is obtained from the well discharge downstream from the check valve (Figure 12.2). In this way, the chlorinator operates only when the pump is running. The chlorine solution is fed down the polyethylene tube. Polyphosphate is fed down the same tube by means of a plastic tee. The phosphate is fed by means of an electrically operated solution feeder so connected as to run when the well pump runs.

The chlorine solution flowing through the polyethylene is extremely corrosive. If the tube does not discharge into flowing water, the corrosive effect of the solution on a metal surface can be disastrous. Wells have been destroyed by corrosion from this cause. The following simple test should be made at least once every three months.

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[4] *Aquifer (ACK-wi-fer). A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.*

[5] *Bench Scale Tests. A method of studying different ways or chemical doses for treating on a small scale in a laboratory*

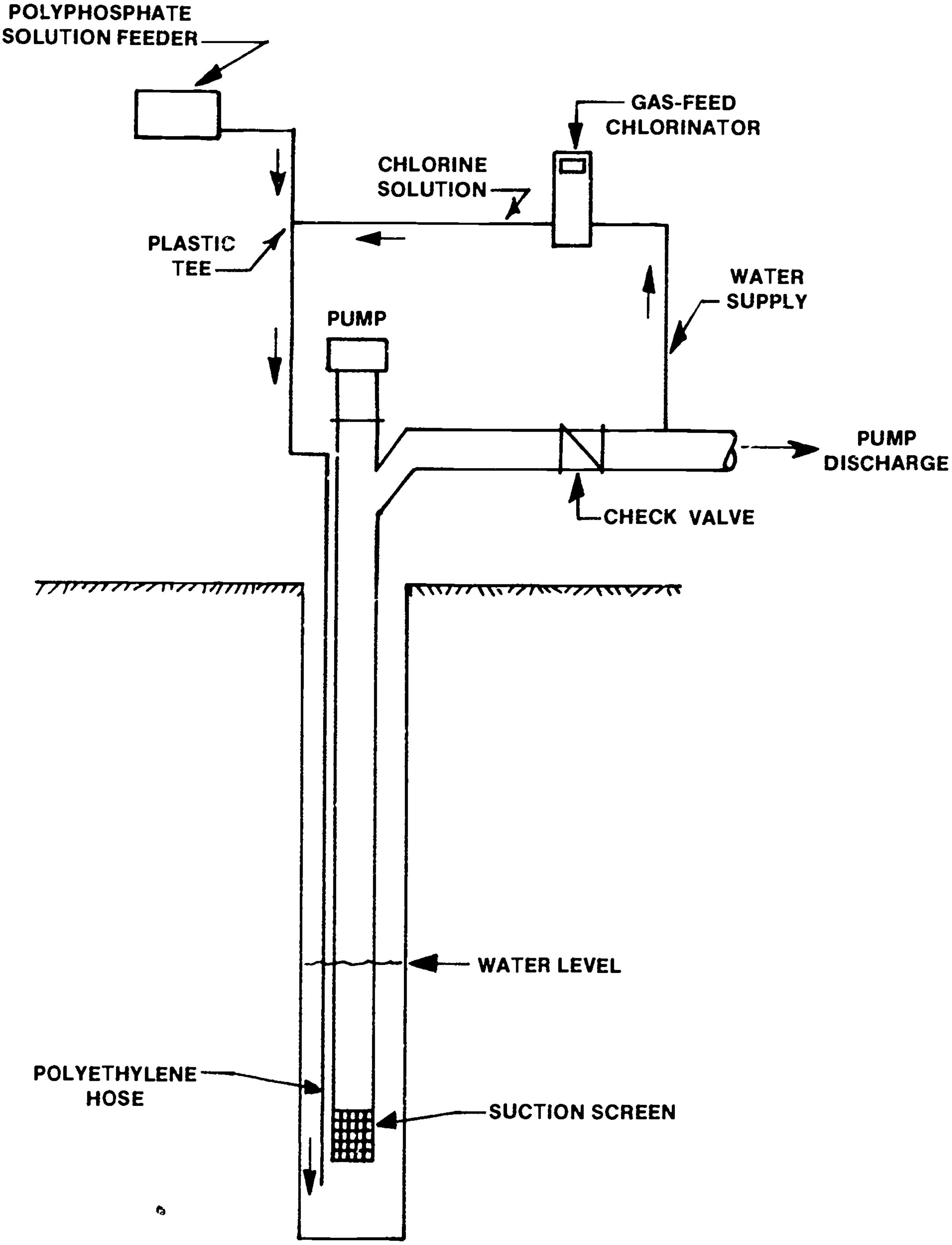


Fig. 12.2 Polyphosphate and chlorine system

EXAMPLE 1

1. Calculate the time required for water to flow from the pump suction to the pump discharge.
   a. Record the following information:
      (1) Length of pump column from suction to discharge in feet, 324 ft.
      (2) Diameter of pump column in inches, 8 in.
      (3) Discharge rate from pump in gallons per minute, 423 GPM.
   b. Calculate the volume of the pump column in inches.

$$\text{Volume, cu in} = (0.785)(\text{Diameter, in})^2(\text{Length, ft})(12\ \text{in/ft})$$
$$= (0.785)(8\ \text{in})^2(324\ \text{ft})(12\ \text{in/ft})$$
$$= 195{,}333\ \text{cubic inches}$$

   c. Convert the pump column volume from cubic inches to gallons.

$$\text{Volume, gal} = \frac{\text{Volume, cu in}}{231\ \text{cu in/gal}}$$
$$= \frac{195{,}333\ \text{cu in}}{231\ \text{cu in/gal}}$$
$$= 846\ \text{gallons}$$

   d. Determine the time required for the water to flow from the pump suction to the pump discharge.

$$\text{Time, min} = \frac{\text{Volume, gallons}}{\text{Pump Discharge, GPM}}$$
$$= \frac{846\ \text{gallons}}{423\ \text{gal/min}}$$
$$= 2.0\ \text{minutes}$$

2. Turn off the water supply to the chlorinator. Since some of the chlorine in the feed line will drain into the well, it may take several minutes for the chlorine residual to disappear. Check to be sure there is no chlorine residual in the water.
3. Turn the chlorinator back on, noting the exact time. Take samples for chlorine residual every 15 seconds. If the chlorine residual has reached its proper value within 30 seconds of the calculated time, you can be sure that the polyethylene tube is properly positioned below the suction screen.

Solutions of polyphosphate containing more than one-half pound per gallon (60 gm/*L*) may be very viscous (thick like molasses), depending upon which of the polyphosphates is used. Do not use a solution much over 48 hours old because the polyphosphates react slowly with water to form orthophosphates which are much less effective in preventing manganese deposits.

There are some reports in the literature of the successful use of tetrasodium pyrophosphate on iron-bearing waters, but many attempts to control iron have failed. The available information is not clear as to whether the process works only under special conditions or whether the reports of success are in error.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 22.

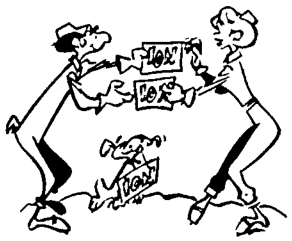
12.2A If a well produces water containing dissolved oxygen as well as iron and manganese, how would you attempt to solve the iron and manganese problem?

12.2B How could you find out if nearby wells produce water containing iron and manganese?

12.2C What are bench scale tests?

12.2D Why should polyphosphate solutions over 48 hours old not be used?

12.22 Removal by *ION EXCHANGE*[6]



The actual location of the *ION EXCHANGE RESINS*[7] with respect to other water treatment processes will depend on the raw water quality and the design engineer. If the water to be treated contains no oxygen, both iron and manganese may be removed by ion exchange using the same resins that are used for water softening. If the water being treated contains any dissolved oxygen, the resin becomes fouled with iron rust or manganese dioxide. The resin can be cleaned but this is expensive and the capacity is reduced. Well water may contain no oxygen in normal operating conditions except immediately after the well is first turned on. If this is the case, provisions should be made to run the well to waste until the oxygen is no longer present.

In one Eastern city, an ion exchange plant had operated for seven years, reducing iron from 52 mg/*L* to 0.1 mg/*L* and manganese from 1.3 mg/*L* to zero. When a pump was repaired, a gasket on the suction side of the pump was improperly installed, allowing air to enter the raw water. Within three months the resin was fouled by iron oxide.

The main advantage of ion exchange for iron and manganese removal is that the plant requires little attention. The disadvantages are the danger of fouling the ion exchange resin with oxides and high initial cost.

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[6] *Ion Exchange A water treatment process involving the reversible interchange (switching) of ions between the water being treated and the solid resin. Undesirable ions in the water are switched with acceptable ions on the resins.*

[7] *Ion Exchange Resins Insoluble polymers, used in water treatment, that are capable of exchanging (switching or giving) acceptable cations or anions to the water being treated for less desirable ions.*

To operate an ion exchange unit, try to operate as close as possible to design flows. Monitor the treated water for iron and manganese on a daily basis. When iron and manganese start to appear in the treated water, the unit must be regenerated. Regeneration is accomplished with a brine solution that is treated with 0.01 pound of sodium bisulfite per gallon (1.2 gm/*L*) of brine to remove oxygen present. After regeneration is complete, the brine must be disposed of in an approved manner.

See Chapter 14, "Softening," for procedures on how to calculate the frequency for regenerating the unit Details are given in Chapter 17, "Handling and Disposal of Process Wastes," on how to properly dispose of brine solutions.

12.23 Oxidation by Aeration

Iron can be oxidized by aerating the water to form insoluble ferric hydroxide. As shown in Figure 12.3, this reaction is accelerated by an increase in pH. The rates indicated in Figure 12.3 were determined at 25°C under laboratory conditions. If the water contains any organic substances, the rates will be significantly lower, reduced temperatures will also lower the rates.

Since pH is increased by the removal of carbon dioxide, it is important that the aeration (which removes carbon dioxide) be as efficient as possible. Lime is sometimes added to the water to increase the pH as well as remove carbon dioxide. The higher the pH, the shorter the time required for aeration, as shown in Figure 12.3.

Operation of the aeration process to remove iron and manganese requires careful control of the flow through the process. If the flow becomes too great, not enough time will be available for the reactions to occur. Flows are controlled by the use of variable speed pumps or the selection of the proper number or combinations of pumps. Carefully monitor the iron and manganese content of the treated water. If iron is detected, the flows may have to be reduced.

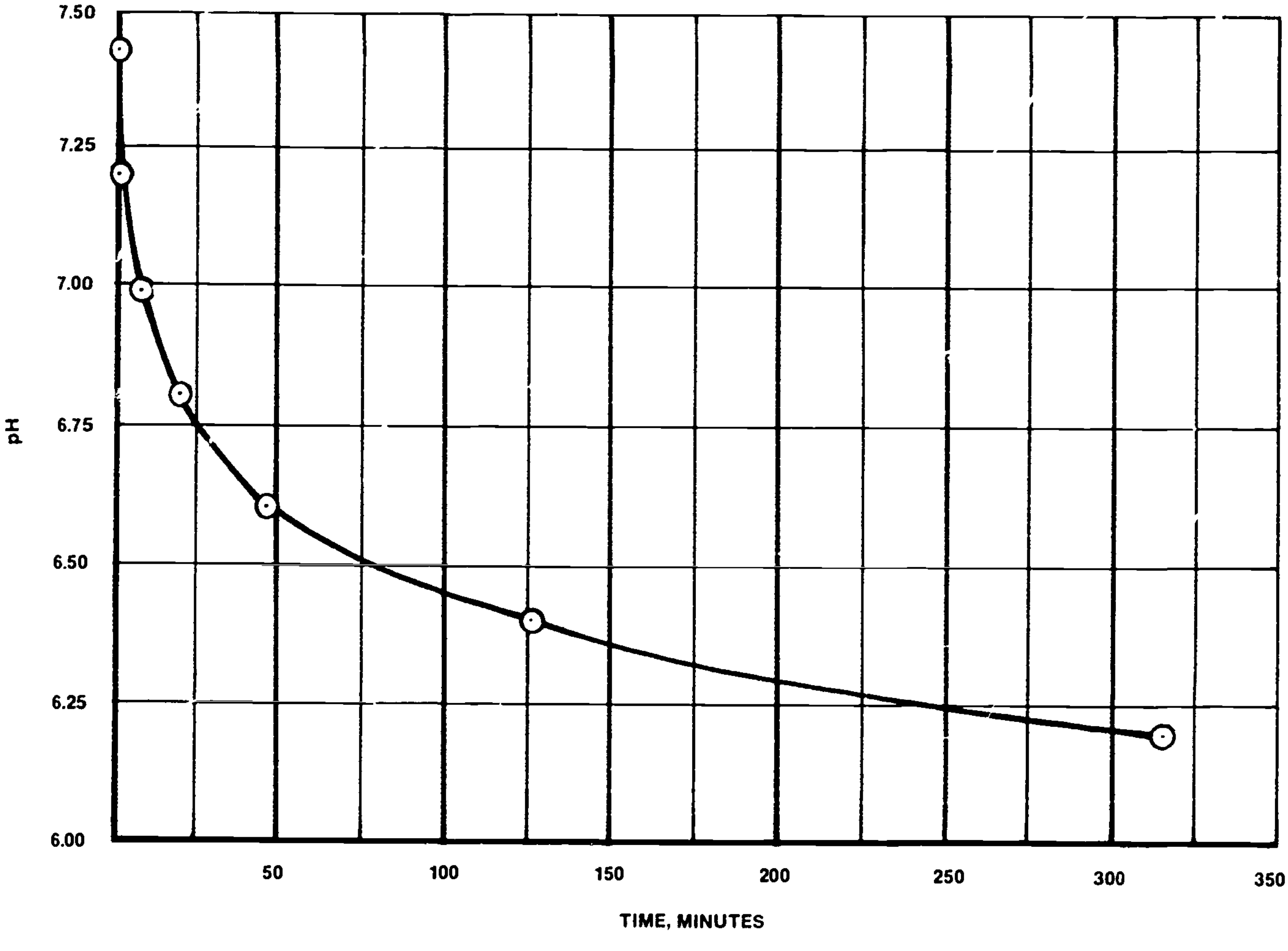

Fig. 12.3 pH vs. time to oxidize 99 percent iron

There are several methods of providing aeration. Either the water being treated is dispersed (scattered) into the air or air is bubbled through the water. Aeration may be achieved by the use of compressed air which passes through diffusers in the water. These diffusers produce many small bubbles which allow the transfer of oxygen in the air to dissolved oxygen in the water.

Other aeration techniques include forced draft, multiple trays, cascades and sprays These methods may develop slime growths on surfaces or coatings on media. Slime growths and coatings on media should be controlled to prevent the development of tastes and odors in the product water and the sloughing off of the slimes. Chlorination may be used to control slime growths and coatings. Regularly inspect aeration equipment for the development of anything unusual.

A reaction basin (sometimes called a collection or detention basin) follows the aeration process. The purpose of the reaction basin is to allow time for the oxidation reactions to take place. The aeration process should produce sufficient dissolved oxygen for the iron to be oxidized to insoluble ferric hydroxide. A minimum recommended detention time is 20 minutes with desirable detention times ranging from 30 to 60 minutes (see Example 4, page 16). As shown in Figure 12.3, the pH of the water strongly influences the time for the reaction to take place. Sometimes chlorine is added before the reaction basin.

The reaction basin may be a cylindrically (circular) shaped basin similar to a clarifier. Often the basin is baffled to prevent short-circuiting and the deposition of solids. Since there are no provisions for sludge removal, the basin must be drained and cleaned regularly. If the basins are not cleaned, slugs of deposits or sludge or also mosquito or fly larvae (young or any insect) could reach the filters in the next process and cause them to plug.

Operators of reaction basins must always be on the alert for potential sources of contamination. These basins should have covers and protective lids to keep out rain, storm water runoff, rodents and insects. All vents must be properly screened. The outlet to the drain must not be connected directly to a sewer or storm water drain. There must be an air gap or some other protective device to prevent contamination from *BACKFLOW*.[8]

After the ferric hydroxide is formed, it is removed by sedimentation or by filtration alone. If only filtration is used, water from the reaction basin is usually pumped to pressure filters for filtration. The water may also be pumped or flow by gravity to rapid sand filters. For details on how to operate and maintain filters, see Chapter 5, "Filtration."

The oxidation of manganese by aeration is so slow that this process is not used on waters with high manganese concentrations.

The main advantage of this method is that no chemicals are required; however, lime may be added to increase the pH The major disadvantage is that small changes in raw surface water quality may affect the pH and soluble organics level and slow the oxidation rates to a point where the capacity of the plant is reduced.

12.24 Oxidation with Chlorine

Chlorine will oxidize manganese to the insoluble manganese dioxide and will oxidize iron to insoluble ferric hydroxide which can then be removed by filtration. The higher the chlorine residual, the faster this reaction occurs. Some very compact plants have been constructed by treating the water to a free chlorine residual of 5 to 10 mg/*L*, filtering, and dechlorinating to a residual suitable for domestic use. Do not use high doses of chlorine if the water contains a high level of organic color because excessive concentrations of total trihalomethanes (TTHMs) could develop. The water is dechlorinated by the use of reducing agents such as sulfur dioxide (SO_2), sodium bisulfite ($NaHSO_3$), and sodium sulfite (Na_2SO_3). Bisulfite is commonly used because it is cheaper and more stable than sulfite. When dechlorinating with reducing agents be very careful not to overdose because inadequate disinfection could result (no chlorine residual remains) and if the dissolved oxygen level in the water is depleted, fish kills could occur in home aquariums. Frequently, a reaction basin (as described in Section 12.23, "Oxidation by Aeration") is installed between the chlorination processes to allow time for the reactions to occur.

Chlorine oxidizes iron to insoluble ferric hydroxide which is removed by filtration along with the manganese dioxide.

12.25 Oxidation with Permanganate

Potassium permanganate oxidizes iron and manganese to insoluble oxides, and can be used to remove these elements in the same way chlorine is used. The dose of potassium permanganate must be exact. Bench scale tests are required to determine the proper dosage. Too small a dose will not oxidize all the manganese in the water and too large a dose will allow permanganate to enter the system and may produce a pink color in the water. Actual observations of the water being treated will tell you if any adjustments of the chemical feeder are necessary.

Experience from many water treatment plants has shown that a regular filter bed (a rapid sand filter or a dual media filter bed) can remove manganese as long as iron and manganese are both under one milligram per liter. These plants use either chlorine or permanganate to oxidize the iron and manganese before the water being treated flows through the filter bed.

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[8] *Backflow A reverse flow condition, created by a difference in water pressures, which causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source.*

Potassium permanganate is often used with "manganese *ZEOLITE*[9]" or "manganese *GREENSAND.*[10]" Greensand is a granular material. After the greensand has been treated with potassium permanganate it can oxidize both iron and manganese to their insoluble oxides. The greensand also acts as a filter. This mineral is regenerated with potassium permanganate after backwashing to remove the insoluble oxides.

A modification of this procedure called CR (Continuous Regeneration) consists of feeding a potassium permanganate solution into the water. If an excess of permanganate is fed, the effluent may be colored pink. For more information on this process, see Section 12.3, "Operation of an Iron and Manganese Removal Plant."

12.26 Operation of Filters

When iron and manganese are oxidized to insoluble forms by aeration, chlorination or permanganate, the oxidation processes are usually followed by filters to remove the insoluble material. In addition to the procedures for operating and maintaining filters that were outlined in Chapter 6, "Filtration," the procedures discussed in this section apply to filters used to remove iron and manganese.

Iron tests should be made monthly on the water entering a filter to be sure the iron is in the ferric (Fe^{3+}) state. Collect a sample of the water and pass the water through a filter paper. Run an iron test on the water which has passed through the filter. If the iron is still in the soluble ferrous (Fe^{2+}) state, there will be iron in the water. If aeration is being used to oxidize the iron from the soluble ferrous to the insoluble ferric state and iron is still present in the soluble state in the water entering the filter, try adding chlorine or potassium permanganate. If chlorine or potassium permanganate are being used and soluble iron is in the water entering the filter, try increasing the chemical dose. If potassium permanganate is being used, the sand may be replaced by greensand to improve the efficiency of the process.

If oxidation is being accomplished by either aeration or chlorination, a free chlorine residual must be maintained in the effluent of the filter to prevent the insoluble ferric iron from returning to the soluble ferrous form and passing through the filter.

Most iron removal treatment plants are designed so that the filters are backwashed according to head loss. If iron breakthrough is a problem, filters should be backwashed when breakthrough occurs or just before breakthrough is expected. Accurate records can reveal when breakthrough occurs and also when breakthrough can be expected.

12.27 **Proprietary Processes** by Bill Hoyer

There are several patented processes that are available for iron and manganese control. The best way to learn about the effectiveness and maintenance requirements of these processes is to contact someone who has one. Once you are operating one of these processes, the manufacturer is a good source of help when troubleshooting. Remember that various sources of raw water are different and what works for one operator may not work at your water treatment plant.

Electromedia iron and manganese removal systems are generally used on groundwater supplies at individual well sites because of their compactness and simplicity of treatment The system uses reaction vessels where chemical reactions take place and an adsorbtive media that requires no regeneration by special chemicals. Chlorine is used as the oxidizing chemical because of its cost and efficiency. (Any suitable oxidizing chemical can be used.) Almost 30 percent less chlorine, pound for pound, is required to perform the same amount of oxidation as potassium permanganate.

After oxidation with chlorine a small dose of sulfur dioxide (0 25 to 0 50 mg/*L*) is introduced prior to the second reaction vessel. This dosage is factory set according to the general mineral analysis of the raw water. Dosage should not be altered. The sulfur dioxide is used to accelerate the oxidation of any sulfur compounds in the water to form compounds having no objectionable taste or odor.

The water is then sent to a filter operating at a preset rate of up to 15 gallons per minute per square foot (10 liters per second per square meter or 10 millimeters per second). In the filter vessel, the iron and manganese are adsorbed on the surface of the media until backwashing. The media can withstand a very high backwash rate (20 gallons per minute per square foot, 13.6 *L*/sec/sq m or 13.6 mm/sec) and requires only a four-minute backwash to obtain thorough cleaning.

The filter effluent can be sampled by a continuously monitoring analyzer that drives a 30-day strip chart recorder. The recorder may have a color-coded indicating strip to direct the operator in the proper chemical dosage. If the recorder trace falls out of the green, the operator increases the chlorine dosage. The dosage is adjusted by turning one knob and can be read immediately. The effect of the change can be seen on the chart trace in five minutes and will reach a steady state within ten minutes. Thus the operator can quickly determine the proper dosage. With the chemical dosage set properly, a free chlorine residual exists in the filter effluent providing the required disinfection in the distribution system. Variations in water quality are quickly reflected in the chart tracing. Since no permanganate is used, there are no "black water" or "pink water" complaints from accidental underdosage or overdosage of chemicals.

The process uses *BREAKPOINT CHLORINATION,*[11] and the very effective adsorbtive qualities of the media. Each system is provided with an automatic control panel that permits adjustment of any of the filter cycles simply by rotating a timer knob. Status of the system is displayed on the front panel with pilot lights for easy viewing. The automatic control panel operates the manually set chemical feed system using gaseous chlorine and gaseous sulfur dioxide. Backwash is accomplished automatically by using a process signal and filtration timer with a differential pressure override.

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[9] *Zeolite A type of ion exchange material used to soften water Natural zeolites are siliceous compounds (made of silica) which remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials which remove calcium or magnesium and replace them with either sodium or hydrogen. Manganese zeolites are used to remove iron and manganese from water.*

[10] *Greensand A sand which looks like ordinary filter sand except that it is green in color. The sand is a natural ion exchange material which is capable of softening water and removing iron and manganese.*

[11] *Breakpoint Chlorination. Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.*

Maintenance on the system is quite limited. Most systems are built with an automatic standby for the chemicals that will switch from an empty container to a full container. Table 12.1 lists the recommended maintenance.

Each application for iron and manganese removal is based on the general mineral analysis of the raw water. The required chemical treatment is provided for iron, manganese and sulfide treatment. Additional equipment may be provided where corrosivity and/or chelating compounds are found to be present. Aeration may precede the process where methane extraction and/or carbon dioxide removal is required. Plant operators are directed to the operation and maintenance instructions provided with the equipment for additional details.

TABLE 12.1 RECOMMENDED MAINTENANCE FOR THE ELECTROMEDIA PROCESS

	Daily	*Weekly*	*Monthly*
1. Inspection of chart paper for proper chemical dosage	X		
2. Free chlorine residual test	X		
3. Total chlorine residual test	X		
4. Addition of buffer solution in the analyzer		X	
5. Colorimeteric analysis of the influent and effluent for iron concentration		X	
6. Laboratory tests for analysis of influent and effluent for iron and manganese concentration			X
7. Changing of chart paper			X
8. Routine maintenance checks associated with valves, pipes and pumps			X

12.28 Monitoring of Treated Water

When controlling iron and manganese by aeration or with chemicals, the product water must be monitored closely. If lab facilities are available, the treated water can be analyzed for iron and manganese to be sure treatment is adequate. A quick way to monitor treated water is to collect a sample and add a dose of chlorine. If a brown or rust-colored floc develops, then the treatment is inadequate. You will either have to increase the chemical doses or reduce the flows. If a pink color appears in the product water when using permanganate, then the dose is too high and must be reduced until the pink color is no longer visible.

12.29 Summary

Small iron and manganese water treatment plants can be very difficult to operate. If your plant is not operating as desired, talk to other operators in your area and see if they have any suggestions. If you have problems, you will have to try different chemical doses and procedures. Keep accurate records so you can evaluate the effectiveness of your efforts.

A lot of "iron complaints" in drinking water are caused by old steel or cast iron water mains. A possible solution to this problem is to inject polyphosphates directly into the distribution mains. See Section 12.5, "Troubleshooting Red Water Problems," for additional ideas on how to solve problems.

FORMULAS

A standard polyphosphate solution is prepared by mixing and dissolving a known amount of polyphosphate in a container and adding distilled water to the one liter mark. To determine the settings on polyphosphate chemical feeders:

1. Prepare a series of samples and test with polyphosphate,
2. Select the optimum dosage in mg/L, and
3. Calculate the chemical feeder setting in pounds of polyphosphate per day.

$$\text{Stock Solution, mg/m}L = \frac{(\text{Polyphosphate, grams})(1000\text{ mg/gram})}{(\text{Solution, liter})(1000\text{ m}L/L)}$$

$$\text{Dose, mg/}L = \frac{(\text{Stock Solution, mg/m}L)(\text{Volume Added, m}L)}{\text{Sample Volume, }L}$$

$$\text{Dose, lbs/MG} = \frac{(\text{Dose, mg/}L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(1000\text{ mg/gm})(454\text{ gm/lb})(1\text{ Million})}$$

$$\text{Chemical Feeder, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

EXAMPLE 2

A standard polyphosphate solution is prepared by mixing and dissolving 1.0 grams of polyphosphate in a container and adding distilled water to the one-liter mark. Determine the concentration of the stock solution in milligrams per milliliter. If 5 milliliters of the stock solution are added to a one-liter sample, what is the polyphosphate dose in milligrams per liter and pounds per million gallons?

Known		Unknown
Polyphosphate, gm	= 1.0 gm	1. Stock Solution, mg/mL
Solution, L	= 1.0 L	2. Dose, mg/L
Stock Solution, mL	= 5 mL	3. Dose, lbs/MG
Sample, L	= 1 L	

1. Calculate the concentration of the stock solution in milligrams per milliliter.

$$\text{Stock Solution, mg/m}L = \frac{(\text{Polyphosphate, gm})(1000\text{ mg/gm})}{(\text{Solution, }L)(1000\text{ m}L/L)}$$

$$= \frac{(1.0\text{ gm})(1000\text{ mg/gm})}{(1\ L)(1000\text{ m}L/L)}$$

$$= 1.0\text{ mg/m}L$$

2. Determine the polyphosphate dose in the sample in milligrams per liter.

$$\text{Dose, mg/}L = \frac{(\text{Stock Solution, mg/m}L)(\text{Vol. Added, m}L)}{\text{Sample Volume, }L}$$

$$= \frac{(1.0\text{ mg/m}L)(5\ L)}{1\ L}$$

$$= 5.0\text{ mg/}L$$

3. Determine the polyphosphate dose in the sample in pounds of phosphate per million gallons.

$$\text{Dose, lbs/MG} = \frac{(\text{Dose, mg/}L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(1000\text{ mg/gm})(454\text{ gm/lb})(1\text{ Million})}$$

$$= \frac{(5.0\text{ mg/}L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(1000\text{ mg/gm})(454\text{ gm/lb})(1\text{ Million})}$$

$$= 42\text{ lbs/MG}$$

EXAMPLE 3

Determine the chemical feeder setting in pounds of polyphosphate per day if 0.4 MGD is treated with a dose of 5 mg/*L*.

Known	Unknown
Flow, MGD = 0.4 MGD	Chemical Feeder, lbs/day
Dose, mg/*L* = 5 mg/*L*	

Determine the chemical feeder setting in pounds per day.

$$\text{Chemical Feeder, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (0.4\text{ MGD})(5\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 17\text{ lbs/day}$$

FORMULAS

To calculate the average detention time for a reaction basin:

1. Determine the dimensions of the basin, and
2. Measure and record the flow of water being treated.

$$\text{Basin Vol., cu ft} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})$$

$$\text{Basin Vol., gal} = (\text{Basin Vol., cu ft})(7.48\text{ gal/cu ft})$$

$$\text{Detention Time, min} = \frac{(\text{Basin Vol., gal})(24\text{ hr/day})(60\text{ min/hr})}{(\text{Flow, gal/day})}$$

EXAMPLE 4

A reaction basin 12 feet in diameter and 5 feet deep treats a flow of 200,000 gallons per day. What is the average detention time in minutes?

Known	Unknown
Diameter, ft = 12 ft	Detention Time, min
Depth, ft = 5 ft	
Flow, GPD = 200,000 GPD	

1. Calculate the basin volume in cubic feet

$$\text{Basin Vol., cu ft} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})$$

$$= (0.785)(12\text{ ft})^2(5\text{ ft})$$

$$= 565\text{ cu ft}$$

2. Convert the basin volume from cubic feet to gallons

$$\text{Basin Vol., gal} = (\text{Basin Vol., cu ft})(7.48\text{ gal/cu ft})$$

$$= (565\text{ cu ft})(7.48\text{ gal/cu ft})$$

$$= 4226\text{ gal}$$

3. Determine the average detention time in minutes for the reaction basin

$$\text{Detention time, min} = \frac{(\text{Basin Vol., gal})(24\text{ hr/day})(60\text{ min/hr})}{\text{Flow, gal/day}}$$

$$= \frac{(4226\text{ gal})(24\text{ hr/day})(60\text{ min/hr})}{200{,}000\text{ gal/day}}$$

$$= 30\text{ minutes}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 23.

12.2E What happens if water being treated for iron and manganese by ion exchange contains any dissolved oxygen?

12.2F How does the pH of the water influence the rate of oxidation of iron to insoluble ferric hydroxide?

12.2G What is the purpose of a reaction basin following the aeration process?

12.2H After chlorine has been added to oxidize iron and manganese, how is the water dechlorinated?

12.2I How are greensands regenerated after being used to oxidize iron and manganese?

12.3 OPERATION OF AN IRON AND MANGANESE REMOVAL PLANT by Gerald Davidson

12.30 Description of Process

The operation of an iron and manganese removal plant using continuously regenerated manganese greensand involves a number of operational procedures which must be checked on a daily basis.

The very low recommended limits for iron (0.3 mg/*L*) and manganese (0.05 mg/*L*) in water makes these contaminants difficult to treat and sometimes the processes are expensive. Because of this, operators should know how the processes work and what to check for when something goes wrong and the limits are exceeded.

The filter is the most important piece of treatment equipment. Figure 12.4 illustrates a typical filter consisting of layers of gravel, filter sand, greensand and anthracite coal. One inch (25 mm) of filter sand is placed on top of the support gravel. This layer helps support the fine greensand. Differences between greensand filters and conventional filters are: (1) the greensand is very fine; and (2) the filtration rate is slower and should not exceed 3 GPM/sq ft (2 liters per sec/sq m or 2 mm/sec); the backwash rate is lower and should be less if anthracite coal is used; and, the time of the backwash should be increased when using greensand to insure that the media is clean.

12.31 Description of the Plant (Figure 12.5)

The following is a description of an iron and manganese removal plant using continuously regenerated manganese greensand. The treatment plant provides chemical flocculation, sedimentation, pressure filtration (anthracite coal, greensand, and filter sand), and chlorination of raw well water that contains three mg/*L* iron and 0.75 to one mg/*L* manganese.

The treatment plant in Figure 12.5 has two flocculator/clarifiers (solids contact units) 32 feet (10 m) in diameter with 2.0 hours detention time at maximum flow. The clarifiers can be operated in series or in parallel. At the present time they are being operated in series. The raw water is being pumped from a 50-foot (15 m) deep well to the first clarifier. The raw water is injected with chlorine at 8.65 mg/*L*, flash mixed, and flocculated for a period of ten minutes. The water is then injected with 60 cfm of air through sixteen fine bubble diffusers. The aeration detention time is 1.9 hours at maximum flows. The raw water changes from zero mg/*L* dissolved oxygen to saturation at the water temperature. The colder the water is, the more oxygen it will hold. During aeration the iron concentration drops from 3 mg/*L* to 0.15 mg/*L* which is 95 percent removal in primary clarification

The chlorination and air injection also remove 100 mg/*L* carbon dioxide (CO_2) and 0.03 mg/*L* hydrogen sulfide (H_2S) which helps in taste and odor control. This process also raises the pH of the raw water from 6.2 to 7.0. The air will oxidize most of the manganese to an insoluble precipitate. After primary clarification, the water goes to the secondary clarifier, in the secondary treatment, and the water is injected with potassium permanganate (1.22 mg/*L*) and sodium hydroxide (30 mg/*L*).[12] The sodium hydroxide is added to raise the pH for control of corrosion. Detention times are the same as with primary clarification. After secondary clarification, the water is passed through pressure filters with greensand and the iron and manganese levels are reduced to 0.01 mg/*L* iron and 0.01 mg/*L* manganese, which is a 99 percent removal.

The potassium permanganate feed system consists of a 50-gallon (190 *L*) polyethlene solution [illegible], two ¼-HP mixers, liquid level switches, and a metering pump. Provision has been made to add dilution water to the chemical feeder pump discharge. The dilution water will prevent the crystalization of potassium permanganate which could cause failure of the pump discharge piping. The mixers do not have to run continuously because of the solubility of potassium permanganate in water. When a batch of potassium permanganate solution is prepared, the potassium permanganate chemical is mixed with hot water to help disperse the chemical in the solution.

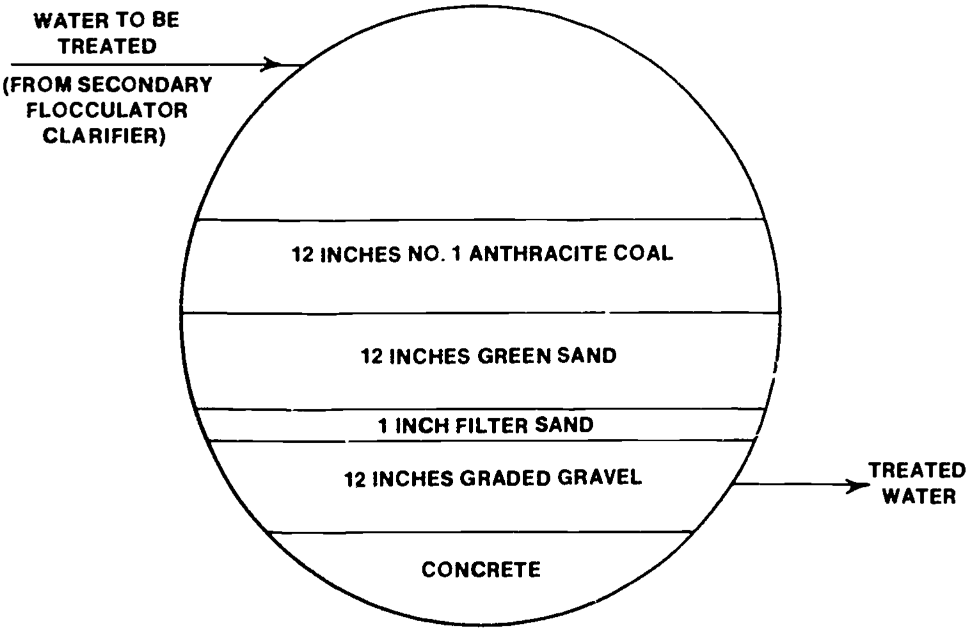

Fig. 12.4 Multimedia manganese greensand filter (horizontal)

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[12] *NOTE. Addition of 30 mg/L of sodium hydroxide (NaOH) will increase the sodium content of the water by 17 mg/L. If you are trying to keep the sodium level below 20 mg/L, then the sodium in the raw water must be below 3 mg/L*

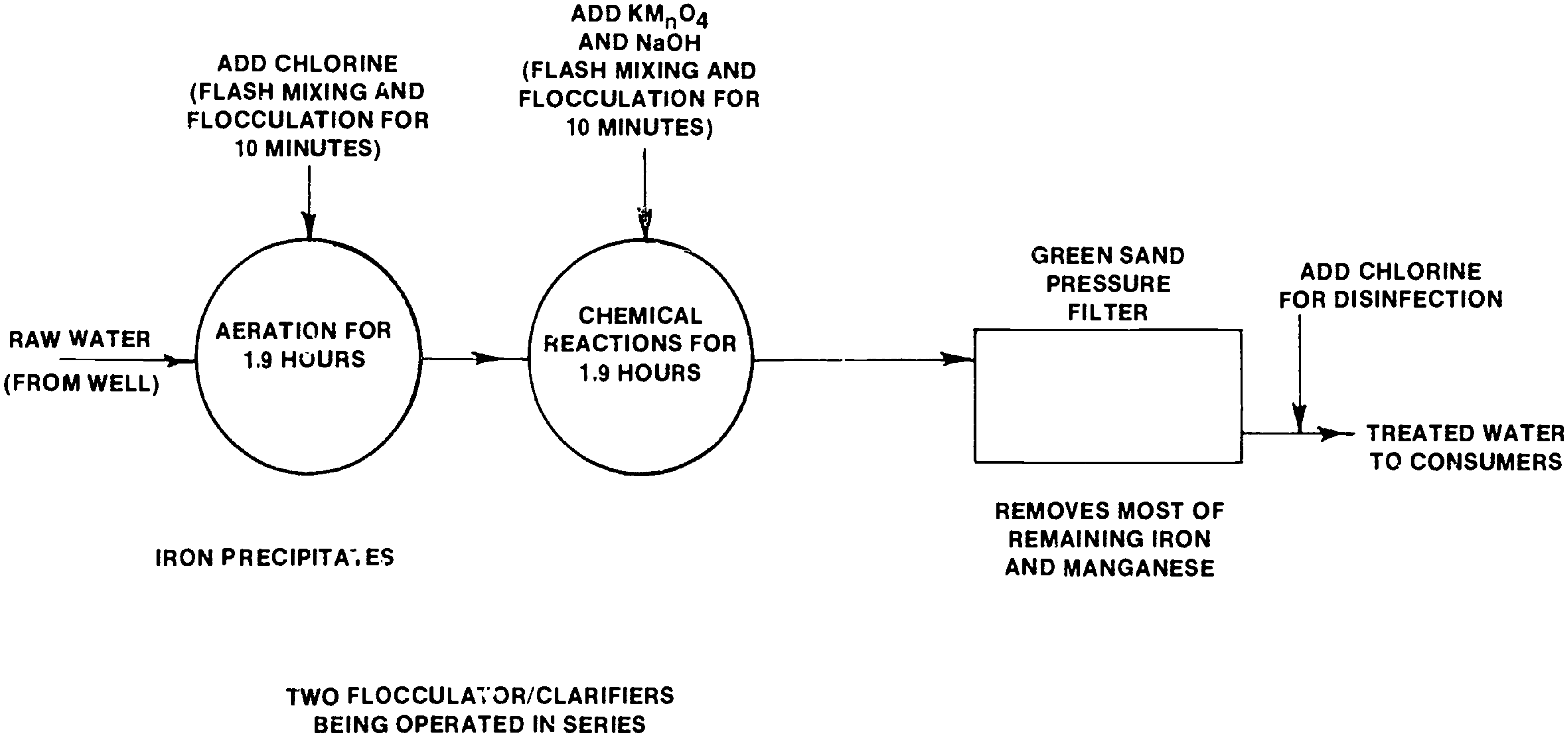


Fig. 12.5 Schmatic of iron and manganese removal plant using greensand

12.32 Operation of the Greensand Process

Good iron and manganese removal with greensand can remove 95 percent of both iron and manganese. However, if the iron is above 20 mg/*L*, the efficiency of the greensand drops very quickly. A residual of potassium permanganate must be present in the effluent water from the greensand for the greensand media to be effective.

When using the continuously regenerated manganese greensand for iron and manganese removal, the greensand must be regenerated or recharged with potassium permanganate ($KMnO_4$) If the potassium permanganate charge is lost in the filter bed (none in the filter effluent), the operator must regenerate the greensand. There are two ways to regenerate the bed:

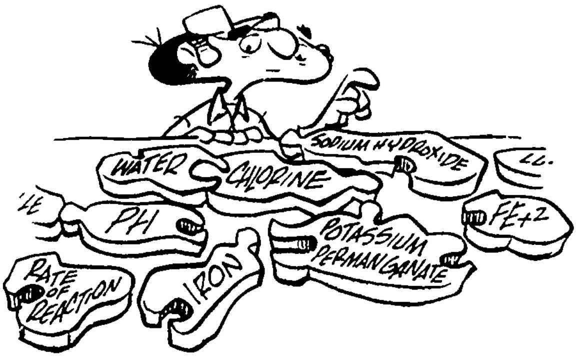
1. Shut down and pour a saturated solution of potassium permanganate (about 5 percent) into the filters; let the saturated solution sit for approximately 24 hours. After the saturated solution sits for 24 hours, backwash the filters at a normal rate to flush out the excess potassium permanganate; or
2. Recharge the greensand by increasing the potassium permanganate dosage until pink water flows out of the greensand media. Then decrease the potassium permanganate until you have a slight pink color before filtration. There should be no pink water after filtration when the water is being pumped into the distribution system. If there is still pink water after filtration, keep decreasing the potassium permanganate dose until no pink water is present in the water after filtration. The pink color is the best indication that the greensand is regenerated or recharged with potassium permanganate. One problem with this method is that you might reduce the permanganate level too far and pass water with iron and manganese. This could cause red-colored water in the distribution system and stain clothes and/or bathroom fixtures. Because of the importance of the potassium permanganate in the greensand process, it is highly recommended that some type of fail-safe system be installed to prevent filtering water in the event the potassium permanganate solution vat reaches a low level. When a low level is reached, the plant should be automatically shut down. Typical fail-safe systems include low-level alarms in the vat or an automatic switch over system to another vat when the level drops too low in the vat in use.

Some operators find that method No. 1 is more effective. Since all treatment plants are unique in some respect, one method or the other or some modification may work best for your plant. Therefore, procedures and methods should be developed through actual experience. These methods should be adopted only if they provide the desired results without eliminating any concepts of design or of good operating practice.

Problems will develop in the iron and manganese removal process using greensand if you have too short a detention time for the chemicals to react. That is, it takes a little time for the chemicals to start working. If the plant you are operating does not have sufficient detention time for the chemical reactions to take place, you should perform extensive jar tests to see if a flash mix will improve performance. In some plants the injection of the potassium permanganate solution in the volute of the pump will produce complete mixing of potassium permanganate.

To prepare a potassium permanganate solution, mix the potassium permanganate chemical with hot water in a solution tank to make the chemical disperse completely. Inject the potassium permanganate solution into the water being treated

The operator of an iron and manganese removal plant using greensand must run jar tests to determine the dosage of all chemicals used (chlorine, permanganate, and sodium hydroxide). In Chapter 3 of this water treatment manual, there is a complete description of how to run jar tests. Iron in the ferrous form (Fe^{2+}) takes about 0.60 mg/*L* potassium permanganate for each mg/*L* iron (Figure 12.6) and 0.64 mg/*L* chlorine for each mg/*L* of iron. The pH of the water has a pronounced effect on iron removal. The oxidation potential of chlorine and potassium permanganate decreases as the pH increases, although the rate of reaction increases significantly with the increase in pH.



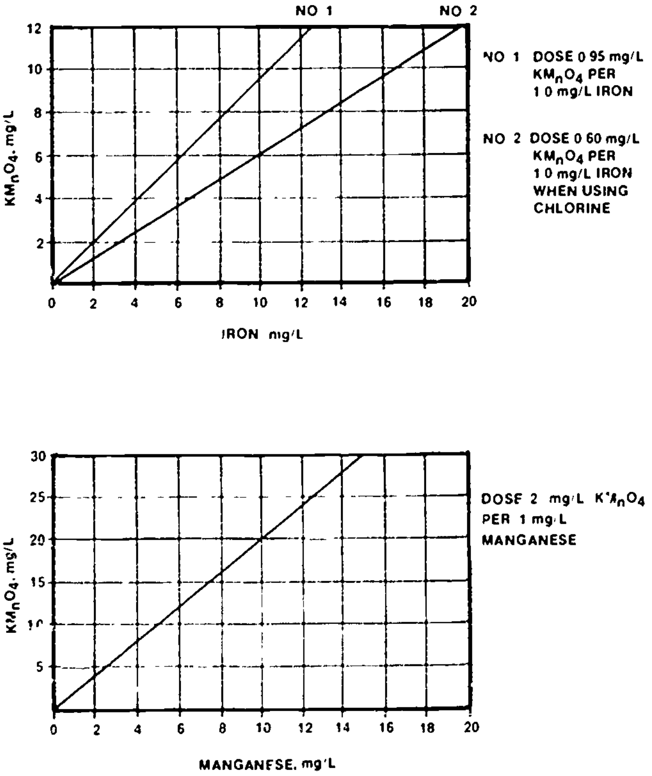


Fig. 12 6 Potassium permanganate demand for oxidation of iron and manganese

If the filtration system you are using does not have surface washers, it is highly recommended that they be installed. The benefits of surface washers in plants that treat for iron and manganese removal are well recognized. The surface washers help prevent mudballs (in any type of plant) and the buildup or iron and manganese oxide on the filter bed. The buildup is even greater when anthracite coal is used.

Remember that daily tests should also be performed. These daily tests should include iron, manganese, pH and chlorine residual. The iron and manganese test tells the operator if the treatment plant is working and meeting state and federal water quality requirements. The pH test is also very important because of the relationship between pH and the corrosivity of water. Corrosive waters can cause deterioration of water mains and red water complaints.

FORMULA

To calculate the potassium permanganate dosage, you need to know the concentration of iron and manganese in the water being treated at the location in the process where the permanganate is added.

$KMnO_4$ Dose, mg/*L* = 0.6(Iron, mg/*L*) + 2.0(Manganese, mg/*L*)

EXAMPLE 5

Calculate the potassium permanganate dose in milligrams per liter for a well water with 3 mg/*L* iron before aeration and 0.2 mg/*L* after aeration. The manganese concentration is 1.0 mg/*L* both before and after aeration.

Known		Unknown
Iron, mg/*L*	=0.2 mg/*L*	$KMnO_4$ Dose, mg/*L*
Manganese, mg/*L*	=1.0 mg/*L*	

Calculate the potassium permanganate dose in milligrams per liter.

$$\begin{aligned} KMnO_4 \text{ Dose, mg}/L &= 0.6(\text{Iron, mg}/L) + 2.0(\text{Manganese, mg}/L) \\ &= 0.6(0.2 \text{ mg}/L) + 2.0(1.0 \text{ mg}/L) \\ &= 2.12 \text{ mg}/L \end{aligned}$$

NOTE: The calculated 2.12 mg/*L* potassium permanganate dose is the minimum dose. This dose assumes there are no oxidizable compounds in the raw water. However, typical oxidizable compounds usually found include organic color, bacteria and even hydrogen sulfide (H_2S). Therefore, the actual dose may be higher. A bench scale test should be performed to determine the required dose

QUESTIONS

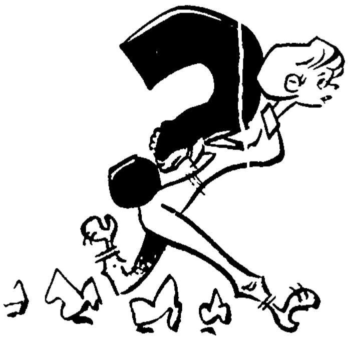
Write your answers in a notebook and then compare your answers with those on page 23.

12.3A What are the accepted limits for iron and manganese?

12.3B What happens in the two flocculator/clarifiers described in this chapter?

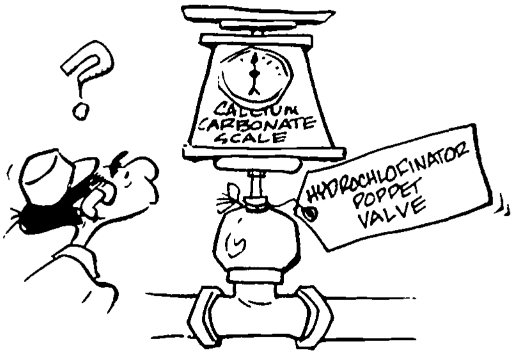
12.3C Why is dilution water added at the discharge of the chemical feeder pump?

12.3D Why should a greensand plant be shut down when the permanganate solution level in the vat gets low?



12.4 MAINTENANCE OF A CHEMICAL FEEDER

In small water treatment plants that remove iron and manganese, a hypochlorite solution may be used to provide chlorine instead of using chlorine gas. Commercial sodium hypochlorite solutions (such as chlorox) contain an excess of caustic (sodium hydroxide, NaOH). When the solution is diluted with water containing carbonate alkalinity,[13] the resulting solution becomes supersaturated with calcium carbonate. This calcium carbonate tends to form a coating on the poppet valves in the solution feeder. The coated valves do not seal properly and the feeder fails to pump the hypochlorite solution properly.



This calcium carbonate scale can be removed by using the following procedure:

1. Fill a one quart (946 m*L*) Mason jar half full of tap water.
2. Add one fluid ounce (44 m*L*) of 30 to 37 percent hydrochloric acid (HCl) to the Mason jar.
3. Finish filling the jar to the top with tap water.
4. Place the suction hose of the hypochlorinator in the jar and pump the entire contents of the jar through the system.
5. Return the suction hose to the solution tank and resume normal operation.

---

[13] *See Chapter 14, "Softening," for a discussion of carbonate alkalinity*

The hydrochloric acid (HCl), also called muriatic acid, can be obtained from stores selling swimming pool supplies

One way to avoid the formation of calcium carbonate coatings is to obtain the dilution water for the hypochlorite from an ordinary home water softener.

For additional information on the operation and maintenance of various types of chemical feeders, see Chapter 13, "Fluoridation."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 23

12.4A What problems may develop in a chemical feeder pumping sodium hypochlorite?

2.4B How can the problems caused by calcium carbonate scale on a hypochlorinator's poppet valves be solved?

12.5 TROUBLESHOOTING RED WATER PROBLEMS

The first step when troubleshooting red or dirty water complaints is to be sure the iron and manganese treatment processes are working properly. If the iron and manganese are being removed by the treatment processes, investigate the distribution system for sources to the problem.

Red water or dirty water problems may be caused by corrosive waters or iron bacteria in the distribution system When an unstable or corrosive water (see Chapter 8, "Corrosion Control") is pumped into the distribution system, the water attacks cast iron pipes and/or metal service lines, picks up iron, and causes red water complaints All water treatment plants should run a "Marble Test" see page 353 in Chapter 8) If the test indicates that the water is corrosive, the addition of caustic (sodium hydroxide, NaOH) to the water to increase the pH will help When the water becomes stable (according to the Marble Test), some of the red water complaints could be eliminated.

The growth of iron bacteria inside water mains causes one of the most troublesome and most difficult to eliminate red water problems These bacteria are not harmful. They live and accumulate the iron in the water flowing through the distribution system. As the bacterial growths increase, slimes will build up in the mains and eventually slough off into the water. When these slimes come out a consumer s water tap, you can expect complaints of red water and slimes.

Slime growths can be controlled by maintaining a free chlorine residual throughout the distribution system. Sometimes the residual is very difficult to maintain. If bacterial growths have been in the distribution system for a long time and are flourishing, it is very difficult to maintain a free chlorine residual at the extremes or in dead ends of the system. Also if the water has a natural high chlorine demand, your chlorination equipment may not be capable of feeding enough chlorine to maintain a free chlorine residual. Remember that frequently when consumers complain about chlorine or swimming pool tasting water, the solution is to add more chlorine in order to get past the breakpoint.

One way to rid a distribution system of iron bacteria is to develop a flushing program.[14] Flushing should start at the location where the water enters the distribution system, such as an elevated tank. Flush the water mains by working towards the extremes or most distant points of the distribution system Usually only one portion of the distribution system is flushed, followed by another portion until the entire system has been flushed.

A common practice is to open a hydrant at the extreme end of the system at the start of the flushing job to be sure the water being flushed will carry the sediment and insoluble precipitates in the desired direction and out of the system Flushing is often done late at night when water demands are low so facilities won't be overworked and consumers will not be inconvenienced.

Valves will have to be opened and closed in the proper sequences to be sure the desired mains are being flushed and that no one will be without water Hydrants that are opened to allow flushing must be of sufficient size to produce flushing velocities (2 5 up to 5 0 ft/sec preferred or 0 75 to 1 5 m/sec) in the mains. Also the mains providing the flushing flows must have sufficient capacity to deliver the desired flows.

When flushing a system, be sure the pressure in the distribution system does not drop below 20 psi (1 4 kg/sq cm or 138 kPa). If a four-inch (100 mm) water main is flushed using a six-inch (150 mm) hydrant, the water pressure in the main downstream from the hydrant could become dangerously low. When this happens, the distribution system could be subject to contamination by *BACKSIPHONAGE*.[15] *NEVER ALLOW A BACKSIPHON CONDITION TO DEVELOP IN A DISTRIBUTION SYSTEM.*

In summary, to minimize red water or dirty water problems and complaints, you must provide adequate treatment to control iron and manganese. This is necessary to assure that the water pumped into the distribution system contains little or no iron and manganese. The water must be stable (noncorrosive) so that iron will not be picked up in the distribution system. Corrosion control treatment processes can produce a stable water. If bacterial growths are a problem, a free chlorine residual must be maintained in all water throughout the distribution system If red or dirty water problems exist in a distribution system, a thorough flushing program can be very helpful

12.6 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.30, "Iron and Manganese Control " Check all of the arithmetic in this section using an electronic calculator You should be able to get the same answers

12.7 ADDITIONAL READING

1. *NEW YORK MANUAL*. Chapter 13, "Iron and Manganese."
2. *TEXAS MANUAL*. Chapter 11, "Special Water Treatment (Iron and Manganese Removal) "

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 23.

12 5A List the possible causes of red or dirty water complaints

12 5B How can slime growths be controlled in water distribution systems?

---

[14] *See WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE, page 215, Pipe Flushing.*

[15] *Backsiphonage. A form of backflow caused by a negative or below atmospheric pressure within a water system.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 12. IRON AND MANGANESE CONTROL

Please answer these discussion and review questions before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions before continuing with the Objective Test on page 23

1. Why should iron and manganese be controlled in drinking water?
2. Why are accurate results of tests for iron and manganese difficult to obtain?
3. Why is chlorine usually fed with polyphosphates when controlling iron and manganese?
4. How do polyphosphates control manganese?
5. How is the proper polyphosphate dose determined?
6. What happens when an ion exchange resin becomes fouled with iron rust or manganese dioxide?
7. When should iron and manganese ion exchange units be regenerated?
8. How would you determine whether or not to adjust the flows to an oxidation by aeration process to remove iron?
9. Why should reaction basins be drained and cleaned?
10. What are the advantages and disadvantages of the oxidation by aeration process to remove iron?
11. What happens if the dose of potassium permanganate to remove iron and manganese is not exact?
12. What must you do if the potassium permanganate charge is lost in the filter bed?
13. Why should the filtration system for the greensand process have surface washers?
14. How would you attempt to prevent red or dirty water complaints?

SUGGESTED ANSWERS

Chapter 12. IRON AND MANGANESE CONTROL

Answers to questions on page 6.

12.0A When clothes are washed in water containing iron and manganese, they will come out stained. Iron bacteria will cause thick slimes to form on the walls of water mains. These slimes are rust colored from iron and black from manganese. Variations in flow cause these slimes to slough which results in dirty water. Furthermore, these slimes will impart foul tastes and odors to the water.

12.0B The growth of iron bacteria is easily controlled by chlorination. However, when water containing iron is chlorinated, the iron is converted into rust particles and manganese is converted into a jet black compound, manganese dioxide.

12.0C The generally accepted limit for iron is 0.3 mg/*L* and that for manganese is 0.05 mg/*L*.

Answers to questions on page 7.

12.1A Iron and manganese react with dissolved oxygen or chlorine to form insoluble compounds.

12.1B Iron and manganese samples are acidified when they are collected to prevent the formation of iron and manganese scales on the walls of the sample bottles.

12.1C Samples for iron and manganese testing should be collected as close to the well or source of water as possible.

Answers to questions on page 11.

12.2A If a well produces water containing dissolved oxygen as well as iron and manganese, the iron and manganese are probably coming from the lower aquifers. Try to seal off the lower aquifers.

12 2B To determine if nearby wells contain iron and manganese, samples could be collected and analyzed from nearby private wells. Also, discussions with well drillers who have been active in the locality and with engineers with the state agency responsible for the regulation of well drilling will be helpful.

12.2C Bench scale tests are a method of studying different ways or chemical doses for treating water on a small scale in a laboratory.

12 2D If polyphosphate solutions are much over 48 hours old, they will react slowly with water to form orthophosphates which are much less effective in preventing manganese deposits.

Answers to questions on page 16.

12.2E If water being treated for iron and manganese by ion exchange contains any dissolved oxygen, the resin becomes fouled with iron rust or insoluble manganese dioxide.

12.2F The higher the pH, the faster the rate of oxidation of iron to insoluble ferric hydroxide.

12.2G The purpose of the reaction basin is to allow time for the oxidation reactions to take place. The aeration process should produce sufficient dissolved oxygen for the iron to be oxidized to insoluble ferric hydroxide.

12.2H Water can be dechlorinated by the use of reducing agents such as sulfur dioxide (SO_2), sodium bisulfite ($NaHSO_3$), and sodium sulfite (Na_2SO_3) Bisulfite is commonly used because it is cheaper and more stable than sulfite.

12.2I To oxidize greensands used to oxidize iron and manganese, backwash the greensands. After backwashing, regenerate with potassium permanganate

Answers to questions on page 20.

12.3A The accepted limits for iron and manganese are 0.3 mg/*L* for iron and 0.05 mg/*L* for manganese.

12.3B In the first flocculator/clarifier, chlorine is added with flash mixing and flocculation for 10 minutes. During the next 1.9 hours, aeration occurs through fine bubble diffusers. This process removes 95 percent of the iron. The treated water then flows to the second flocculator/clarifier and the water is injected with potassium permanganate and sodium hydroxide. This is followed by flash mixing, 10 minutes of flocculation and 1.9 hours of settling. After this process, the water is passed through filters which produce treated waters with 0.01 mg/*L* of iron and also 0.01 mg/*L* of manganese.

12.3C Dilution water is added at the discharge of the chemical feeder pump to prevent the crystallization of potassium permanganate which could cause failure of the pump discharge piping

12.3D A greensand plant should be shut down when the permanganate solution level in the vat gets low because of the importance of the permanganate in the process. Without permanganate the greensand could lose its charge and iron and manganese will enter the distribution system.

Answers to questions on page 21.

12.4A When a chemical feeder pumps hypochlorite, calcium carbonate coatings may develop on the poppet valves if the dilution water contains carbonate alkalinity. Coated valves do not seal properly and the feeder fails to pump the hypochlorite solution properly.

12.4B The problems caused by calcium carbonate scale on a hypochlorinator's poppet valves can be solved in two ways:

1. A hydrochloric acid solution can be pumped through the system, or
2. The dilution water for the feeder can be obtained from an ordinary home water softener.

Answers to questions on page 21.

12.5A Red or dirty water complaints may be caused by:

1. Iron and/or manganese in the water,
2. Corrosive waters, and
3. Iron bacteria in the distribution system.

12.5B Slime growths in distribution systems can be controlled by maintaining a free chlorine residual throughout the distribution system and by a distribution system flushing program.

OBJECTIVE TEST

Chapter 12. IRON AND MANGANESE CONTROL

Please write your name and mark the correct answer on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the mulitple choice questions.

True-False

1. Iron and manganese must be removed from water due to adverse health effects.
   1. True
   2. False

2. Iron and manganese are rarely found in groundwater.
   1. True
   2. False

3. Acidified samples for iron may produce high results if clay particles are present.
   1. True
   2. False

4. If the water produced by a well contains dissolved oxygen along with iron and manganese, this is an indication that water is being drawn from only one aquifer.
   1. True
   2. False

5. Chlorine should never be fed ahead of polyphosphate.
   1. True
   2. False

6. If the water to be treated contains dissolved oxygen, both iron and manganese may be removed by ion exchange using the same resins that are used for water softening.
   1. True
   2. False

7. Oxidation of manganese by aeration is commonly used on waters with high manganese concentrations.
   1. True
   2. False

8. Chlorine will oxidize manganese to insoluble manganese dioxide.
   1. True
   2. False
9. Chlorine will oxidize iron to insoluble ferric hydroxide
   1. True
   2. False
10. Potassium permanganate oxidizes iron and manganese to insoluble oxides in the same way as chlorine.
    1. True
    2. False
11. Greensand is capable of oxidizing both iron and manganese and is also capable of filtration.
    1. True
    2. False
12. The flocculator/clarifiers are the most important process in the greensand treatment plant.
    1. True
    2. False
13. The solution mixers in the solution vat must run continuously to keep the potassium permanganate in solution
    1. True
    2. False
14. A residual of potassium permanganate must be present in the filter effluent for the greensand media to be effective.
    1. True
    2. False
15. Commercial sodium hypochlorite solutions (such as Chlorox) contain an excess of lime
    1. True
    2. False

Multiple Choice

16. Problems caused by iron and manganese in water include
    1. Corrosion.
    2. Dirty water.
    3. Illness.
    4. Stained laundry.
    5. Tastes and odors.
17. Iron and manganese react with _____ to form insoluble compounds.
    1. Alum
    2. Chlorine
    3. Dissolved oxygen
    4. Ion exchange resins
    5. Lime
18. Methods or equipment used to test for iron include
    1. Amperometric.
    2. Atomic absorption.
    3. Nessler tubes.
    4. Phosphate.
    5. Spectrophotometer.
19. The proper polyphosphate dose is the lowest dose that delays noticeable discoloration for a period of at least
    1. 4 hours.
    2. 12 hours.
    3. 24 hours
    4. 2 days.
    5. 4 days.
20. Do not use polyphosphate solution much over _____ hours old.
    1. 3
    2. 6
    3. 12
    4. 24
    5. 48
21. The rate of oxidation of iron to form insoluble ferric hydroxide is decreased by increases in
    1. Carbon dioxide.
    2. Lime dose.
    3. Organic substances
    4. pH.
    5. Temperature.
22. Chemical doses being added to control iron and manganese are inadequate if
    1. Addition of chlorine to the treated water produces a brownish floc.
    2. Analysis of treated water contains iron.
    3. Consumers complain of black particles.
    4. Consumers complain of pink water.
    5. Consumers complain of rusty water.
23. The differences between greensand filters and conventional filters include the
    1. Backwash rate is higher for greensand filters.
    2. Backwash time should be decreased for greensand filters.
    3. Filtration rate is faster for greensand filters.
    4. Greensand is coarser than conventional sand.
    5. Greensand removes iron and manganese.
24. Determine the setting on a potassium permanganate chemical feeder in pounds per day if the chemical dose determined from a jar test is 2.5 mg/*L* and the flow is 0.45 MGD.
    1. 8.4 lbs/day
    2. 9.4 lbs/day
    3. 10.4 lbs/day
    4. 12.9 lbs/day
    5. 22.5 lbs/day
25. Determine the setting on a potassium permanganate chemical feeder in pounds per million gallons if the chemical dose determined from a jar test is 2.5 mg/*L*.
    1. 21 lbs/M Gal
    2. 32 lbs/M Gal
    3. 43 lbs/M Gal
    4. 46 lbs/M Gal
    5. 50 lbs/M Gal
26. A reaction basin 18 feet in diameter and 6 feet deep treats a flow of 500,000 gallons per day. What is the average detention time in minutes?
    1. 25 minutes
    2. 28 minutes
    3. 30 minutes
    4. 33 minutes
    5. 35 minutes

End of Objective Test

CHAPTER 13

FLUORIDATION

by

Harry Tracy

TABLE OF CONTENTS

Chapter 13. Fluoridation

OBJECTIVES

Chapter 13. FLUORIDATION

Following completion of Chapter 13, you should be able to:

1. Explain the reason for fluoridating drinking water,
2. Describe how fluoridation programs are implemented,
3. List the compounds used to furnish fluoride ion,
4. Review designs and specifications of fluoridation equipment,
5. Inspect fluoridation equipment,
6. Start up a chemical feeder,
7. Operate and maintain a chemical feeder,
8. Calculate and prepare fluoride solutions,
9. Develop and keep accurate fluoride log sheets,
10. Prevent overfeeding of fluoride,
11. Shut down chemical feed systems, and
12. Safely handle fluoride compounds.

GLOSSARY

Chapter 13. FLUORIDATION

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated or a chemical solution is prepared, and the tank is emptied. The tank may then be filled and the process repeated.

DAY TANK DAY TANK

A tank used to store a chemical solution of known concentration for feed to a chemical feeder. A day tank usually stores sufficient chemical solution to properly treat the water being treated for at least one day. Also called an AGE TANK.

ENDEMIC (en-DEM-ick) ENDEMIC

Something peculiar to a particular people or locality, such as a disease which is always present in the population.

FLUORIDATION (FLOOR-uh-DAY-shun) FLUORIDATION

The addition of a chemical to increase the concentration of fluoride ions in drinking water to a predetermined optimum limit to reduce the incidence (number) of dental caries (tooth decay) in children.

GRAVIMETRIC FEEDER GRAVIMETRIC FEEDER

A dry chemical feeder which delivers a measured weight of chemical during a specific time period.

POSITIVE DISPLACEMENT PUMP POSITIVE DISPLACEMENT PUMP

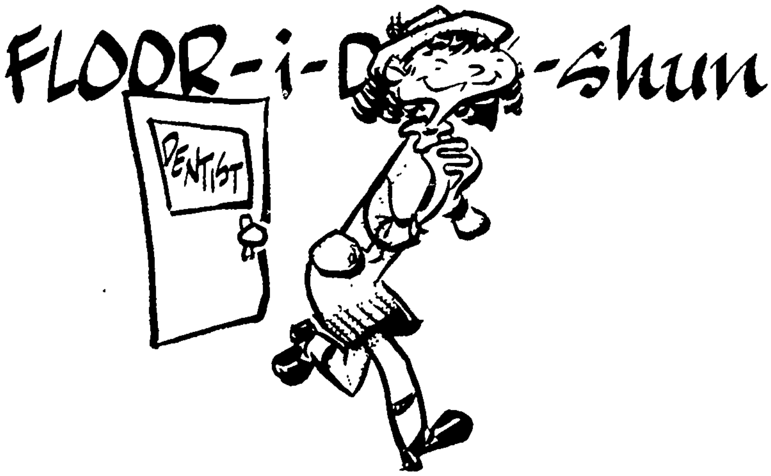
A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. Positive displacement pumps are used as chemical solution feeders.

SATURATOR (SAT-you-RAY-tore) SATURATOR

A device which produces a fluoride solution for the fluoridation process. The device is usually a cylindrical container with granular sodium fluoride on the bottom. Water flows either upward or downward through the sodium fluoride to provide the fluoride solution.

VOLUMETRIC FEEDER VOLUMETRIC FEEDER

A dry chemical feeder which delivers a measured volume of chemical during a specific time period.



CHAPTER 13. FLUORIDATION

13.0 IMPORTANCE OF FLUORIDATION

During the period 1902 to 1931 Dr. Frederick S. McKay, a dentist practicing in Colorado Springs, noted what seemed an *ENDEMIC*[1] brown stain on the teeth of his patients. McKay devoted much of his time researching the case of mottled (brown, chalky deposits) tooth enamel but it was not until 1931 that the cause was found to be excessive fluoride in the water supplies (2 to 13 mg/*L*). During this period McKay had also noted that the mottled teeth seemed to have fewer dental caries (decay or cavities).

The next logical step was to add fluoride to waters that were deficient in fluoride and to discover if children drinking water treated with fluoride had fewer cavities. In 1945 controlled fluoridation was started in the cities of Grand Rapids, Michigan and Newburgh, New York with control cities of Muskegon and Kingston.

Finally in 1955 the results were in and they showed a 60 percent reduction of caries in those children who drank fluoridated water compared to those children in the control cities.

The progress of fluoridation did not go smoothly. Antifluoridationists became increasingly vocal and were able to stop fluoridation in many cities through action in the political arena.

Although dentists practicing in areas with naturally high fluoride waters noted that their patients had remarkably few cavities, there were still those disfiguring brown stains. Mottling of the teeth occurs when the fluoride level exceeds about 1.5 mg/*L*. Fluoride concentrations in excess of 1000 mg/*L* have been found in waters from volcanic regions. Waters with fluoride concentrations more than 1.4 to 2.4 mg/*L* should be treated to reduce the level to approximately the one milligram per liter level. The exact point that exceeds the drinking water standards depends upon the annual average of the maximum daily air temperatures (Tabel 13.1).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.0A What happens if a person drinks water with an excessive concentration of fluoride?

13.0B What happens if children drink a recommended dose of fluoride?

13.1 FLUORIDATION PROGRAMS

Generally speaking, fluoridation programs start with citizens' inquiries about fluoridation of their water supplies and encouragement of the local dental society. These requests for the addition of fluoride to prevent dental caries are passed along to appropriate governing agencies. The governing body will usually rely upon a vote of the people, or it may be forced into a vote by threat of a referendum. If the decision is made to fluoridate, the water department or water company will almost always make the final decisions as to types of chemical and feeding equipment to be used.

13.2 COMPOUNDS USED TO FURNISH FLUORIDE ION

The most commonly used compounds to fluoridate water systems are sodium fluoride, sodium silicofluoride and hydrofluosilicic acid (HI-dro-FLEW-oh-suh-lys-ik). There are

TABLE 13.1 INTERIM PRIMARY DRINKING WATER REGULATIONS FOR FLUORIDE AND RECOMMENDED LEVELS

	Annual Average Maximum Daily Temperatures[a]		Recommended Control Limits of Fluoride Levels, mg/L			Maximum Contaminant Level, mg/*L*
	°F	°C	Lower	Optimum	Upper	
a.	53.7 & Below	12.0 & Below	0.9	1.2	1.7	2.4
b.	53.8 to 58.3	12.1 to 14.6	0.8	1.1	1.5	2.2
c.	58.4 to 63.8	14.7 to 17.6	0.8	1.0	1.3	2.0
d.	63.9 to 70.6	17.7 to 21.4	0.7	0.9	1.2	1.8
e.	70.7 to 79.2	21.5 to 26.2	0.7	0.8	1.0	1.6
f.	79.3 to 90.5	26.3 to 32.5	0.6	0.7	0.8	1.4

[a] Contact your local Weather Service Office to determine the "Annual Average Maximum Daily Air Temperature" for your service area.

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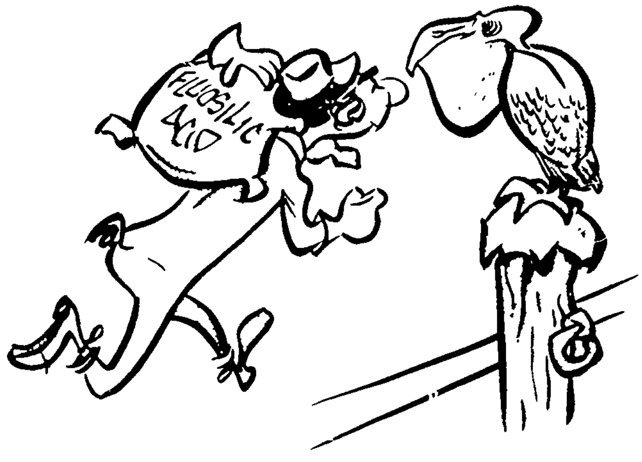
[1] *Endemic (en-DEM-ick) Something peculiar to a particular people or locality, such as a disease which is always present in the population.*

also a few systems using such compounds as hydrofluoric acid and ammonium silicofluoride. All of these chemicals are refined from minerals found in nature and they yield fluoride ions identical to those found in natural waters. Hydrofluosilicic acid (also called fluorsilicic acid) is the compound most commonly used in several states (California, Florida and Illinois).



The compounds most commonly used are covered by American Water Works Association Standards. In order for you to be confident of the fluoride compound you are using, insist that your supplier furnish only compounds meeting the appropriate AWWA specifications.

The plant should have as part of its records several copies of the appropriate AWWA standard for reference. Standards can be purchased from the Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235

		Price		
Standard	Chemical	Members	Nonmembers	Order No.
B701-84	Sodium Fluoride	$5.50	$7.00	42701
B702-84	Sodium Silicofluoride	$5.50	$7.00	42702
B703-84	Hydrofluosilicic Acid	$5.50	$7.00	42703

Only the fluoride ion in these compounds is of any importance in the fluoridation of water; therefore, pound-for-pound, each compound will provide a different final fluoride level. If you switch from one type of fluoride compound to another, you will have to make separate calculations for each type. Table 13.2 summarizes the important properties of fluoride compounds.

When selecting a fluoridation chemical, several important factors must be considered. The solubility of the chemical in water is very important if we are using the powder or crystal form of a chemical because we want the chemical to readily dissolve in water and remain in solution. Operator safety and ease of handling must be given serious consideration. Storage and feeding requirements as well as costs must also be studied when selecting any chemical.

REMEMBER, All fluoridation chemicals are POISONOUS at HIGH LEVELS.

Hydrofluosilicic acid is usually the easiest fluoridation chemical to feed. However, hydrofluosilicic acid produces poisonous fumes that must be vented and is very irritating to your skin. Sodium fluoride is easier to feed than the other powdered fluoridation chemicals because it is more soluble in water.

Operators can receive instructions from the manufacturer on how to make up the chemical solutions and how much solution to meter per million gallons. See Section 13.61, "Preparation of Fluoride Solution," for calculations and procedure details.

Prior to fluoridation, the water should be checked for its natural fluoride level. If there is natural fluoride in the water, it is only necessary to add enough more to bring the total to the desired level recommended by the local health authorities.

TABLE 13.2 FLUORIDE COMPOUNDS

	Sodium Silicofluoride Na_2SiF_6	Sodium Fluoride NaF	Hydrofluosilicic Acid H_2SiF_6
1 Form	Powder	Powder or Crystal	Liquid
2 Molecular Weight	188.1	42.0	144.1
3 Commercial Purity, %	98-99	95-98	22-30 by Weight
4 Fluoride Ion, % (Purity, %)	60.7 (100%) 59.8 (98.5)	45.3 (100%) 43.4 (96)	79.2 (100%) 23.8 (30)
5 Density	55-72 lb/cu ft	65-90 lb/cu ft	10.5 (30%) lb/gal
6 Solubility in Water, % (gram/100 mL water at 77°F or 25°C)	0.76	4.05	100[a]
7 pH of Saturated Solution	3.5	7.6	1.2 (1% Solution)

[a] Infinite because we are dealing with a liquid.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.1A Who makes the final decisions as to types of fluoride chemicals and feeding equipment to be used?

13.2A List the three compounds most commonly used to fluoridate water.

13.3 FLUORIDATION SYSTEMS

Drinking waters may come to contain fluoride ions by three different types of situations. First, the raw water source may have adequate or excessive fluoride ions naturally present. Second, sometimes two water sources are blended together to produce an acceptable level of fluoride ions. This can occur when one source has a higher than acceptable level of fluoride ions and the other is below the desired level. This chapter is mainly concerned with the third situation in which fluoride ions must be added to the water to achieve an acceptable level of fluoride ions.

13.30 Chemical Feeders

Fluoride ions are added to water by either chemical solution feeders or dry feeders. Solution feeders are *POSITIVE DISPLACEMENT*[2] diaphragm pumps (Figure 13 1), peristaltic pumps (Figure 13.2), or electronic pumps (Figure 13 3), that deliver a fixed amount of liquid fluoridation chemical with each stroke or pulse. The dry feeders are either *VOLUMETRIC*[3] or *GRAVIMETRIC*[4] types of chemical feeders. Volumetric feeders (Figures 13.4 and 13.5) are usually simpler, less expensive, less accurate and feed smaller amounts of chemicals than gravimetric feeders. Gravimetric feeders (Figure 13.6) are usually more accurate than volumetric feeders, however, they are more expensive and require more space for installation. The amount fed is measured on the basis of the weight of chemical to be fed to the system Fluoride chemical feeders must be very accurate.

Whatever the type of feeding system or chemical used, the design should be planned by the engineer experienced in developing feeding systems (Figure 13 7). The design must incorporate means to prevent both overfeeding and back siphonage along with a means to monitor the amount of chemical used It is also desirable to incorporate some means of feeding fluoride which is adjusted (paced) according to the plant flow rate. Also a means to continuously measure the finished water's fluoride ion content with an adjustable "high" fluoride alarm is desirable. Fluoride doses must never be metered against a negative or suction head.

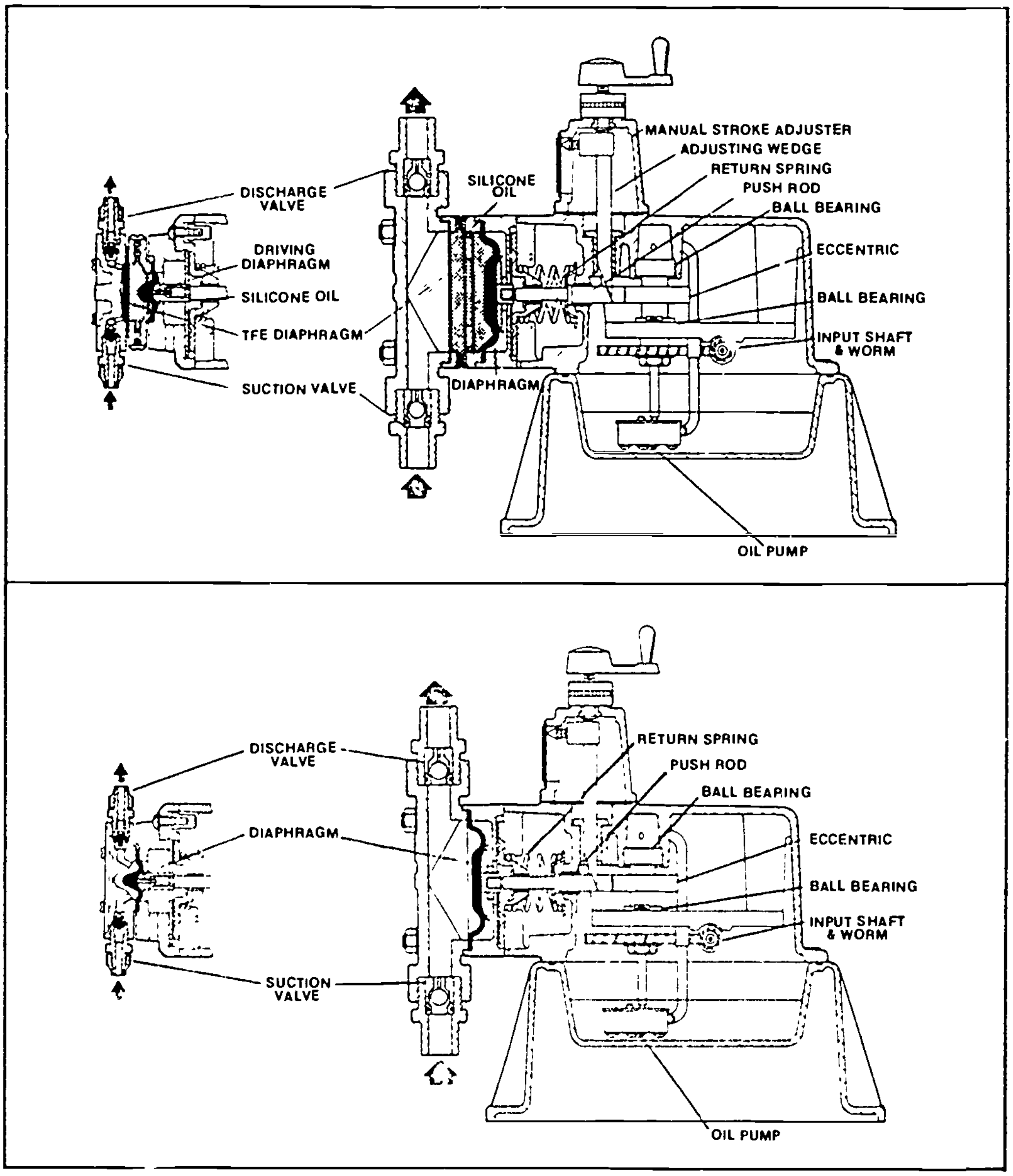


Fig. 13.1 Positive displacement diaphragm pumps

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

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[2] *Positive Displacement Pump A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. Positive displacement pumps are used as chemical solution feeders.*

[3] *Volumetric Feeder A dry chemical feeder which delivers a measured volume of chemical during a specific time period.*

[4] *Gravimetric Feeder. A dry chemical feeder which delivers a measured weight of chemical during a specific time period*

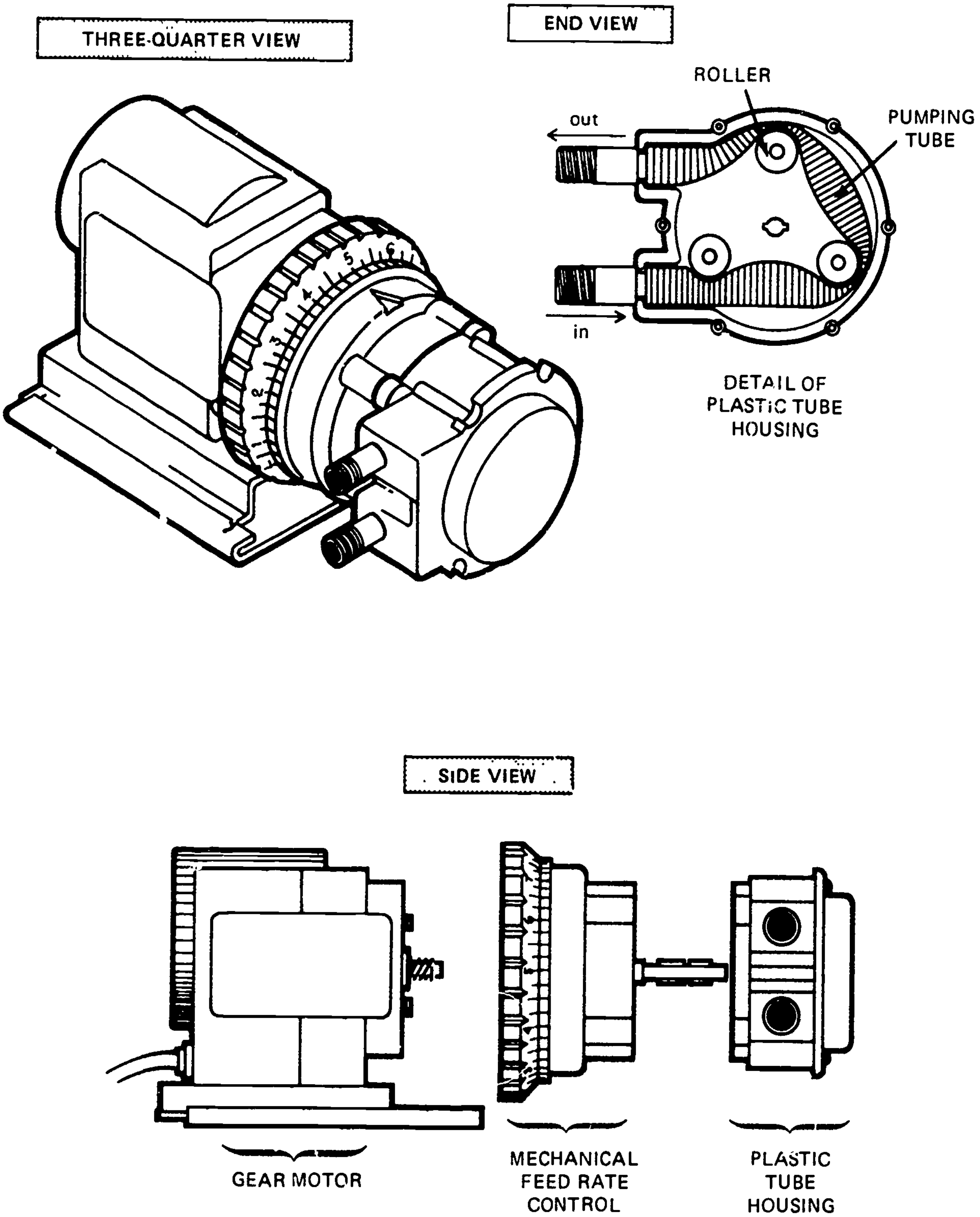

Fig. 13.2 Peristaltic feeder

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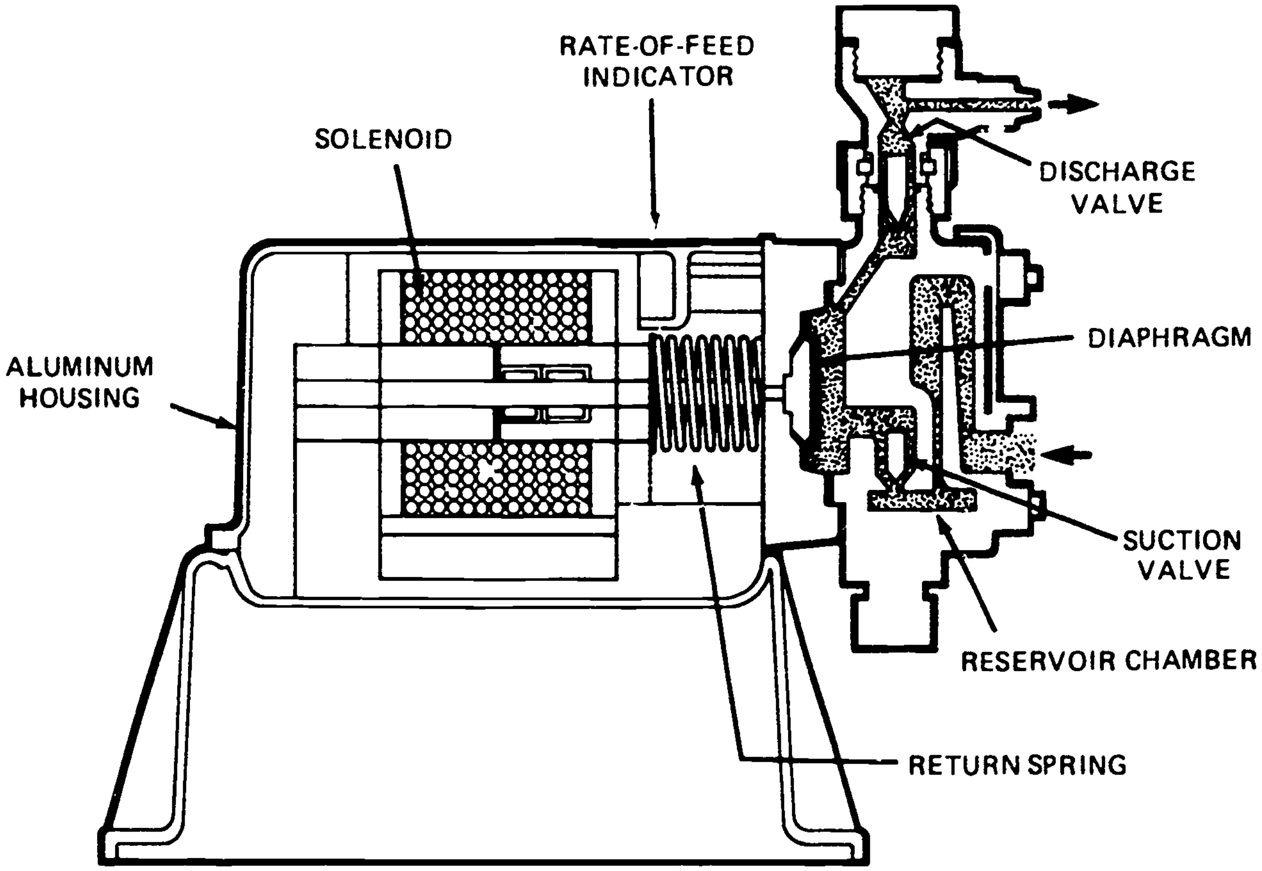

Fig 13.3 Electronic feeder

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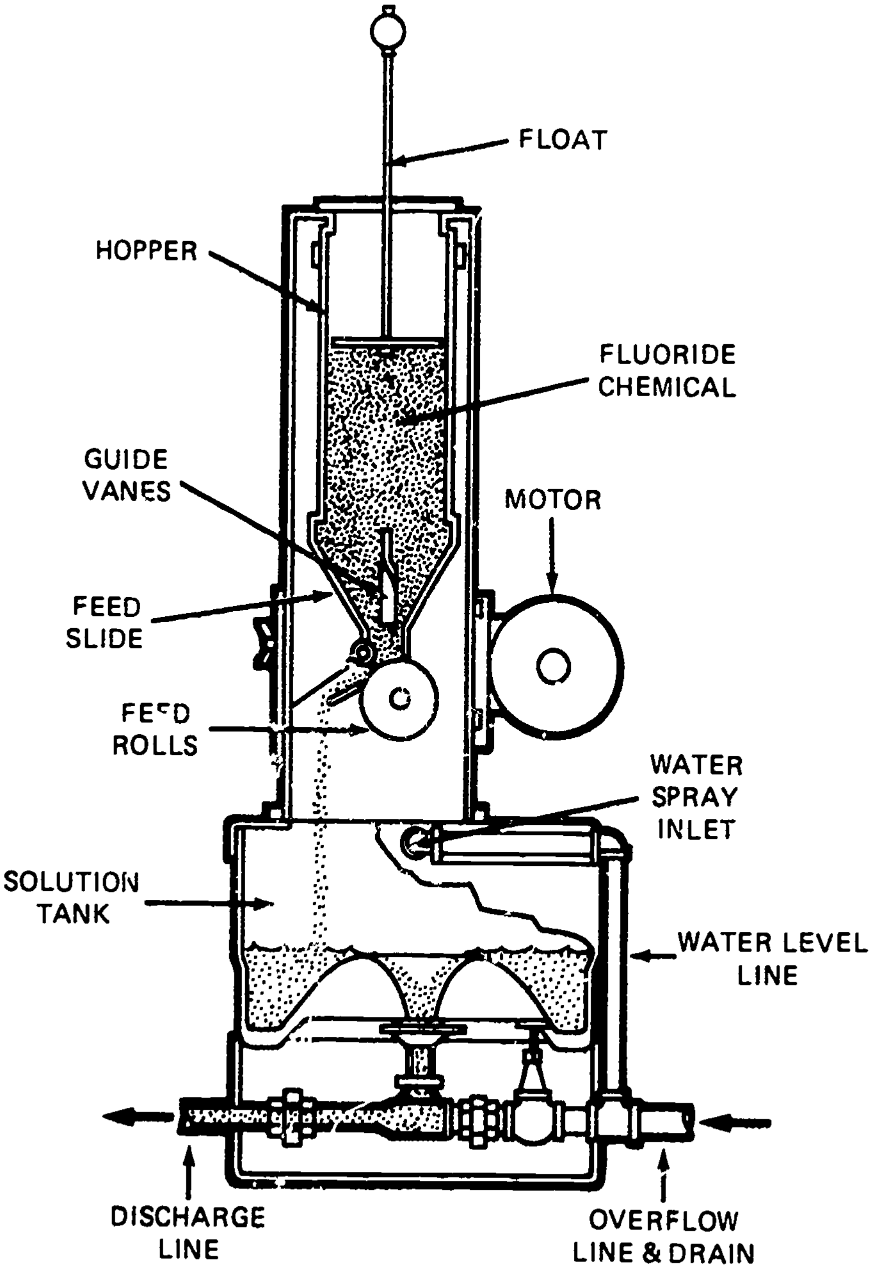

Fig. 13.4 Volumetric feeder, roll-type

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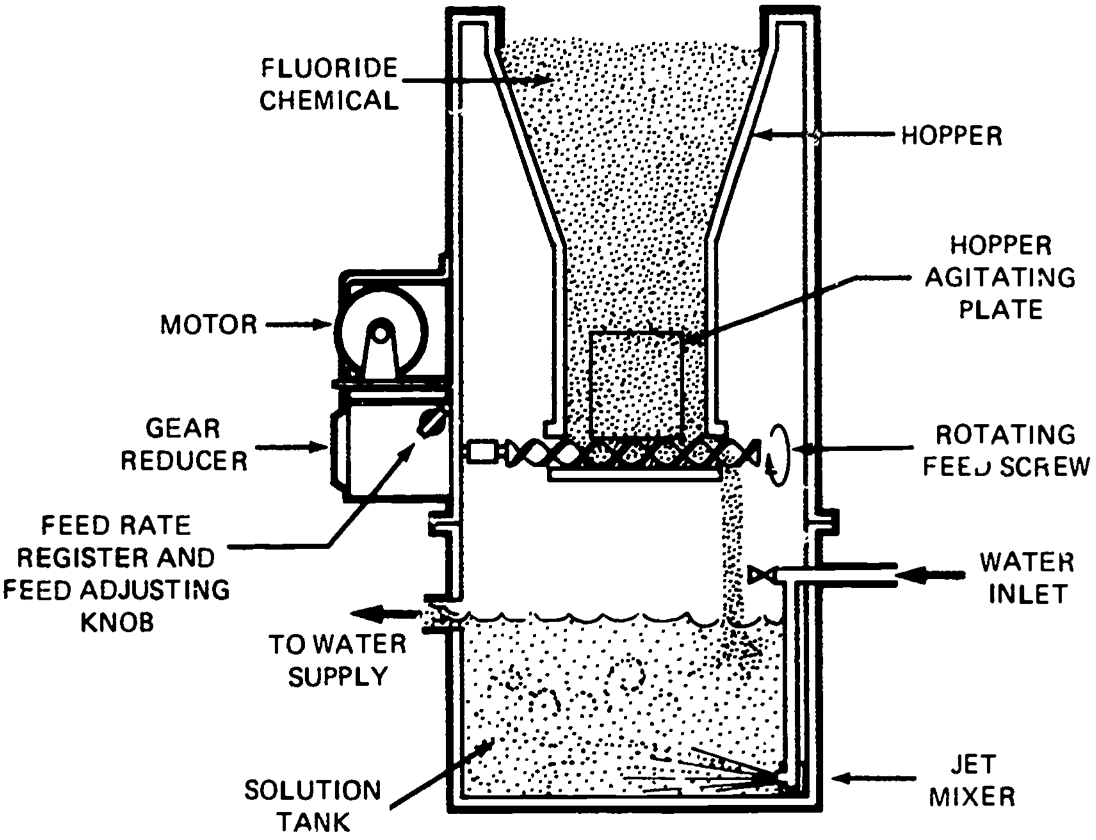

Fig. 13.5 Volumetric feeder, screw-type

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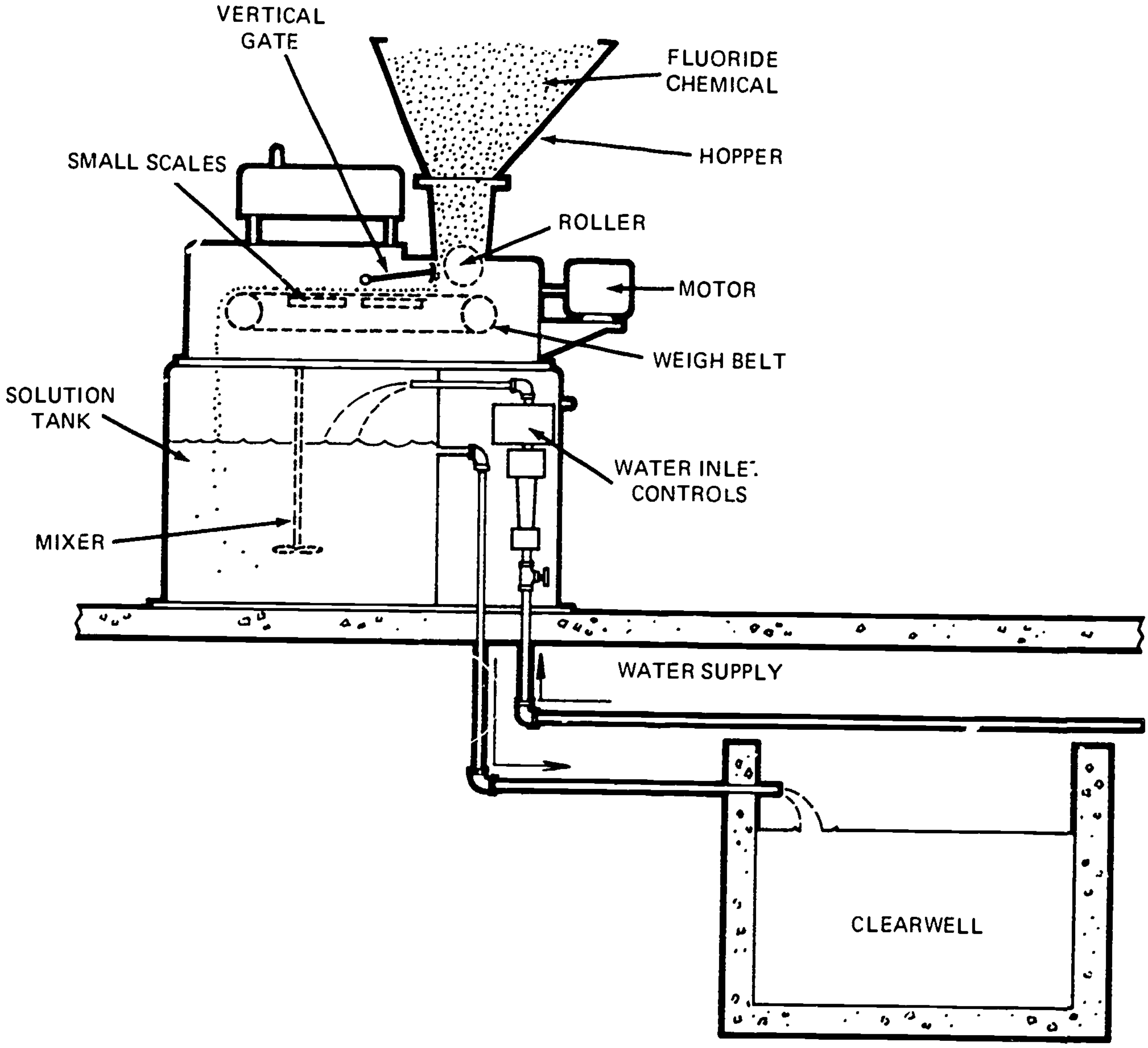

Fig. 13.6 Gravimetric feeder, belt-type

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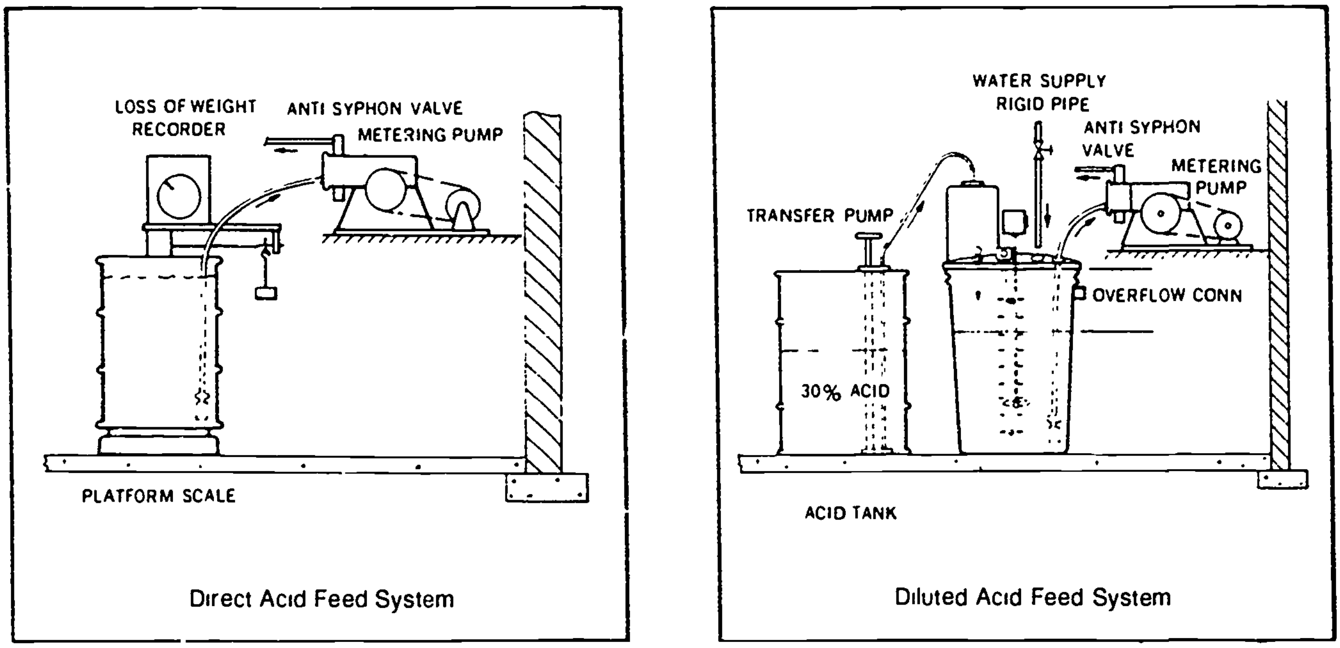
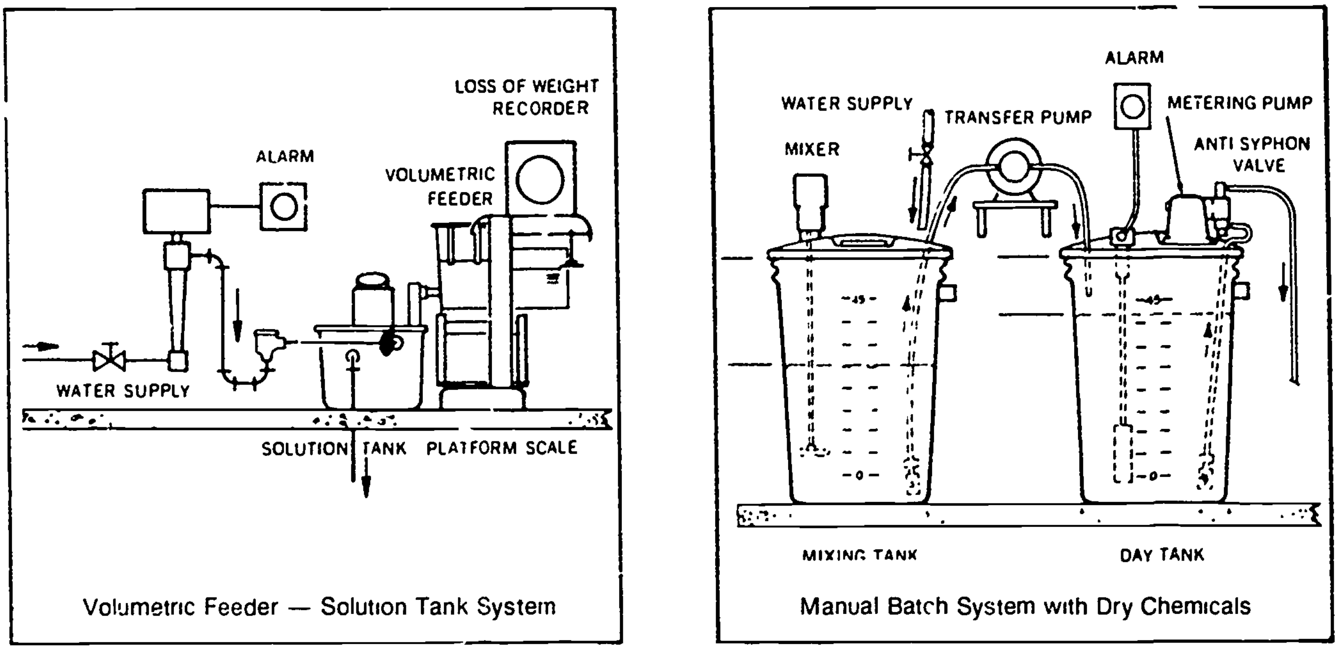


Direct Acid Feed System

Diluted Acid Feed System



Volumetric Feeder — Solution Tank System

Manual Batch System with Dry Chemicals

Fig. 13.7 Typical fluoridation systems

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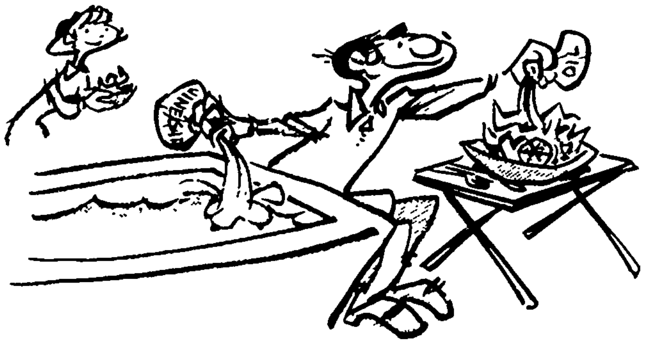
13.31 Saturators

Only crystal-grade (20 to 60 mesh) sodium fluoride should be fed with a *SATURATOR*[5] (Figure 13.8). Sodium fluoride has a nearly constant solubility at normal temperature ranges and thus produces a fluoride solution of uniform strength. Sodium silicofluoride is not recommended to feed through the saturator because of its very low solubility in water (see Table 13.2). Maintain a depth of six to ten inches (150 to 250 mm) in the sodium fluoride bed of the saturator. The use of powdered sodium fluoride is not recommended because this chemical will clog the saturator.

Many dry chemical feed systems include a mixer, dissolving tank and *DAY TANK*[6] (Figure 13.9). The mixer mixes a known amount of chemicals with a measured amount of water in a dissolving tank or solution chamber. This is a "batch mixed" process because the chemicals are mixed with a specified amount of water, rather than being mixed in flowing water. The dissolved tank allows the chemicals to become dissolved in water which is continuously applied to the water being treated or is stored in a day tank or storage tank. The day tank usually stores at least enough chemical solution to properly treat the plant flow for at least one day. The chemical solution is fed from the day tank to the water being treated by a chemical feeder (feed pump) whose feed rate continuously adjusts to the flow being treated (flow-paced).

When working with fluoridation systems using a sodium fluoride solution, the hardness of the water is very important. Hard water can produce problems in systems using saturators and dissolving tanks through the formation of low solubility calcium and magnesium fluoride compounds. If the dilution water has a hardness of less than 10 mg/*L* hardness as $CaCO_3$, there will be no problem. If the hardness range is above 10 mg/*L* and below 75 mg/*L*, it is a case of how much cleaning and maintenance a particular system wants to put up with. Above a hardness of 75 mg/*L*, a softened water must be used for the water to prepare a fluoride solution in order to prevent severe scaling in the equipment.

As an alternative to the water softener, polyphosphates (at 7 to 15 mg/*L*) may be used instead of a zeolite softener to prevent plugging by scale in the feed system. The polyphosphates are added to the day tank to prevent scale deposits. If neither a zeolite softener nor polyphosphates are used, plugging may occur at any point in the feed system, including valves, saturator bed, and injection point. Remove these hardness deposits by flushing the system with vinegar or a five percent solution of hydrochloric acid (muriatic acid). The saturator beds also may require the removal of water hardness deposits.



The saturator is a special application of a solution feeder. A small pump delivers a saturated solution of sodium fluoride into the water system. The principle of a saturator is that a saturated solution will result if water is allowed to trickle through a bed containing sodium fluoride. Although saturated solutions of sodium fluoride can be manually prepared, generally the easiest and best way is an automatic feed device. Saturators should be stirred every day to prevent fluoride solids from building up on the bottom. There are two kinds of saturators, the upflow saturator and the downflow saturator.

13.32 Downflow Saturators (Figure 13.10)

In the downflow saturator, the solid sodium fluoride is held in a plastic drum or barrel and is isolated from the prepared solution by a plastic cone or a pipe manifold. A filtration barrier is provided by layers of sand and gravel to prevent particles of undissolved sodium fluoride from infiltrating the solution area under the cone or within the pipe manifold. The feeder pump draws the solution from within the cone or manifold at the bottom of the plastic drum. Downflow saturators require clean gravel and sand. In some systems the gravel and sand must be cleaned every day or two.

13.33 Upflow Saturators (Figure 13.11)

In an upflow saturator, undissolved sodium fluoride forms its own bed below which water is forced upward under pressure. No barrier is used since the water comes up through the bed of sodium fluoride and the specific gravity of the solid material keeps it from rising into the area of the clear solution above. A spider type water distributor located at the bottom of the tank contains hundreds of very small slits. Water, forced under pressure through these slits, flows upward through the sodium fluoride bed at a controlled rate to assure the desired four percent solution. The feeder pump intake line floats on top of the solution in order to avoid withdrawal of undissolved sodium fluoride. The water pressure requirements are 20 psi (138 kPa) minimum to 125 psi (862 kPa) maximum and the flow is regulated at 4 GPM (0.25 *L*/sec). Since introduction of water to the bottom of the saturator constitutes a definite cross-connection, *A MECHANICAL SIPHON-BREAKER MUST BE INCORPORATED INTO THE WATER LINE;* or better still, the saturator can be factory modified to include an air-gap and a water feed-pump.

Figures 13.8 and 13.11 show two configurations of upflow-type saturators which feed and prepare constant strength fluoride solution from granular sodium fluoride. The upflow type is the preferred type over the downflow saturator, as it is much easier to clean and maintain. Under normal conditions, it should need cleaning only once a year; so, we have discussed its construction and use in some detail.

To prepare an upflow saturator for use, the following steps should be taken.

1. With the distributor tubes in place, and the floating suction device removed, add 200 to 300 pounds (91 to 136 kg) of sodium fluoride directly to the tank. Any type of sodium fluoride can be used, from coarse crystal to fine crystal, but fine crystal will dissolve better than coarse

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[5] *Saturator (SAT-you-RAY-tore)   A device which produces a fluoride solution for the fluoride process. The device is usually a cylindrical container with granular sodium fluoride on the bottom. Water flows either upward or downward through the sodium fluoride to produce the fluoride solution.*

[6] *Day Tank   A tank used to store a chemical solution of known concentration for feed to a chemical feeder. A day tank usually stores sufficient chemical solution to properly treat the water being treated for at least one day. Also called an "AGE TANK."*

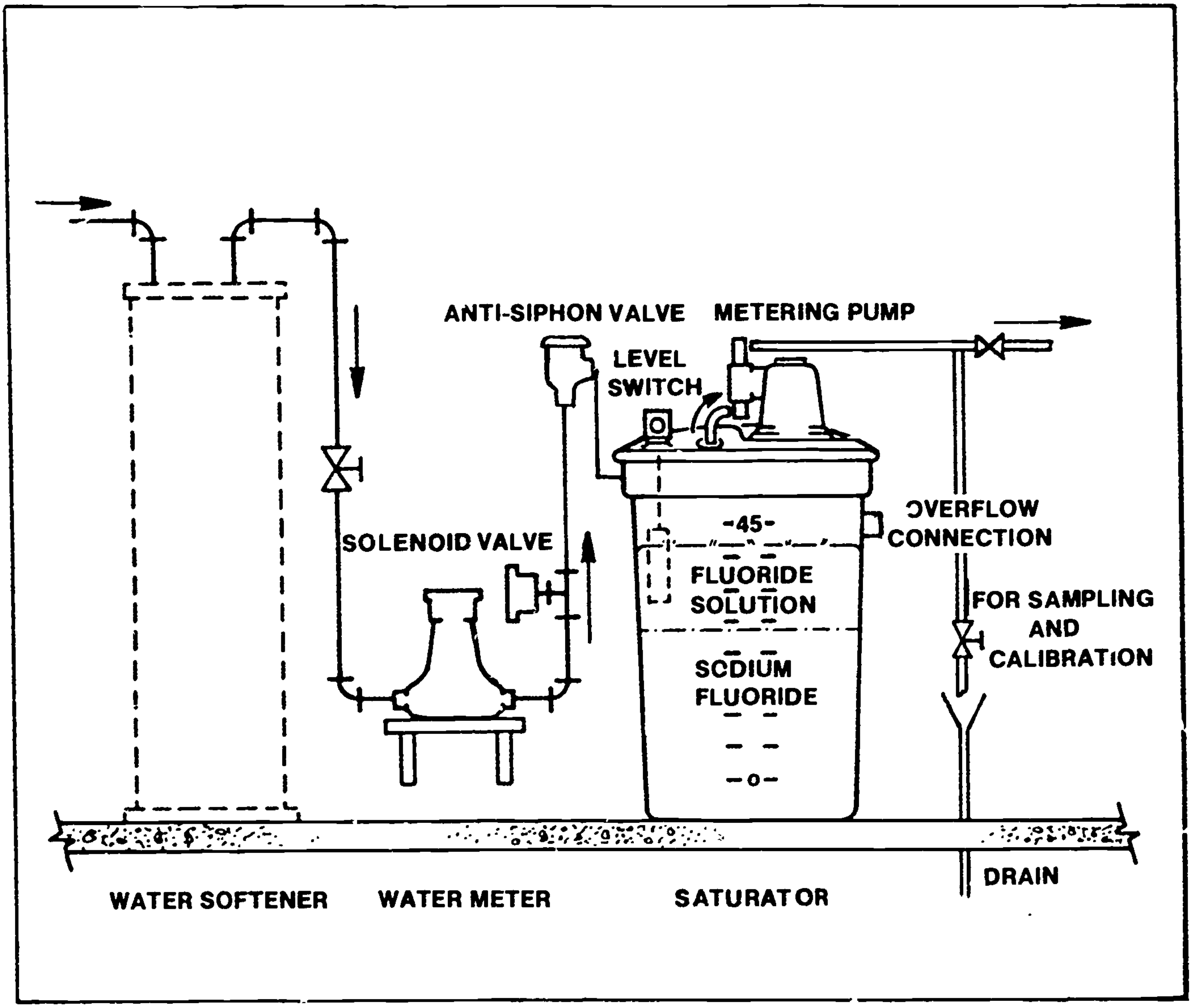

Fig. 13.8 Fluoride saturator
(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

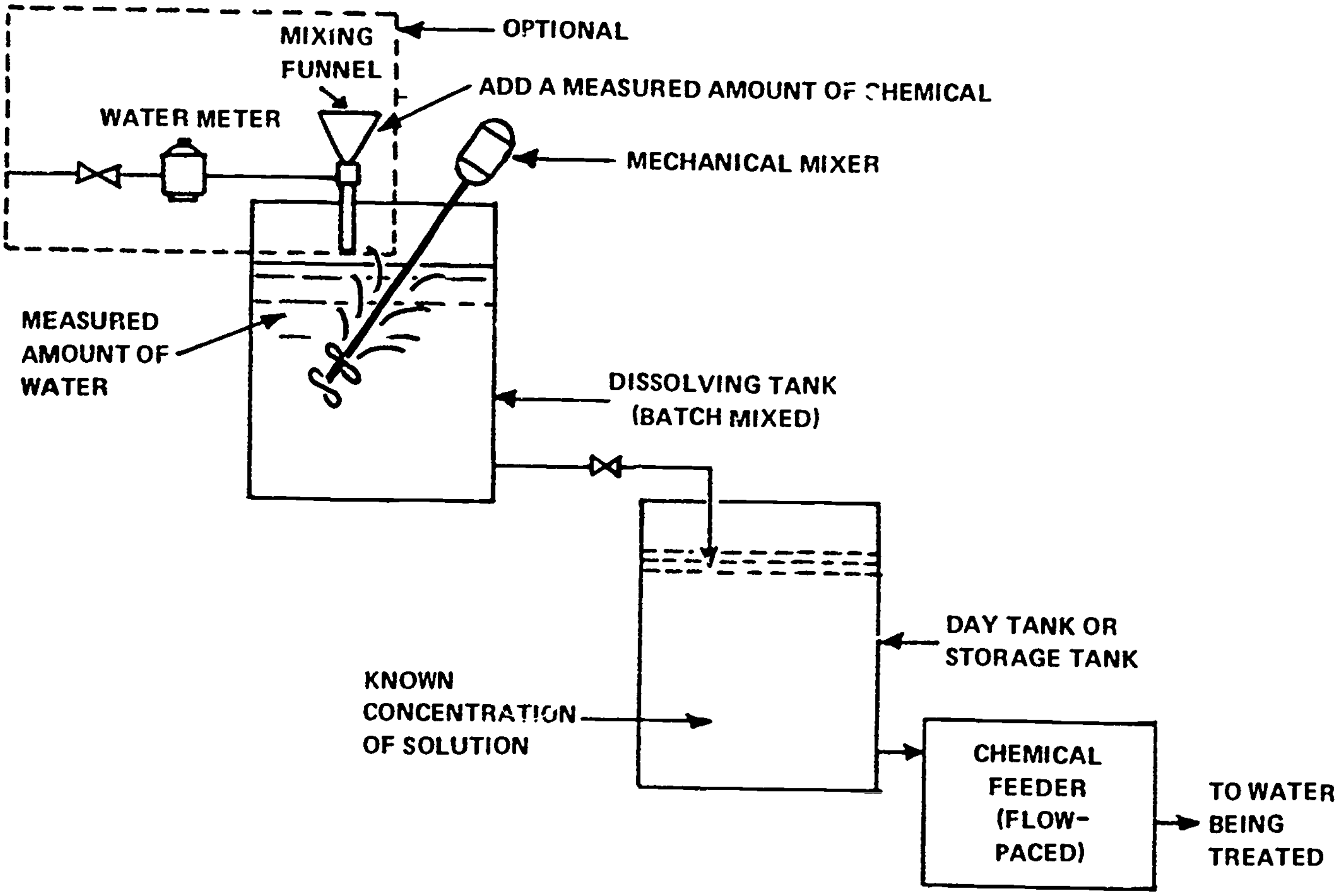

Fig. 13.9 Dry chemical dissolver, day tank and feeder

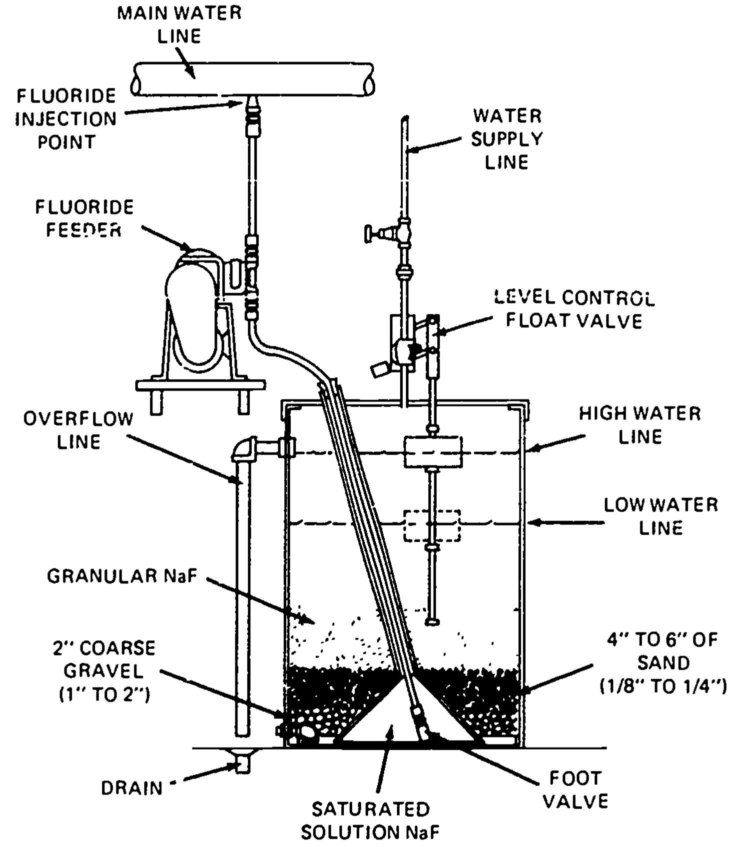

Fig. 13.10 Downflow saturator

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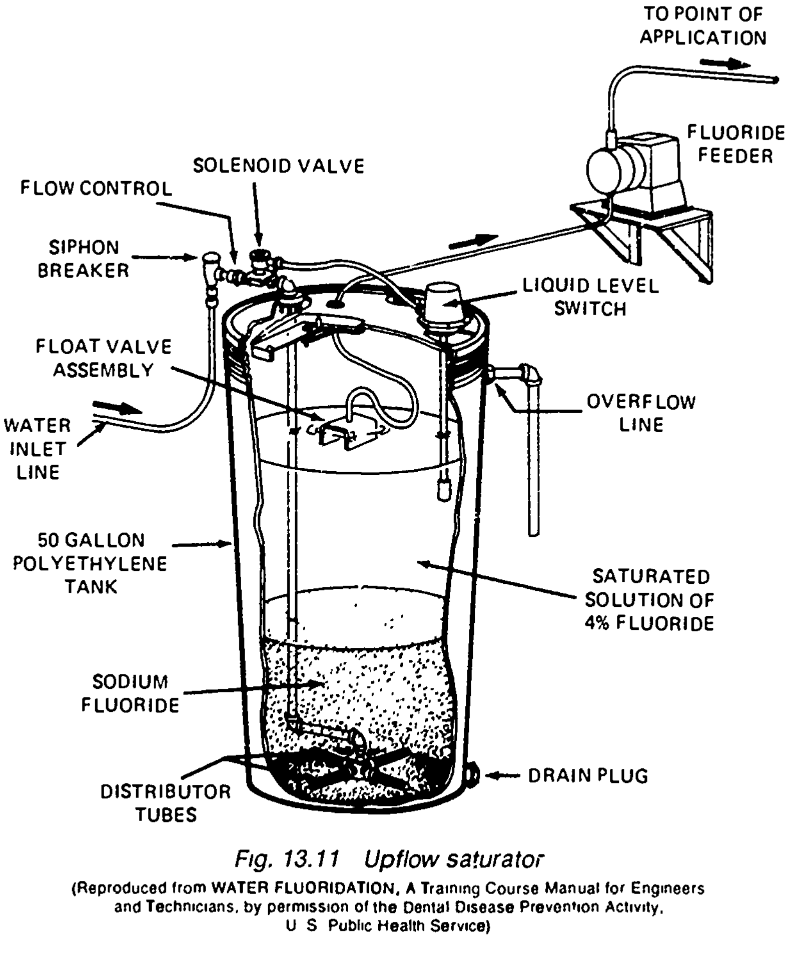


Fig. 13.11 Upflow saturator

(Reproduced from WATER FLUORIDATION, A Training Course Manual for Engineers and Technicians, by permission of the Dental Disease Prevention Activity, U S Public Health Service)

material If crystal is not available for some reason, powder can be used, but is not as desirable as a crystal form of sodium fluoride.

2. Connect the solenoid water valve to an electric outlet and turn on the water supply. The water level should be slightly below the overflow; if it is not, the liquid level switch should be adjusted.
3. Replace the intake float and connect it to the feeder intake line. The saturator is now ready to use.
4. By looking through the translucent wall of the saturator tank, you should be able to see the level of undissolved sodium fluoride. Whenever the level is low enough, add another 100 pounds (45 kg) of fluoride.
5. The water distributor slits are supposed to be essentially self-cleaning, and the accumulation of insolubles and precipitates does not constitute as serious a problem as it does in a down-flow saturator. However, a periodic cleaning is still required Frequency of cleaning is dictated by the severity of use and the rate of accumulation of debris.
6. Because of the thicker bed of sodium fluoride attainable in an upflow saturator, higher withdrawal rates are possible. With 300 pounds (136 kg) of sodium fluoride in the saturator tank, more than 15 gallons per hour (58 *L*/hr) of saturated solution can be fed. This rate is sufficient to treat about 5,000 gallons per minute (135 *L*/sec) of water to a fluoride level of 1.0 mg/*L*.
7. The fixed water inlet rate of 4 GPM (0.25 *L*/sec) should register satisfactorily on a ⅝-inch (16 mm) meter.

From a financial point of view, many water systems will want to design their fluoridation plants for unattended operation; so there will be designed into the system means for automatic shut down and alarm. For the sake of the operator that has to respond at all hours, alarm lights should be wired to indicate reasons for plant shutdown.

A few example alarms include low water flow in the main pipeline; high fluoride flow; high or low fluoride levels, low injection water pressure, power outage, and running time meter to indicate "down" time. These warning systems are partially helpful in large systems.

13.34 Large Hydrofluosilicic Acid Systems (Figure 13.12)

A more complicated system for fluoridation is a closed-loop control feeding system using hydrofluosilicic acid. This system finds use in large installations where the hydrofluosilicic acid can be delivered by tanker truck of around 4,000 gallons (15,140 *L*); although of course, smaller amounts can be purchased. The installation depicted in Figure 13.12 can treat up to 285 million gallons per day (1,079 M*L*/day). The advantages in this system are the elimination of dusting and also labor requirements are at a minimum.

The storage tanks are fiberglass filament wound with interior lining of Dera Kane 411-45 Resixl with a final barrier of Nexus Veil which has replaced Dynel. Steel tanks lined with at least 3/32 inch (2.34 mm) polyvinyl chloride sheet or neoprene sheet secured to the metal surface with adhesive can also be used. Hydrofluosilicic acid storage tanks constructed of plastic should be housed in enclosures to protect the tanks from vandalism. Leaks could be dangerous to passers by and will kill surrounding vegetation. The tanks must be vented to the outside as the fumes from the acid are highly corrosive.

Inspection of internal conditions of the hydrofluosilicic tanks should be made on two year intervals as some lining deterioration can be expected over a period of time. Should small leaks occur in the PVC piping, repairs should be made at once as they will only become worse and any acid dripping on concrete surfaces will dissolve the surface fairly quickly.

The use of a closed-loop control system in an unattended plant utilizing a fluoride analyzer as one of the controls is not recommended. The problem is that if the analyzer goes haywire and incorrectly indicates low fluoride levels, the system will try to correct itself and increase the addition of fluoride chemical. The net result will be to actually over-fluoride the water supply.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.3A List the three different types of situations whereby drinking waters may contain fluoride ions.

13.3B List three important design features of fluoridation systems.

13.3C What problems can be created by hard water in systems using saturators and dissolving tanks?

13.3D What is a saturator?

13.4 FINAL CHECKUP OF EQUIPMENT

13.40 Avoid Overfeeding

The operator must be certain that there will be no overfeed of fluoride ions. A gross overfeed can cause illness and bad public relations. Of all the chemicals used in the water treatment plant, fluoride concentrations are probably the most sensitive to correct maximum dosages.

13.41 Review of Designs and Specifications

When reviewing fluoride feeding system designs and specifications, the operator should check the items listed below.

1. Review the results of pre-design tests to determine the fluoride rate for both the present and future. The fluoridator should be sized to handle the full range of chemical doses or provisions should be made for future expansion.
2. Determine if sampling points are provided to measure chemical feeder output.

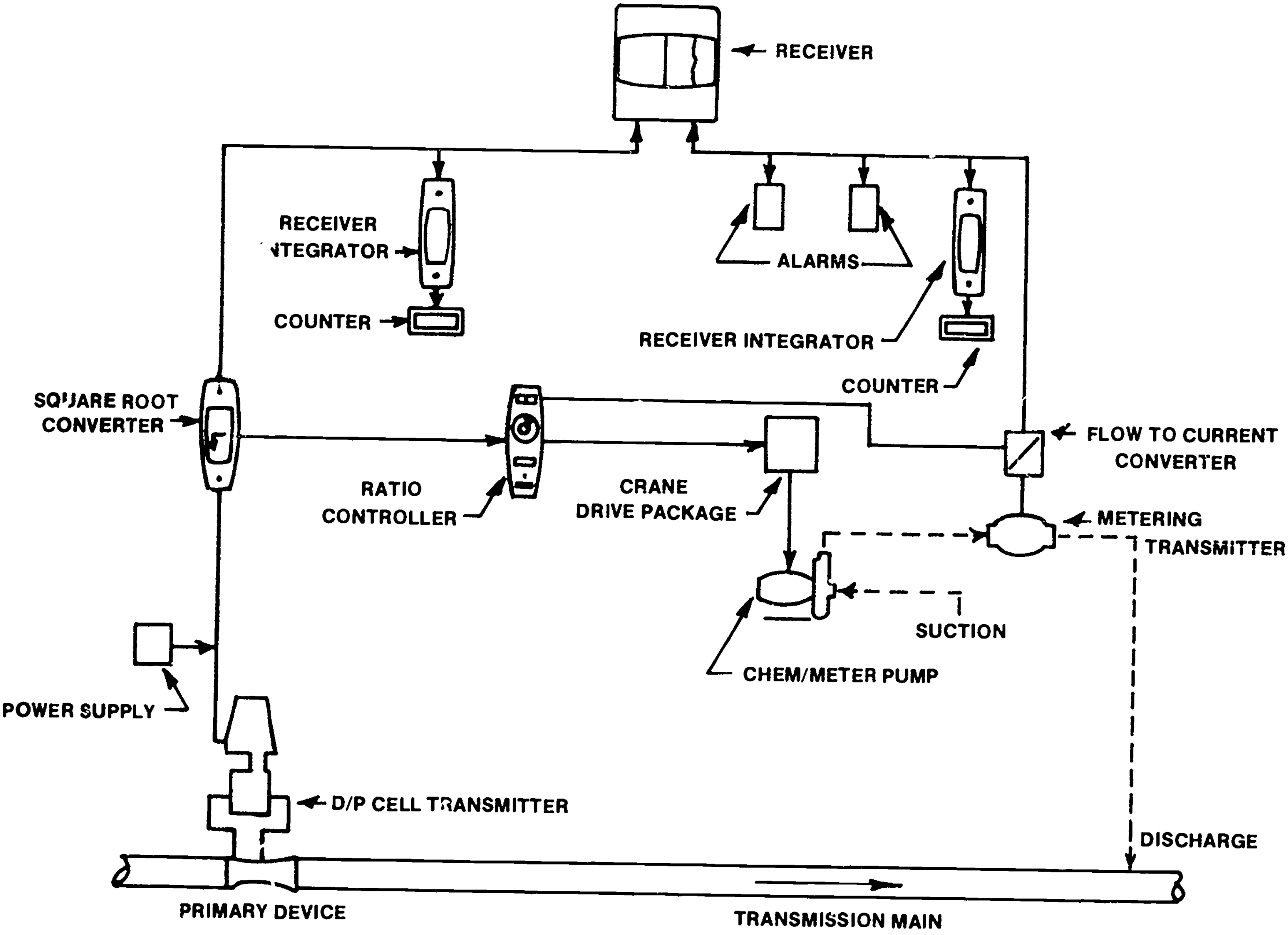


Fig. 13.12 Large automatic hydrofluosilicic system

3. Examine plans for valving to allow flushing the system with water before removing from service
4. Be sure corrosion-resistant drains are provided to prevent chemical leaks from reaching the floor, for example, drips from pump packing.
5. Check that all piping, valves and fittings are made of corrosion-resistant materials such as PVC or Stainless Steel Type 316.
6. Determine the amount of maintenance required. The system should require a minimum of maintenance. Equipment should be standard, with replacement parts readily available.
7. Consider the effect of changing head conditions (both feeder suction and discharge head conditions) on the chemical feeder output. Changing head conditions will not affect the output if the proper chemical feeder has been specified and installed.
8. Determine whether locations for monitoring readouts and dosage controls are convenient to the operation center and easy to read and record.
9. Any switches that throw the equipment from automatic into a hand or manual mode should be equipped with a red warning light to indicate that the equipment is on "hand" or "manual." This can easily be accomplished by a double-throw, double-pole, toggle switch. Lights with different colors can be used to indicate normal or automatic operation as well as on or off in order to avoid confusion.
10. The location where fluoride is added to the water should be where there will be the least possible removal of fluoride by other chemicals added to the water (after filtration and before the clear well)
11. Be sure the chemical hoppers are located where there is plenty of room so they can be conveniently and safely filled with the fluoride chemical.
12. Dust exhaust systems should be installed where substantial amounts of dry chemicals are handled.
13. In any fluoridation system, except the sodium fluoride saturator, scales are necessary for weighing the quantity of chemical (including solution) fed per day.
14. Alarms are important to signal and prevent both the loss of feed and overfeeding.
15. Any potable water line connected to a chemical feeder unit must be provided with a vacuum breaker or an air gap to prevent a cross-connection.

13.5 CHEMICAL FEEDER STARTUP

After the chemical feed system has been purchased and installed, carefully check the system out before startup Even if the contractor who installed the system is responsible for insuring that the equipment operates as designed, the operation by plant personnel, the functioning of the equipment and the results from the process are the responsibility of the chief operator. Therefore, before startup, check the items listed below.

1. Inspect the electrical system, for proper voltage; for properly sized overload protection; for proper operation of control lights on the control panel; for proper safety lock-out switches and operation; and for proper equipment rotation.
2. Confirm that the manfacturer's lubrication and startup procedures are being followed Equipment may be damaged in minutes if it is run without lubrication.
3. Examine all fittings, inspection plates and drains to assure that they will not leak when placed into service.
4. Determine the proper positions for all valves. A positive displacement pump will damage itself or rupture lines in seconds if allowed to run against a closed valve or system.
5. Be sure that the type of fluoride to be fed is available and in the hopper or feeder. A progressive cavity pump will be damaged in minutes if it is allowed to run dry.
6. Inspect all equipment for binding or rubbing.
7. Confirm that safety guards are in place.
8. Examine the operation of all auxiliary equipment including the dust collectors, fans, cooling water, mixing water, and safety equipment.
9. Check the operation of alarms and safety shut-offs. If it is possible, operate these devices by manually tripping each one. Examples of these devices are alarms and shut-offs for high water, low water, high temperature, high pressure and high chemical levels.
10. Be sure that safety equipment such as eyewash, drench showers, dust masks face shields, gloves and vent fans, are in place and functional.
11. Record all important nameplate data and place it in the plant files for future reference.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.4A Why must overfeeding of fluoridation chemicals be prevented?

13.4B What should be the capacity or size of the fluoridator?

13.5A What items should be considered when inspecting the fluoridation electrical system?

13.5B List the safety equipment that should be available near a fluoridation system

13.6 CHEMICAL FEEDER OPERATION

13.60 Fine Tuning

Once the chemical feed equipment is in operation and the major "bugs" are worked out, the feeder will need to be "fine tuned " To aid in fine tuning and build confidence in the entire chemical feed system, the operator must maintain accurate records (see Section 13.62, "Fluoridation Log Sheets").

A comment or remarks section should be used to note abnormal conditions, such as a feeder plugged for a short time, related equipment that malfunctions and other problems Daily logs should be summarized into a form that operators can use as a future reference.

13.61 Preparation of Fluoride Solution

To learn how to make up a fluoride solution, let's assume a hypothetical case using the following data:

1. Flow to be treated is 10 million gallons per day,
2. Hydrofluosilicic Acid 20% is the chemical to be used,
3. The unfluoridated water contains 0.05 mg/*L* (ppm) fluoride ion (F^-), and
4. The desired fluoride concentration in the treated water is 1.0 mg/*L*.

What should the feed rate be?

See Treatment Chart I, Hydrofluosilicic Acid, located on the next page.

Locate the *10 MGD* flow on the left hand scale of the graph and follow that line to the right until it intersects the *20 PERCENT* diagonal line. Project this point down vertically to the intersection of bottom line indicating gallons per day (or gallons per hour) required to produce a one mg/*L* (ppm) dose of fluoride (F). The answer is *50 GALLONS PER DAY* or a little less than *2.1 GFH* (gallons per hour). Multiply the 50 by (1.00-0.05) to give the needed treatment of 47.5 gallons per day or 2 GPH. The 1.00 is the desired dose of 1.00 mg/*L* and the 0.05 is the actual fluoride concentration of 0.05 mg/*L* in the untreated water.

In some cases it might be desirable to use a weaker acid solution to avoid feed rates below the minimum capacity of the metering pump. Dilution then is in order. The concentration may be reduced by volumetric proportions, for example one gallon of 20 percent acid plus one gallon of water results in two gallons of 10 percent acid. If possible try to avoid having to dilute acid because of potential errors and problems, especially with hard water. Peristaltic and electronic feeder pumps (Figures 13.2 and 13.3) may be used when the feed rates are low.

See Section 13.12, "Calculating Fluoride Dosages," for eleven example problems.

13.62 Fluoridation Log Sheets

You will probably want to design your own log sheets so they will be consistent with the installation features at your plant. Sample log sheets are shown on Figures 13.13, 13.14 and 13.15 (see pages 49, 50 and 51).

13.620 Hydrofluosilicic Acid

Figure 13.13 shows a typical log sheet from a hydrofluosilicic acid station. An explanation of the various columns is given below.

1. "Date" refers to calendar date when readings were logged or the date a shipment of fluoride was received.
2. "Time" refers to time event happened.
3. "Tank" that is supplying the feeder is circled. "Gals." refers to the gage reading of the amount of acid in the tank.
4. "% & Sp.Gr." Each delivery is accompanied by a vendor's laboratory analysis. The specific gravity is not measured until the tank is ready to be placed in service. When mixing acids of varying strengths, the end percentage must be calculated and entered in the proper column. See Example 10 in Section 13.12, "Calculating Fluoride Dosages."
5. For each tank follow the directions given in Step 4.
6. "Tank Loss Gals" refers to the amount of feed during the reporting period. In the sample 2930-2600 = 330 gallons. The feeding equipment should be equipped with an acid totalizer readout.
7. The "ratio" column indicates the feed setting computed using the acid strength, specific gravity and required dosage. The following steps illustrate how to calculate the feed setting for a specific piece of equipment.
   - (a) (Sp.Gr.)(lbs/gal water)(% H_2SiF_6)(% F^- (in H_2SiF_6)) = lbs F^-/gal.
   - (b) Substituting figures in the above formula.
   - (c) (1.226)(8.34)(0.229)(0.791) = 1.85 lbs F^-/gal.
   - (d) Dosage: 8.34 ÷ 1.85 = 4.51 gallons acid/M.G. water.
   - (e) In order to compensate for the .05 mg/*L* F^- in the raw water supply, the above figure of 4.51 should be reduced by 5% which is the relationship of the desired level of say 1 mg/*L* F^- to the raw water level of .05 mg/*L* F^-.
   - (f) 4.51 − (.05 × 4.51) = 4.51 − .23 = 4.28.
   - (g) Ratio setting therefore is 4.28 ÷ 4.80 or 0.89.
   - (h) The flow capacity of the pipeline water meter at 100% is 300 MGD.
   - (i) The flow capacity of the acid feed pump is 1440 gallons of H_2SiF_6/day.

     The ratio of the above two 100% capacities is 1440 ÷ 300 or 4.8 gal/MG.

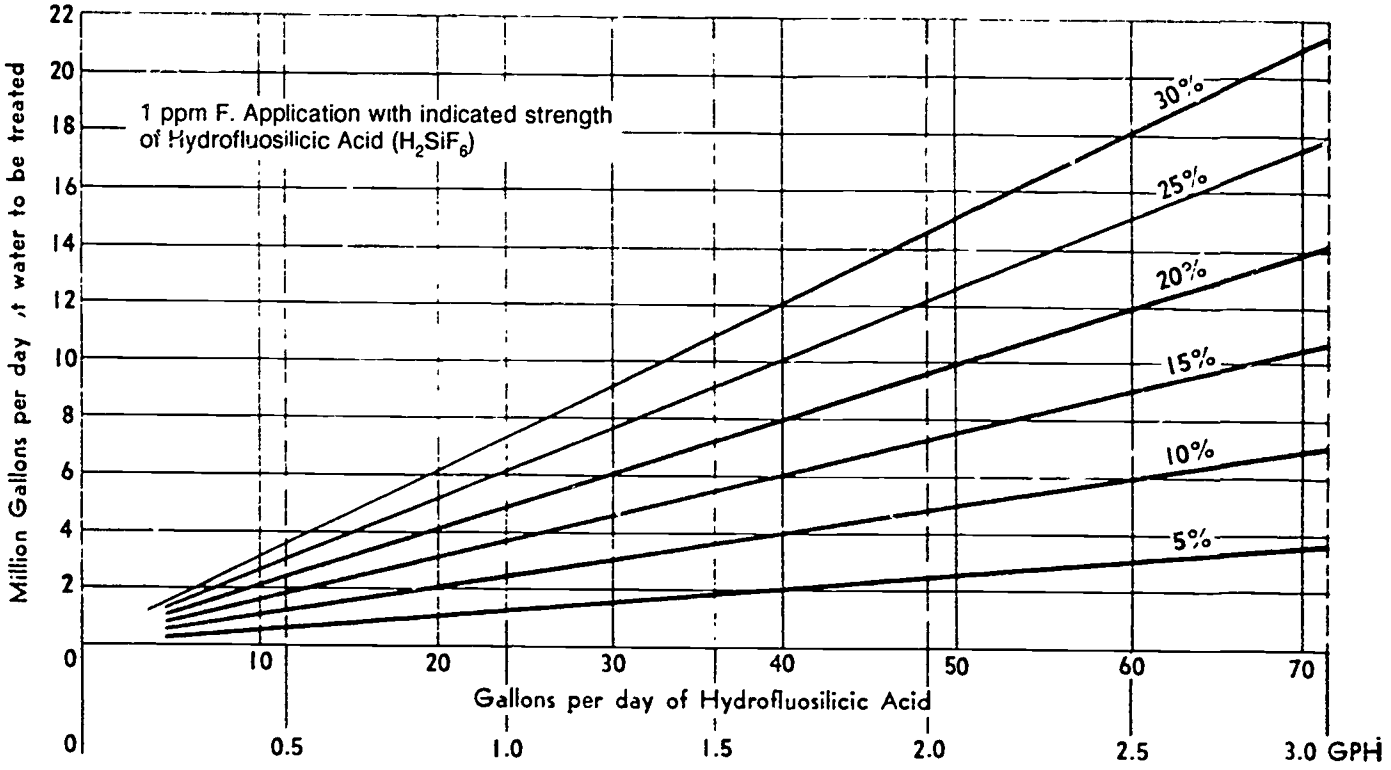
     Note the difference of the setting of 0.88 and the calculated figure of 0.89. This adjustment is made in order that the fluoride dosage will agree with the laboratory results. In all instances, the laboratory results should govern the feed settings.

     The small difference in calculated setting and actual setting can also result from accumulated errors in the control equipment, i.e., flow transmitter, √ extractor, and ratio controller.
8. "H_2SiF_6 Gals." is the actual amount of acid fed into the system and is derived as follows:

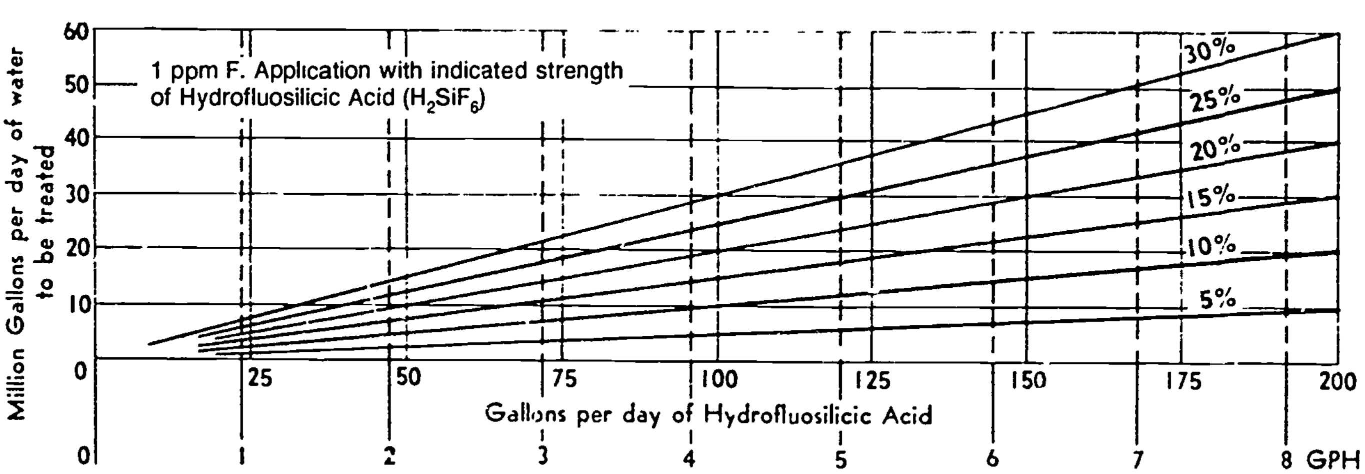
   885005.50 − 884676.08 = 329.42 gallons

   This figure should be fairly close to the reading obtained at Step 6. If it is not, look for errors in readings, leaks or equipment malfunctioning.
10. "Water Meter Totalizer" is the cumulative total of the amount of water being treated measured by a venturi or some other type of primary water meter.
11. "Water M/Gals." is the actual amount of water passing through the water meter for the time period involved and again is derived by simple subtraction:

    268.00 − 191.01 = 76.99 Million Gallons.

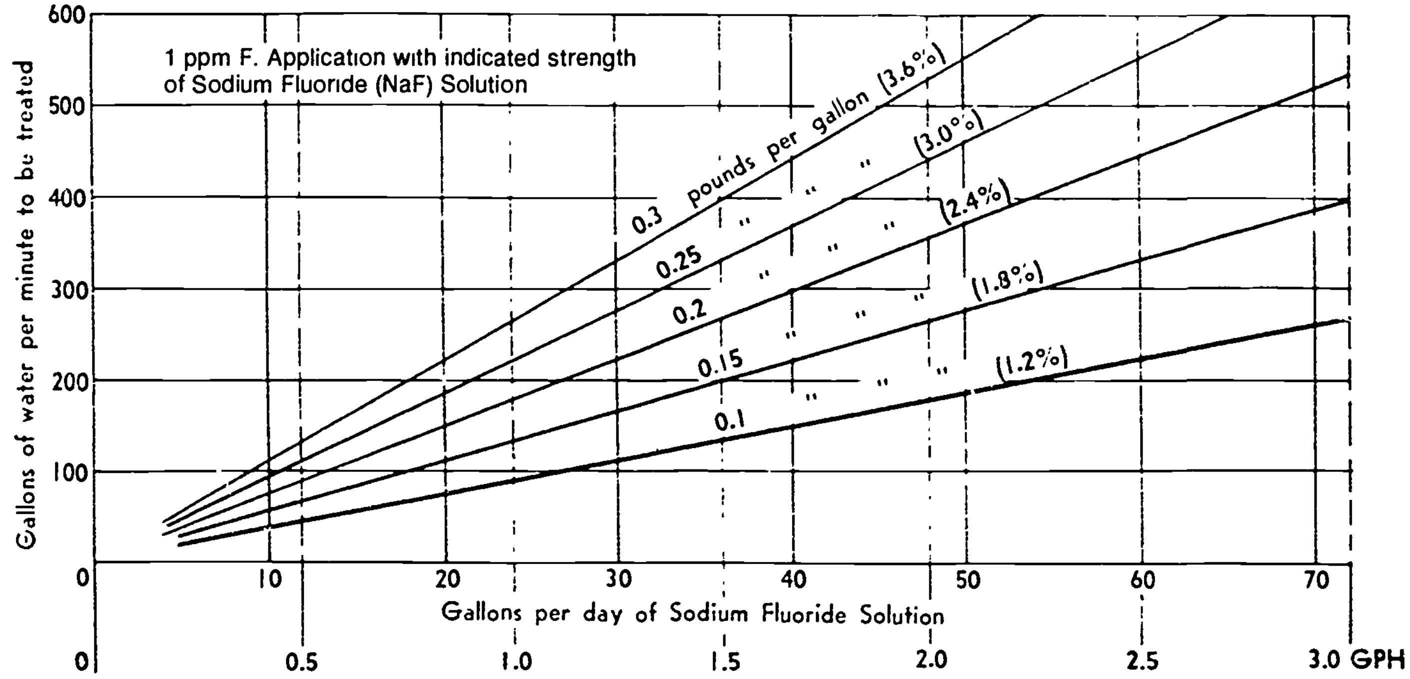


TREATMENT CHART I
Hydrofluosilicic Acid

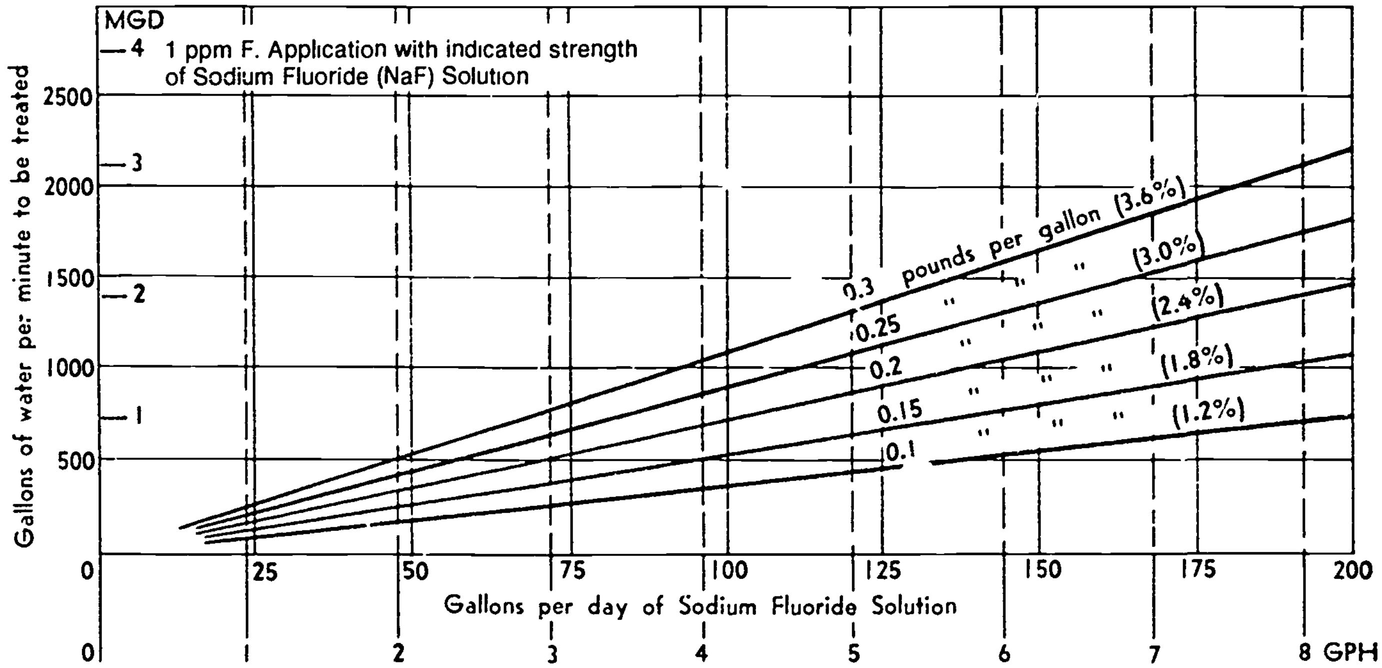


TREATMENT CHART II
Hydrofluosilicic Acid

Treatment Charts Courtesy of
Wallace & Tiernan Division, Pennwalt Corporation



TREATMENT CHART III
Sodium Fluoride



TREATMENT CHART IV

Treatment Charts Courtesy of
Wallace & Tiernan Division, Pennwalt Corporation

12. "Acid Gal/MG" is the rate of treatment for hydrofluosilicic acid and is obtained by dividing the figures from Step 9 by the figure from Step 11.
    329.42 ÷ 76.99 = 4.28

13. "F RESID. PPM" is actual fluoride content in the treated water as read by continuous flow fluoride ion analyzer.

14. "Down Time" The equipment should be equipped with a running time meter reading in seconds that begins to operate any time the plant shuts down. This will give reasons for low feed as indicated by the readings in Step 12. The operator should know why this deviation occurred.

15. "OBS.BY" This will be the operator's initials.

13.621 Sodium Silicofluoride

1. Figure 13.14 is a typical log sheet for a gravimetric feeder feeding powder sodium silicofluoride.

2. "Date" and "Time" are entered in the first two columns.

3. "Totalizer Reading (lbs.)" This reading indicates a cumulative reading of the amount of silicofluoride that has been fed by the machine.

4. "Weight Loss per 24 hrs. (lbs.)" is the amount of silicofluoride actually fed during the time frame and is determined from the readings observed in Step 3 as follows.
   44165.5 − 43276.9 = 888.6.

5. "Mach. Feed Setting" is the feed rates being used. This rate may vary from machine to machine depending upon gear ratios and other devices used to control the rate of chemical feed. If the laboratory tests indicate low or high fluoride ion level, the adjustment is made with this setting on a percentage basis. If the laboratory fluoride ion level is 10 percent low, then this setting should be raised 10 percent.

6. "Chem Added to Bin (lbs.)" is the amount of chemical taken from storage and dumped into the feeder hopper.

7. "Chemical Left in Storage (lbs.)" is the amount of fluoride in the bulk storage. This is useful in programming supply orders and in checking the accuracy of the feeder over a period of time To check accuracy, compare this amount with the amount indicated in Step 4 over a six month or one-year period.

8. "Pump Operating" is useful if several pumps are available to inject the dissolved sodium silicofluoride into the water main.

9. "Water Meter Reading (10,000 gals)" is the reading from the main line water meter.

10. "Water Treated (m.g.)" is the amount of water actually treated and is derived from Step 9 data as follows:
    39829.73 − 39762.41 = 67.32.

11. "Dosage (lbs. per m.g.)" represents the actual dosage of fluoride in the water. This figure should be constant, barring down time; changes in machine feed setting, Step 5 or equipment malfunctioning. The value is derived from the weight loss (Step 4) divided by the water treated (Step 10) as follows:
    888.6 ÷ 67.32 = 13.2.

12. "Plant Down Time (Hrs.)" is the period of time fluoride was not being fed and the plant was shut down because of power failure or automatic shutdown. The installation should be equipped with a resettable running time meter reading hours and tenths.

13. Figure 13.15 is a typical small plant log sheet used in plants utilizing sodium silicofluoride. This log sheet is provided through the courtesy of the City of Palo Alto, California.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.6A What should be the feed rate in gallons per day for treating 6 MGD with hydrofluosilicic acid 20 percent if the desired fluoride ion concentration is 1.2 mg/*L*? Assume the raw water does not contain any fluoride ion.

13.6B What could be the causes of differences between the recorded volume of acid used from a storage tank and the volume of acid fed into the system as measured by a flow meter?

13.7 PREVENTION OF OVERFEEDING

1. Operators must be assured that no overfeeding occurs, because no additional benefits result from overfeeding and there is a waste of chemicals and money. Excessive overfeeding could be harmful to consumers.

2. If the size of the installation warrants, a continuous fluoride ion analyser should be installed in the treated water line located downstream a sufficient distance so that adequate mixing is assured.

3. In a large plant involving shift operation, grab samples can be analyzed for the fluoride level during each shift, otherwise, once-a-day checks will suffice.

4. If the plant uses one of the solid fluoride compounds and the operator questions whether there is total solubility, the fluoride feeder can be shut down and the lack of fluoride traced out in the distribution system. There should be a sudden drop to zero fluoride or to the background level if total solubility is not being achieved (the undissolved solid fluoride compound will settle out).

5. All liquid systems should be checked for positive protection against back siphonage from fluoride storage tanks.

6. Shut down the plant if there is any significant overfeeding. Start flushing the affected mains and notify the local and state health departments. The water department and the health departments will then decide if public notification should be undertaken.

13.8 UNDERFEEDING

In contrast to the chlorination operation where continuous operation must be assured, fluoridation does not have to be continuous. Shutdowns for cleaning, adjustments, or due to

BYPASS TUNNEL FLUORIDE STATION

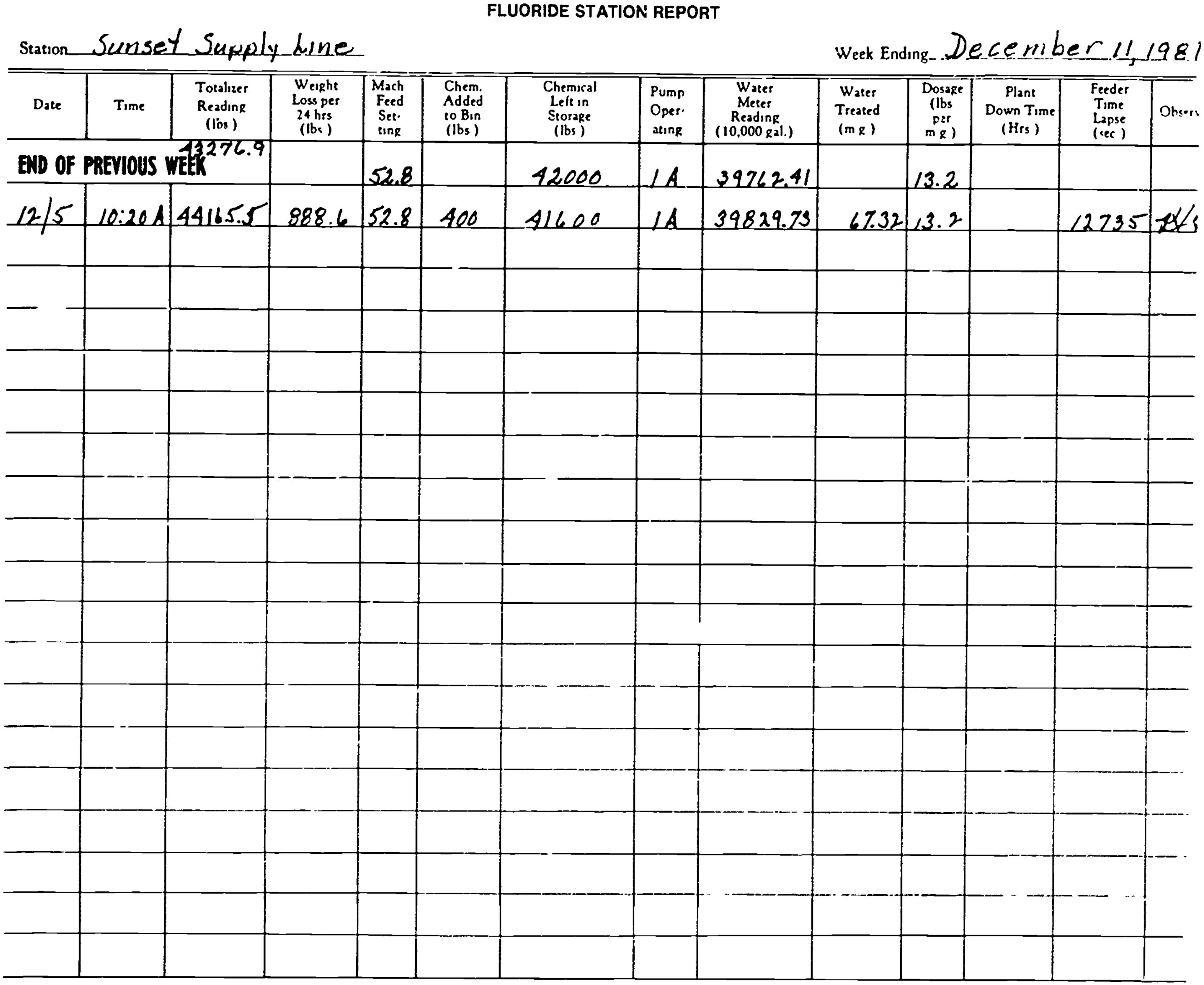
WEEK ENDING December 11, 1981

DATE	TIME	ACID STORAGE								TANK LOSS GALS	RATIO	H_2SiF_6 TOTALIZER	H_2SiF_6 GALS	WATER METER TOTALIZER	WATER M/GALS.	ACID GAL/MG	F RESID PPM	DOWN TIME	OBS BY
		TANK 1		TANK 2		TANK 3		TANK 4											
		GALS.	% & SP. GR	GALS	% & SP GR	GALS	% & SP GR	GALS	% & SP GR										
END OF PREVIOUS WEEK		2930	1.226 22.9	4370	23.0	120	23.9	2315	23.1		0.88	884676.08		191.01			0.98		
12/5	11:00A	2600								330	0.88	885005.50	329.42	268.00	76.99	4.28	0.97		RH

13-33

BIF METER	FLOW	F & P METER	REMARKS

Fig. 13.13 Log sheet for bypass tunnel fluoride station

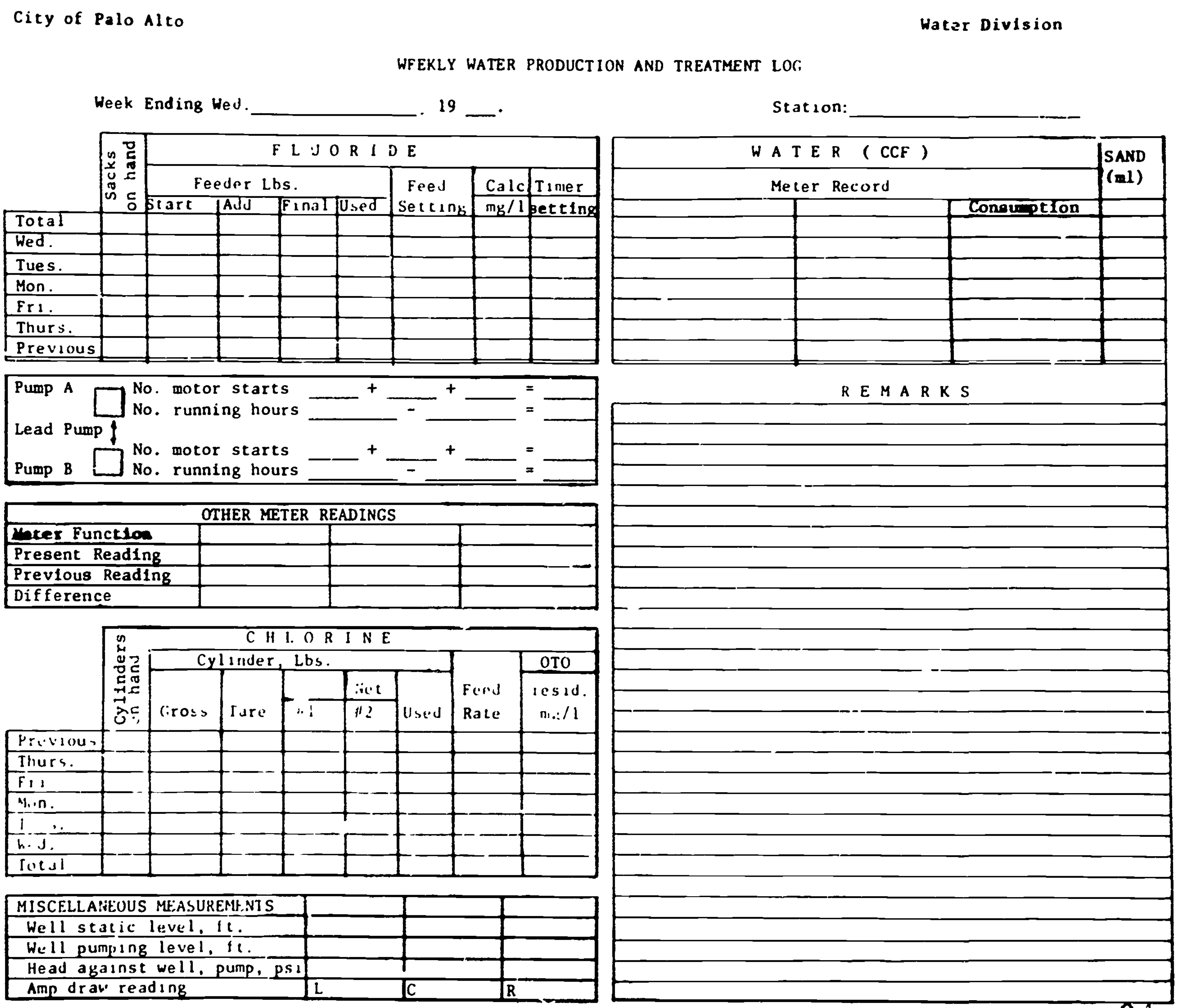


FLUORIDE STATION REPORT

Station Sunset Supply Line Week Ending December 11, 1981

Date	Time	Totalizer Reading (lbs)	Weight Loss per 24 hrs (lbs)	Mach Feed Setting	Chem. Added to Bin (lbs)	Chemical Left in Storage (lbs)	Pump Operating	Water Meter Reading (10,000 gal.)	Water Treated (mg)	Dosage (lbs per mg)	Plant Down Time (Hrs)	Feeder Time Lapse (sec)	Observ
END OF PREVIOUS WEEK		43276.9		52.8		42000	1A	39762.41		13.2			
12/5	10:20A	44165.5	888.6	52.8	400	41600	1A	39829.73	67.32	13.2		12735	[illegible]

Fig. 13.14 Log sheet for fluoride station reports



City of Palo Alto

Water Division

WEEKLY WATER PRODUCTION AND TREATMENT LOG

Week Ending Wed.________________, 19 ___.

Station:______________________

	Sacks on hand	FLUORIDE						
		Feeder Lbs.				Feed Setting	Calc mg/l	Timer Setting
		Start	Add	Final	Used			
Total								
Wed.								
Tues.								
Mon.								
Fri.								
Thurs.								
Previous								

WATER (CCF)			SAND (ml)
Meter Record			
		Consumption	

Pump A ☐ No. motor starts _____ + _____ + _____ = _____

No. running hours ________ - ________ = _____

Lead Pump ↕

☐ No. motor starts _____ + _____ + _____ = _____

Pump B No. running hours ________ - ________ = _____

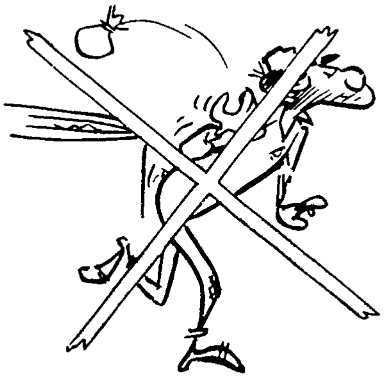
OTHER METER READINGS			
Meter Function			
Present Reading			
Previous Reading			
Difference			

	Cylinders on hand	CHLORINE						
		Cylinder, Lbs.					Feed Rate	OTO
		Gross	Tare	Net #1	#2	Used		resid. mg/l
Previous								
Thurs.								
Fri.								
Mon.								
Tues.								
Wed.								
Total								

MISCELLANEOUS MEASUREMENTS			
Well static level, ft.			
Well pumping level, ft.			
Head against well, pump, psi			
Amp draw reading	L	C	R

REMARKS

Fig. 13.15 Weekly water production and treatment log safety controls can be tolerated for short time periods. This does not mean that sloppy operation and maintenance is desirable. Every attempt should be made to maintain constant feeding. For example, the installation of standby electrical generating equipment just to maintain fluoridation equipment in operation would not be warranted. If the standby generator had to be purchased for other reasons, then the emergency circuit may also include the fluoride feeding equipment. Underfeeding should not be allowed because this results in a very significant reduction of the benefits of fluoridation.



Daily inspection of the fluoridation equipment, fluoride tests on the treated water, and calculation of the dosage from water treatment and chemical use data can greatly minimize the possibility of both overfeeding and underfeeding.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.7A Why should overfeeding be prevented?

13.7B What should be done if significant overfeeding occurs?

13.8A Why might a fluoridation operation be shut down?

13.9 SHUTTING DOWN CHEMICAL SYSTEMS

If the fluoridation equipment is going to be shut down for an extended length of time, it should be cleaned out to prevent corrosion and/or the solidifying of the chemical. Lines and equipment could be damaged when restarted if chemicals left in them solidify. Operators could be seriously injured if they open a chemical line that has not been properly flushed out.

The following items should be included in your checklist for shutting down the chemical system:

1. Flush out the chemical supply with water,
2. Run dry chemicals completely out of the equipment and clean equipment by using a vacuum cleaner,
3. Flush out all the solution lines with water until the lines are clean,
4. Shut off the electrical power,
5. Shut off the water supply and *PROTECT FROM FREEZING*,
6. Drain and clean the mix and feed tanks, and
7. Padlock (lock out) the main electric switch box to the fluoride equipment.

13.10 MAINTENANCE

Maintenance should follow the same routine as with any similar chemical feeder, including regular clean up and painting of the equipment and appurtenant metal piping and conduits. In order to give the plant a fresher look and hold down on painting, consider using all plastic piping even though it is used only for the water supply. Conduit and fittings should also be plastic for the same reason. Vacuum any gears and other similar parts to remove fluoride dust.

Since fluoride solutions are extremely corrosive, be constantly on the lookout for drips or leaks and any other evidence of corrosion. Repair these conditions as quickly as possible. Also look for the buildup of insoluble deposits in feedlines and equipment. Schedule the removal of insoluble deposits on a regular basis to prevent buildups from creating any problems.

All containers of fluoride chemicals must be disposed of in an acceptable manner. Thoroughly rinse all containers with water to remove all traces of chemicals before allowing containers to leave your plant. You may burn the containers if a nuisance will not be created. Remember that fluoride fumes can kill vegetation.

You don't need to be too concerned about checking the feed rate by catching a given amount of fluoride over a time period. The log will show long-period discrepancies and the daily laboratory tests will indicate any drifting from the desired fluoride concentration in the treated water.

Either you or the laboratory personnel must analyze the fluoridated water daily. Check the results for any deviations from the norm and take corrective action. Hand-held colorimeters are available for measuring fluoride in water. See Chapter 21, "Advanced Laboratory Procedures," for details on how to analyze samples for the fluoride ion.

An important part of your maintenance program is the prevention of any sanitary defects that could adversely affect the safety or quality of your treated drinking water. Sanitary defects that could develop in fluoridation systems include:

1. Lack of or inadequate start-stop controls,
2. Inadequate feed rate control equipment,
3. No analyzer to measure fluoride ion levels in treated water,
4. Lack of or inadequate backflow safeguards,
5. Fluoridation chemical not meeting AWWA specifications, and
6. Inadequate free chlorine residual in treated water.

13.11 SAFETY IN HANDLING FLUORIDE COMPOUNDS[7]

From the operators viewpoint, fluoride chemicals have one thing in common with all other chemicals found in treatment plants: *FLUORIDE CHEMICALS* can seriously injure or kill the careless or untrained operator. Safety should be of special concern to *YOU* because it is your own health that is at stake.

13.110 Avoid Overexposure

One of the major causes of overexposure is the inhalation of fluoride dust This usually occurs while a dry feeder or saturator is being loaded. Even with the use of dust collector systems, dust will circulate in the air. Always use approved respirators equipped with cartridges for organic dusts and vapors, protective coveralls and gloves when emptying sacks or cleaning up equipment and plant surfaces.

When loading a saturator, dust will be minimized if crystalline sodium fluoride is fed instead of powdered sodium fluoride. When loading a dry feeder you should wear a mask, apron, and rubber gloves to minimize exposure.

When the protection gear is removed, the remaining small traces of chemical should also be removed from your body. Some large water plants have dust-collection systems that use a partial vacuum to draw dust from your body and vent it to the outside air after filtering.

Care should be taken when emptying bags of chemicals into a feeder hopper. The bags should be opened carefully at the top and the contents poured gently to minimize dust. Care should also be taken during storage of the bags. Bags should be stored in a dry place, preferably off the floor. If bags are stacked too high there is the possibility of them falling and breaking open.

If a saturator is used, you should be cautious about allowing the solution to come in contact with skin and clothing. If this does happen, the affected area should be washed immediately with water. This also applies to other fluoride solutions (such as the dissolving water used in a dry feeder).

If a fluoride acid is being fed, extra precaution must be taken. Fluoride acid is probably the most corrosive chemical found in a water plant The pH of fluoride acid is approximately 1.2 and will eat through glass faster than chlorine. Special care should be taken to keep fumes to a minimum. If the acid does come in contact with your skin, you may not be able to wash it off fast enough to prevent a burn. If this happens, standard first aid should be administered as soon as possible.

A good pair of safety goggles should be worn at all times when working around fluoridation equipment where there is any possibility of splashing fluoride solutions. Be especially cautious around the fluoride acids as the concentrated acid can dissolve the whites of one's eyes in addition to the usual burns associated with acids. Another "must" is a safety shower. This must be located within easy access to both the unloading operation and points of liquid usage.

Another safety precaution that should be followed is the labeling of all feeders and solution tanks. Proper labeling will help prevent placement of chemicals in the wrong feeder. If possible, fluoride chemical should be tinted blue to differentiate it from other water treatment chemicals.

13.111 Symptoms of Fluoride Poisoning

In the event that someone is poisoned, it is vitally important to recognize the early symptoms.

Some of the obvious signs of poisoning are vomiting, stomach cramps, and diarrhea. Usually, the person will become very weak, have trouble speaking, be very thirsty, and have poor color vision. In cases of extreme poisoning, there are strong, jerky muscle contractions in the arms and legs leading to convulsions. If poisoning is not treated immediately, the person may die. Fatal doses range from 4 to 5 gm, or about a tablespoon. This equals about 2,000 times the amount of fluoride swallowed by a person from a water supply.

If a person is poisoned by inhaling fluoride, the first symptoms will be a sharp, biting pain in the nose followed by a runny nose or nose bleed. It is doubtful that a person could inhale enough fluoride to produce the same effects as encountered from drinking a large amount of fluoride. However, the sudden presence of bad stomach cramps and pains in the nose and eyes should not be ignored.

The victim should see a doctor immediately, and the water treatment practices should be checked to determine the source of the fluoride poisoning. It is probably a good idea to check out treatment practices occasionally.

The importance of quick treatment for fluoride poisoning cannot be over emphasized. In such cases a doctor should be called immediately, and if the poisoning is severe, an ambulance should be called.

13.112 Basic First Aid

Once it is established that it is fluoride poisoning, first aid should be started while waiting for medical help The following are recommended first-aid procedures:

1. Move the person away from any contact with fluoride and keep warm,
2. Give the person three teaspoons full of table salt in a glass of warm water,
3. If the person is conscious, induce vomiting by rubbing the back of the throat with a spoon or your finger; if available use syrup of ipecac,
4. Give the person a glass of milk,
5. Repeat the salt and vomiting several times, and
6. Take the person to the hospital as soon as possible.

First aid for a person with a nose bleed from inhaling a high concentration of fluoride is:

1. Take the person away from the source of the fluoride;
2. Tip the person's head back while placing cotton, cloth, or paper towels inside the nostrils (change these often);
3. Take the person to a doctor if you cannot stop the bleeding.

If common sense and good safety practice are used, the hazard to the water plant operator should be as small as the hazard to the water consumer.

Fluoridation chemicals are poisonous.
Protect yourself from these toxic chemicals.

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[7] *Portions of the material in this section were adopted from "Safety Procedures Necessary During Fluoridation Process," by Ed Hansen Reproduced from OPFLOW, Volume 9, No. 7, (July 1983) by permission. Copyright 1983, The American Water Works Association.*

13.113 Protecting Yourself and Your Family

Avoid swallowing fluoridation chemicals. Don't eat, drink or smoke in or around chemical storage or feed areas. Do not inhale chemical dusts or vapors. Wear a respirator. Be sure exhaust fans and dust collectors are operating properly. Prevent hydrofluosilicic acid from coming in contact with your skin or eyes because hydrofluosilicic acid is very corrosive. If any hydrofluosilicic acid touches you, flood the contact area with plenty of water. If you are acutely poisoned by a fluoride chemical, you may be thirsty, vomit and have stomach cramps, diarrhea, difficulty in speaking and disturbed color vision. If any of these symptoms occur, consult a physician immediately.

When leaving the fluoride plant, wash your hands and change coveralls so that fluoride dust is not carried home.

13.114 Training

Special safety training must be given to all operators who will handle fluoride compounds. Training must include how to safely receive compounds from supplier, store until needed, prepare solutions, load feeders, and dose water being treated.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 59.

13.9A Why should fluoridation equipment be cleaned out if the equipment is going to be shut down for an extended length of time?

13.10A How can fluoride dust be removed from gears?

13.10B How would you determine if your fluoridation equipment was providing the desired dosage?

13.11A What are the symptoms of acute fluoride poisoning?

13.12 CALCULATING FLUORIDE DOSAGES

FORMULAS

1. Charts can be used to determine feed rates. The feed rate is usually based on a dose of one mg/*L*; therefore actual feed rates must be adjusted.

$$\text{Actual Feed Rate, GPD} = \frac{(\text{Chart Feed Rate, GPD})(\text{Actual Dose, mg}/L)}{1\ \text{mg}/L}$$

2. Feed rates may be calculated on the basis of pounds per day or gallons per day. Consideration must be given to the pounds of fluoride ion per pound of commercial chemical

$$\text{Feed Rate, lbs/day} = \frac{(\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})(100\%)}{\text{Solution, \% F}}$$

or
$$\text{Feed Rate, lbs/day} = \frac{\text{Feed Rate, lbs F/day}}{\text{lbs F/lb Commercial Chemical}}$$

or
$$\text{Feed Rate, gal/day} = \frac{\text{Feed Rate, lbs/day}}{\text{Chemical Solution, lbs/gal}}$$

3. If the water being treated contains some fluoride ion, but not sufficient, then a feed dose must be calculated.

$$\text{Feed Dose, mg}/L = \text{Desired Dose, mg}/L - \text{Actual Concentration, mg}/L$$

4. Commercial chemicals usually are not 100 percent pure. Also, the chemical only contains a portion of the ion of concern (fluoride ion in this chapter).

$$\text{Portion F} = \frac{(\text{Commercial Purity, \%})(\text{Fluoride Ion, \%})}{(100\%)(100\%)}$$

The portion F is the pounds of F per pound of commercial chemical. For example, 0.6 pounds F per one pound of commercial sodium silicofluoride.

5. To calculate the fluoride dosage or any chemical dosage, you need to know the pounds of chemical and volume of water in million gallons.

$$\text{Dosage, mg}/L = \frac{\text{Chemical, lbs}}{(\text{Water, M Gal})(8.34\ \text{lbs/gal})}$$

$$= \frac{\text{lbs Chemical}}{\text{Million lbs Water}}$$

If we substitute milligrams for pounds, we get

$$= \frac{\text{mg Chemical}}{\text{Million mg Water}}$$

One million milligrams of water occupy a volume of one liter.

$$= \frac{\text{mg Chemical}}{\text{Liter of Water}}$$

$$= \text{mg}/L$$

6. To determine the amount of feed solution in either gallons or gallons per day to treat a water, you need to know the amount of water to be treated in gallons or gallons per day, the feed dose in milligrams per liter and the feed solution in milligrams per liter.

$$\text{Feed Solution, gal} = \frac{(\text{Flow, gal})(\text{Feed Dose, mg}/L)}{\text{Feed Solution, mg}/L}$$

NOTE: If the "Feed Solution" is in gallons per day instead of gallons, then the "Flow" must be in gallons per day also instead of gallons.

7. When mixing the same two acids or chemicals, but of different strengths, the volumes or flows of the chemicals and their strengths must be known.

$$\text{Mixture Strength, \%} = \frac{(\text{Volume 1, gal})(\text{Strength 1, \%}) + (\text{Volume 2, gal})(\text{Strength 2, \%})}{\text{Volume 1, gal} + \text{Volume 2, gal}}$$

NOTE: The "Volumes" may be in gallons or treated as flows in GPD or MGD. The "Strengths" may be in percentages or concentrations such as mg/*L*.

8. When using chemicals for fluoridation, we need to know the percentage fluoride ion purity. This information will allow us to convert the pounds of chemical dosage to pounds of fluoride ion available.

$$\text{Fluoride Ion Purity, \%} = \frac{(\text{Molecular Weight of Fluoride})(100\%)}{\text{Molecular Weight of Chemical}}$$

EXAMPLE 1

A flow of 4 MGD is to be treated with a 20 percent solution of hydrofluosilicic acid (H_2SiF_6). The water to be treated contains no fluoride and the desired fluride concentration is 1.8 mg/*L*. What should be the feed rate of hydrofluosilicic acid? Use the treatment charts.

Known		Unknown
Flow, MGD	= 4 MGD	1. Feed Rate, gal/day
Acid Solution, %	= 20%	2. Feed Rate, gal/hr
Desired F, mg/*L*	= 1.8 mg/*L*	

1. Use treatment Chart I on page 46 because we are treating a relatively small flow (4 MGD).
2. Start on the left side at the 4 MGD value and move horizontally to the right to the 20 percent diagonal line.
3. At this point drop vertically downward to the bottom lines and read the feed rates for one mg/L (ppm).
   - a. Feed Rate, gallons per day = 19 gal/day
   - b. Feed Rate, gallons per hour = 0.8 gal/hr
4. Calculate the feed rate to produce the desired fluoride concentration of 1.8 mg/L.

a. Feed Rate, GPD

$$= \frac{\text{(Feed Rate, GPD)(Desired F, mg/}L)}{1\ \text{mg/}L}$$

$$= \frac{(19\ \text{GPD})(1.8\ \text{mg/}L)}{1\ \text{mg/}L}$$

$$= 34.2\ \text{gallons/day}$$

b. Feed Rate, gal/hr

$$= \frac{\text{(Feed Rate, gal/hr)(Desired F, mg/}L)}{1\ \text{mg/}L}$$

$$= \frac{(0.8\ \text{gal/hr})(1.8\ \text{mg/}L)}{1\ \text{mg/}L}$$

$$= 1.44\ \text{gal/hr}$$

EXAMPLE 2

A flow of 4 MGD is to be treated with a 20 percent solution of hydrofluosilicic acid (H_2SiF_6). The water to be treated contains no fluoride and the desired fluoride concentration is 1.8 mg/L. Assume the hydrofluosilicic acid weighs 9.8 pounds per gallon. What should be the feed rate of hydrofluosilicic acid? Calculate the feed rate.

Known	Unknown
Flow, MGD = 4 MGD	1. Feed Rate, gal/day
Acid Solution, % = 20%	2. Feed Rate, gal/hr
Acid, lbs/gal = 9.8 lbs/gal	
Desired F, mg/L = 1.8 mg/L	

1. Calculate the hydrofluosilicic acid feed rate in pounds per day.

Feed Rate, lbs/day

$$= \frac{\text{(Flow, MGD)(Desired F, mg/}L\text{)(8.34 lbs/gal)(100\%)}}{\text{Acid Solution, \%}}$$

$$= \frac{(4\ \text{MGD})(1.8\ \text{mg/}L)(8.34\ \text{lbs/gal})(100\%)}{20\%}$$

$$= 300\ \text{lbs acid/day}$$

2. Determine the feed rate of the acid in gallons per day.

Feed Rate, gal/day

$$= \frac{\text{Feed Rate, lbs/day}}{9.8\ \text{lbs/gal}}$$

$$= \frac{300\ \text{lbs acid/day}}{9.8\ \text{lbs acid/gal acid}}$$

$$= 31\ \text{gal acid/day}$$

NOTE: We obtained a feed rate of 34 gallons of acid per day from Treatment Chart I. The differences result from the problems of drawing and reading the chart accurately.

3. Calculate the feed rate in gallons of acid per hour.

$$\text{Feed Rate, gal/hr} = \frac{\text{Feed Rate, gal/day}}{24\ \text{hr/day}}$$

$$= \frac{31\ \text{gal acid/day}}{24\ \text{hr/day}}$$

$$= 1.3\ \text{gal acid/hr}$$

EXAMPLE 3

A flow of 200 GPM is to be treated with a 2.4 percent (0.2 lbs/gallon) solution of sodium fluoride (NaF). The water to be treated contains 0.7 mg/L of fluoride ion and the desired fluoride ion concentration is 1.6 mg/L. What should be the feed rate of sodium fluoride? Use the treatment charts.

Known	Unknown
Flow, MGD = 200 MGD	1. Feed Rate, gal/day
NaF Solution, % = 2.4%	2. Feed Rate, gal/hr
Desired F, mg/L = 1.6 mg/L	
Actual F, mg/L = 0.7 mg/L	

1. Use treatment Chart III on page 47 because we are treating 200 GPM.
2. Start at the left side at the 200 GPM value and move horizontally to the right to the 2.4 percent diagonal line.
3. At this point drop vertically downward to the bottom lines and read the feed rates for one mg/L (ppm).
   - a. Feed Rate, gallons per day = 26.5 gal/day
   - b. Feed Rate, gallons per hour = 1.1 gal/hr
4. Calculate the feed rate to produce the desired fluoride concentration of 1.6 mg/L.

Feed Dose, mg/L = Desired Dose, mg/L − Actual Conc., mg/L

$$= 1.6\ \text{mg/}L - 0.7\ \text{mg/}L$$

$$= 0.9\ \text{mg/}L$$

Feed Rate, GPD

$$= \frac{\text{(Feed Rate, GPD)(Feed Dose, mg/}L)}{1\ \text{mg/}L}$$

$$= \frac{(26.5\ \text{gal/day})(0.9\ \text{mg/}L)}{1\ \text{mg/}L}$$

$$= 23.8\ \text{GPD}$$

Feed Rate, gal/hr

$$= \frac{\text{(Feed Rate, gal/hr)(Feed Dose, mg/}L)}{1\ \text{mg/}L}$$

$$= \frac{(1.1\ \text{gal/hr})(0.9\ \text{mg/}L)}{1\ \text{mg/}L}$$

$$= 0.99\ \text{gal/hr or 1 gal/hr}$$

EXAMPLE 4

A flow of 200 GPM is to be treated with a 2.4 percent (0.2 pounds per gallon) solution of sodium fluoride (NaF). The water to be treated contains 0.7 mg/L of fluoride ion and the desired fluoride ion concentration is 1.6 mg/L. What should be the feed rate of sodium fluoride? Calculate the feed rate. Assume the sodium fluoride has a fluoride purity of 43.4 percent.

Known	Unknown
Flow, MGD = 200 MGD	1. Feed Rate, gal/day
NaF Solution, % = 2.4%	2. Feed Rate, gal/hr
NaF Solution, lbs/gal = 0.2 lbs/gal	
Desired F, mg/L = 1.6 mg/L	
Actual F, mg/L = 0.7 mg/L	
Purity, % = 43.4%	

1. Convert flow from gallons per minute to million gallons per day.

$$\text{Flow, MGD} = \frac{(\text{Flow, gal/min})(60\text{ min/hr})(24\text{ hr/day})(1\text{ Million})}{1{,}000{,}000}$$

$$= \frac{(200\text{ gal/min})(60\text{ min/hr})(24\text{ hr/day})(1\text{ Million})}{1{,}000{,}000}$$

$$= 0.288\text{ MGD}$$

2. Determine the fluoride feed dose in milligrams per liter.

$$\text{Feed Dose, mg/}L = \text{Desired Dose, mg/}L - \text{Actual Conc, mg/}L$$

$$= 1.6\text{ mg/}L - 0.7\text{ mg/}L$$

$$= 0.9\text{ mg/}L$$

3. Calculate the feed rate in pounds of fluoride ion per day

$$\text{Feed Rate, lbs F/day} = (\text{Flow, MGD})(\text{Feed Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (0.288\text{ MGD})(0.9\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 2.16\text{ lbs F/day}$$

4. Convert the feed rate from pounds of fluoride per day to gallons of sodium fluoride solution per day.

$$\text{Feed Rate, gal/day} = \frac{(\text{Feed Rate, lbs F/day})(100\%)}{(\text{NaF Solution, lbs F/gallon})(\text{Purity, }\%)}$$

$$= \frac{(2.16\text{ lbs F/day})(100\%)}{(0.2\text{ lbs F/gal})(43.4\%)}$$

$$= 24.9\text{ gal/day}$$

NOTE: We obtained a feed rate of 23.8 gal/day using the treatment chart. The differences could have resulted from accurately preparing and reading the chart as well as the assumed purity of fluoride ion in the sodium fluoride.

5. Convert the feed rate from gallons per day to gallons per hour.

$$\text{Feed Rate, gal/hr} = \frac{(\text{Feed Rate, gal/day})}{24\text{ hr/day}}$$

$$= \frac{(24.9\text{ gal/day})}{24\text{ gal/hr}}$$

$$= 1.0\text{ gal/hr}$$

EXAMPLE 5

A flow of 1 MGD is treated with sodium silicofluoride (Na_2SiF_6) to provide a fluoride ion dose of 1.4 mg/*L*. What is the feed rate in pounds per day? Commercial sodium silicofluoride has a purity of 98.5 percent and the fluoride ion purity as sodium silicofluoride is 60.7 percent.

Known		Unknown
Flow, MGD	= 1 MGD	1. Feed Rate, lbs/day
Dose, mg/*L*	= 1.4 mg/*L*	
Na_2SiF_6 Purity, %	= 98.5%	
Fluoride Ion Purity, %	= 60.7%	

1. Calculate the portion of fluoride ion in the commercial sodium silicofluoride.

$$\text{Portion F} = \frac{(Na_2SiF_6\text{ Purity, }\%)(\text{Fluoride Ion Purity, }\%)}{(100\%)(100\%)}$$

$$= \frac{(98.5\%)(60.7\%)}{(100\%)(100\%)}$$

$$= 0.598$$

This says that there are 0.598 pounds of fluoride ion in a pound of commercial sodium silicofluoride.

2. Calculate the pounds of fluoride required per day.

$$\text{Fluoride, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (1\text{ MGD})(1.4\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 11.7\text{ lbs F/day}$$

3. Determine the chemical feed rate for the commercial sodium silicofluoride in pounds per day.

$$\text{Feed Rate, lbs/day} = \frac{\text{Fluoride, lbs/day}}{\text{Fluoride, lbs/lb Commercial }Na_2SiF_6}$$

$$= \frac{11.7\text{ lbs F/day}}{0.598\text{ lbs F/lb Commercial }Na_2SiF_6}$$

$$= 19.5\text{ lbs/day Commercial }Na_2SiF_6$$

EXAMPLE 6

A flow of 1.4 MGD is treated with sodium silicofluoride. The raw water contains 0.4 mg/*L* of fluoride ion and the desired fluoride ion concentration is 1.6 mg/*L*. What should be the chemical feed rate in pounds per day? Assume each pound of commercial sodium silicofluoride (Na_2SiF_6) contains 0.6 pounds of fluoride ion.

Known		Unknown
Flow, MGD	= 1.4 MGD	Feed Rate, lbs/day
Raw Water F, mg/*L*	= 0.4 mg/*L*	
Desired F, mg/*L*	= 1.6 mg/*L*	
Chemical, lbs F/lb	= 0.6 lbs F/lb	

1. Determine the fluoride feed dose in milligrams per liter.

$$\text{Feed Dose, mg/}L = \text{Desired Dose, mg/}L - \text{Actual Conc., mg/}L$$

$$= 1.6\text{ mg/}L - 0.4\text{ mg/}L$$

$$= 1.2\text{ mg/}L$$

2. Calculate the fluoride feed rate in pounds per day.

$$\text{Feed Rate, lbs F/day} = (\text{Flow, MGD})(\text{Feed Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (1.4\text{ MGD})(1.2\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 14.0\text{ lbs F/day}$$

3. Determine the chemical feed rate in pounds of commercial sodium silicofluoride per day.

$$\text{Feed Rate, lbs/day} = \frac{\text{Feed Rate, lbs F/day}}{\text{lbs F/lb Commercial }Na_2SiF_6}$$

$$= \frac{14.0\text{ lbs F/day}}{0.6\text{ lbs F/lb Commercial }Na_2SiF_6}$$

$$= 23.4\text{ lbs/day Commercial }Na_2SiF_6$$

EXAMPLE 7

The totalizer for a water treatment plant indicated that a total of 100,000 gallons of water had been treated with three pounds of 98 percent pure sodium fluoride (NaF). The fluoride ion purity for sodium fluoride is 45.3 percent. What was the added fluoride ion dosage in milligrams per liter?

Known	Unknown
Water Treated, MG = 0.1 M Gal	Fluoride Dosage, mg/*L*
NaF, lbs = 3 lbs	
NaF Purity, % = 98%	
F Ion Purity, % = 45.3%	

1. Calculate the portion of fluoride ion in the commercial sodium fluoride.

$$\text{Portion F} = \frac{(\text{NaF Purity, \%})(\text{Fluoride Ion Purity, \%})}{(100\%)(100\%)}$$

$$= \frac{(98\%)(45.3\%)}{(100\%)(100\%)}$$

$$= 0.444$$

or $= 0.444$ lbs F/lb commercial NaF

2. Calculate the pounds of fluoride used.

$$\text{Fluoride, lbs} = (\text{Commercial NaF, lbs})(0.444 \text{ lbs F/lb Comm. NaF})$$

$$= (3 \text{ lbs Comm. NaF})(0.444 \text{ lbs F/lb Comm. NaF})$$

$$= 1.33 \text{ lbs F}$$

3. Calculate the fluoride dosage in milligrams per liter

$$\text{Fluoride Dosage, mg}/L = \frac{\text{Fluoride, lbs F}}{(\text{Water Treated, M Gal})(8.34 \text{ lbs/gal})}$$

$$= \frac{1.33 \text{ lbs F}}{(0.1 \text{ M Gal})(8.34 \text{ lbs/gal})}$$

$$= \frac{1.33 \text{ lbs F}}{(0.834 \text{ Million lbs Water})}$$

$$= \frac{1.6 \text{ lbs F}}{1 \text{ M lbs Water}}$$

$$= 1.6 \text{ mg}/L$$

EXAMPLE 8

Determine the percentage of fluoride ion in the feed solution from a saturator. The saturator contains 95 percent pure sodium fluoride, the maximum water solubility for sodium fluoride is four percent, and sodium fluoride is 45.3 percent fluoride ion.

Known	Unknown
Commercial NaF Purity, % = 95%	Solution, % F
NaF Solubility, % = 4%	
F Ion Purity, % = 45.3%	

Calculate the percentage of fluoride ion in the feed solution.

$$\text{Solution, \% F} = \frac{(\text{NaF Solubility, \%})(\text{F Ion Purity, \%})}{(100\%)}$$

$$= \frac{(4\%)(45.3\%)}{(100\%)}$$

$$= 1.8\%$$

NOTE: In a saturator, the commercial NaF purity of 95 percent does not enter into the calculations because the four percent solubility is all NaF.

EXAMPLE 9

The feed solution from a saturator containing 1.8 percent fluoride ion is used to treat a total flow of 400,000 gallons of water. The raw water has a fluoride ion content of 0.5 mg/*L* and the desired fluoride in the finished water is 1.8 mg/*L*. How many gallons of feed solution are needed?

Known	Unknown
Flow Vol., gal = 400,000 gal	Feed Solution, gallons
Raw Water F, mg/*L* = 0.5 mg/*L*	
Desired F, mg/*L* = 1.8 mg/*L*	
Feed Solution, % F = 1.8% F	

1. Convert the feed solution from a percentage fluoride ion to milligrams fluoride ion per liter of water.

1.0% F = 10,000 mg F/*L*

$$\text{Feed Solution, mg}/L = \frac{(\text{Feed Solution, \%})(10{,}000 \text{ mg}/L)}{1\%}$$

$$= \frac{(1.8\%)(10{,}000 \text{ mg}/L)}{1\%}$$

$$= 18{,}000 \text{ mg}/L$$

2. Determine the fluoride feed dose in milligrams per liter.

$$\text{Feed Dose, mg}/L = \text{Desired Dose, mg}/L - \text{Raw Water F, mg}/L$$

$$= 1.8 \text{ mg}/L - 0.5 \text{ mg}/L$$

$$= 1.3 \text{ mg}/L$$

3. Calculate the gallons of feed solution needed.

$$\text{Feed Solution, gal} = \frac{(\text{Flow Vol, Gal})(\text{Feed Dose, mg}/L)}{\text{Feed Solution, mg}/L}$$

$$= \frac{(400{,}000 \text{ gal})(1.3 \text{ mg}/L)}{18{,}000 \text{ mg}/L}$$

$$= 28.9 \text{ gallons}$$

EXAMPLE 10

A hydrofluosilicic acid (H_2SiF_6) tank contains 300 gallons of acid with a strength of 18 percent. A commercial vendor delivers 2000 gallons of acid with a strength of 20 percent to the tank. What is the resulting strength of the mixture as a percentage?

Known	Unknown
Tank Contents, gal = 300 gal	Mixture Strength, %
Tank Strength, % = 18%	
Vendor, gal = 2000 gal	
Vendor Strength, % = 20%	

Calculate the strength of the mixture as a percentage.

$$\text{Mixture Strength, \%} = \frac{(\text{Tank, gal})(\text{Tank, \%}) + (\text{Vendor, gal})(\text{Vendor, \%})}{\text{Tank, gal} + \text{Vendor, gal}}$$

$$= \frac{(300 \text{ gal})(18\%) + (2000 \text{ gal})(20\%)}{300 \text{ gal} + 2000 \text{ gal}}$$

$$= \frac{5400 + 40{,}000}{2300}$$

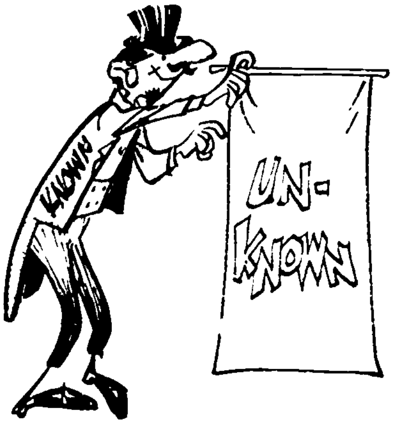
$$= \frac{45{,}400}{2{,}300}$$

$$= 19.7\%$$

EXAMPLE 11

Sodium silicofluoride (Na_2SiF_6) is used as the chemical to fluoridate a water supply. What is the fluoride ion purity as a percentage?

Known	Unknown
Atomic Weights	Fluoride Ion Purity, %
Na = 22.99	
Si = 28.09	
F = 19.00	



1 Determine the molecular weight of the fluoridation chemical, sodium silicofluoride, Na_2SiF_6.

Symbol	No. Atoms	×	Atomic Wt.*	=	Molecular Wt.
Na_2	2	×	22.99	=	45.98
Si	1	×	28.09	=	28.09
F_6	6	×	19.00	=	114.00
Molecular Wt of Chemical				=	188.07

---

* Atomic weight values can be obtained from a chemistry book.

2 Calculate the fluoride ion purity as a percentage.

$$\text{Fluoride Ion Purity, \%} = \frac{(\text{Molecular Weight of Fluoride})(100\%)}{\text{Molecular Weight of Chemical}}$$

$$= \frac{(114.00)(100\%)}{188.07}$$

$$= 60.62\%$$

This means that there are 0.6062 pounds of fluoride ion in every pound of sodium silicofluoride.

13.13 ARITHMETIC ASSIGNMENT

Turn to the Arithmetic Appendix at the back of this manual. In Section A.3, "Typical Water Treatment Plant Problems," read and work the problems in Section A.31, "Fluoridation."

13.14 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 16, "Fluoridation."
2. *TEXAS MANUAL*, Chapter 11, "Special Water Treatment (Fluoridation)."
3. *WATER FLUORIDATION PRINCIPLES AND PRACTICES* (M4). Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price for members, $13.50; Non-members, $17.00. Order No. 30004.
4. *WATER FLUORIDATION*, A Training Course Manual for Engineers and Technicians. Available from Dental Disease Prevention Activity, Center for Prevention Services, Centers for Disease Control, U. S. Public Health Service, Atlanta, Georgia 30300.

13.15 ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance graciously given by Robert A. Hewitt, Assistant Water Quality Engineer, San Francisco Water Department, San Francisco, California, and Tom Reeves, Centers for Disease Control, Center for Prevention Services, Dental Disease Prevention Activity, Atlanta, Georgia.

DISCUSSION AND REVIEW QUESTIONS

Chapter 13. FLUORIDATION

Please work these discussion and review questions before continuing with the Objective Test on page 60 The purpose of these questions is to indicate to you how well you understand the material in the chapter. Write the answers to these questions in your notebook.

1. Why are drinking waters fluoridated?
2. What factors would you consider when selecting a fluoridation chemical?
3. Why should the finished water's fluoride ion content be automatically monitored on a continuous basis?
4. How can water be softened prior to use with fluoridation equipment?
5. What items should be considered when reviewing plans and specifications for the location of fluoride chemical hoppers?
6. How can overfeeding be prevented?
7. What should be done if significant overfeeding occurs?
8. What should be done when fluoridation equipment is going to be shut down for an extended length of time?
9. How would you dispose of fluoride chemical containers?
10. How would you protect yourself from the dusts of dry fluoride compounds?

SUGGESTED ANSWERS

Chapter 13. FLUORIDATION

Answers to questions on page 29.

13.0A If a person drinks water with an excessive amount of fluoride, the teeth become mottled (brown, chalky deposits).

13.0B Children who drink a recommended dose of fluoride have fewer dental caries (decay or cavities).

Answers to questions on page 30.

13.1A The water department or water company makes the final decisions as to types of fluoride chemicals and feeding equipment to be used.

13.2A The three compounds most commonly used to fluoridate water are hydrofluosilicic acid, sodium fluoride and sodium silicofluoride.

Answers to questions on page 42.

13.3A Drinking waters may contain fluoride ions by three different types of situations:

1. Raw water source may have adequate or excessive fluoride ions naturally present,
2. Two water sources may be blended together (one higher and one lower than acceptable level) to produce an acceptable level, and
3. Fluoride ions must be added to the water to achieve an acceptable level

13.3B Fluoridation systems must incorporate means to prevent both overfeeding and backsiphonage along with means to monitor the amount of chemical used.

13.3C Hard water can produce problems in systems using saturators and dissolving tanks through the formation of low solubility (deposits of) calcium and magnesium fluoride compounds.

13.3D A saturator is a device which produces a fluoride solution for the fluoridation process. The device is usually a cylindrical container with granular sodium fluoride on the bottom. Water flows either upward or downward through the sodium fluoride to produce the fluoride solution.

Answers to questions on page 44.

13.4A Overfeeding of fluoridation chemicals must be prevented to avoid illness and bad public relations.

13.4B The fluoridator should be sized to handle the full range of both present and future doses or provisions should be made for future expansion.

13.5A When inspecting the fluoridation electrical system, inspect the system for (1) proper voltage; (2) properly sized overload protection; (3) proper operation of control lights on control panel; (4) proper safety lockout switches and operation; and (5) proper equipment rotation.

13.5B Safety equipment that should be available near a fluoridation system include an eyewash, drench showers, dust masks, face shields, gloves and vent fans.

Answers to questions on page 48

13.6A

Known		Unknown
Flow, MGD	= 6 MGD	Feed Rate, gal/day
Conc Fluoride, mg/*L*	= 1.2 mg/*L*	
Hydrofluosilicic acid	= 20%	

1. Use Treatment Chart I, Hydrofluosilicic Acid. Start at the left side with 6 MGD and move horizontally to the right to the intersection of the 20% diagonal line.
2. Drop down vertically to the chemical feed rate of *30 GALLONS PER DAY*, for 1 mg/*L* fluoride application.
3. Adjust the flow rate for a dose of 1.2 mg/*L*.

$$\text{Flow Rate, gal/day} = \frac{(\text{Flow Rate from Chart, gal/day})(\text{Desired Dose, mg}/L)}{1\ \text{mg}/L}$$

$$= \frac{(30\ \text{gal/day})(1.2\ \text{mg}/L)}{1\ \text{mg}/L}$$

$$= 36\ \text{gal/day}$$

13.6B Differences between the volume of acid used from a storage tank and the volume actually fed into the system could be caused by errors in readings, leaks or equipment malfunctions.

Answers to questions on page 52.

13.7A Overfeeding should be prevented because no additional benefits result from overfeeding and there is a waste of chemicals and money. Excessive overfeeding could be harmful to consumers.

13.7B If significant overfeeding occurs, the plant should be shut down. The affected mains should be flushed and the local and state health departments notified.

13.8A A fluoridation operation could be shut down for cleaning, adjustments or due to safety controls.

Answers to questions on page 54.

13.9A If fluoridation equipment is going to be shut down for an extended length of time, it should be cleaned out to prevent corrosion and/or the solidifying of the chemical. Lines and equipment could be damaged when started if chemicals left in them solidify.

13.10A Fluoride dust can be removed from gears by the use of a vacuum cleaner.

13.10B To determine if the fluoridation equipment is providing the desired dosage, monitor the fluoride ion concentration in the treated water.

13.11A If you are acutely poisoned by a fluoride chemical, you may be thirsty, vomit and have stomach cramps, diarrhea, difficulty in speaking and disturbed color vision.

OBJECTIVE TEST

Chapter 13. FLUORIDATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True-False

1. Governing bodies usually rely upon a vote of the people to decide the types of fluoride chemicals and feeding equipment to be used.
   1. True
   2. False
2. Water should be analyzed for its natural fluoride level before fluoridation.
   1. True
   2. False
3. Fluoridation chemicals are harmful to consumers at high levels.
   1. True
   2. False
4. Scale formation in chemical feed systems may be prevented by the use of polyphosphates instead of a zeolite softener
   1. True
   2. False
5. A day tank usually stores sufficient chemical solution to treat water for at least one day.
   1. True
   2. False
6. Chemical feed systems should allow the chemical feed to vary with changing head conditions.
   1. True
   2. False
7. Equipment may be damaged in minutes if it is run without lubrication.
   1. True
   2. False
8. A positive displacement pump will damage itself or rupture lines in seconds if allowed to run against a closed valve or system.
   1. True
   2. False
9. Fluoridation must be a continuous operation.
   1. True
   2. False
10. Operators could be seriously injured if they open a chemical line that has not been properly flushed out.
    1. True
    2. False
11. Hydrofluosilicic acid solutions can irritate your skin.
    1. True
    2. False
12. Never eat, drink or smoke in or around fluoridation chemical storage or feed areas.
    1. True
    2. False
13. Sanitary defects may develop in fluoridation systems.
    1. True
    2. False
14. Hydrofluosilicic acid must be washed off your skin immediately.
    1. True
    2. False
15. Special safety training must be given to all operators who must handle fluoride compounds.
    1. True
    2. False

Multiple Choice

16. The Maximum Contaminant Level (MCL) for fluoride in drinking water ranges from _______ mg/*L*, depending on the annual average maximum daily air temperatures.
    1. 0.4 to 0.8
    2. 0.9 to 1.3
    3. 1.4 to 2.4
    4. 2.5 to 3.5
    5. 3.6 to 5.0
17. The compounds most commonly used to fluoridate water include
    1. Ammonium silicofluoride.
    2. Calcium fluoride.
    3. Hydrofluosilicic.
    4. Silicofluoride.
    5. Sodium fluoride.
18. Which of the following items must be considered when selecting a fluoridation chemical?
    1. Costs
    2. Ease of handling
    3. Operator safety
    4. Solubility of chemical in water
    5. Storage requirements
19. Water with a hardness above _______ mg/*L* must be softened to prevent severe scaling of fluoridation equipment.
    1. 10
    2. 25
    3. 40
    4. 55
    5. 75

20. Fluoridation chemicals that may be fed with a saturator include

    1. Granular calcium fluoride.
    2. Granular sodium fluoride.
    3. Hydrofluosilicic acid.
    4. Powdered calcium fluoride.
    5. Powdered sodium fluoride.

21. The responsibility of the chief operator regarding fluoridation equipment includes

    1. Design.
    2. Functioning of equipment.
    3. Maintenance.
    4. Operation by plant personnel
    5. Results from the process.

22. Fluoridation operations may be temporarily shut down due to

    1. Adjustments.
    2. Calculating dosages.
    3. Cleaning.
    4. Maintaining storage area
    5. Safety controls.

23 Which of the following items should be included in your checklist for shutting down a fluoridation chemical system?

    1. Clean the mix and feed tanks.
    2. Drain the mix and feed tanks.
    3. Fill the chemical hoppers.
    4. Flush out all the solution lines.
    5. Turn on the electrical power.

24. A flow of 2 MGD is to be treated with an 18 percent solution of hydrofluosilicic acid H_2SiF_6). The water to be treated contains no fluoride and the desired fluoride concentration is 1.2 mg/*L*. Assume the hydrofluosilicic acid weighs 9.6 pounds per gallon. Calculate the hydrofluosilicic acid feed rate in gallons per day. Select the closest answer.

    1. 12 GPD
    2. 15 GPD
    3. 30 GPD
    4. 110 GPD
    5. 300 GPD

25 A flow of 250 GPM is to be treated with a 2.4 percent (0.2 pounds per gallon) solution of sodium fluoride (NaF). The water to be treated contains 0.3 mg/*L* of fluoride ion and the desired fluoride ion concentration is 1.4 mg/*L*. Calculate the sodium fluoride feed rate in gallons per day. Assume the sodium fluoride has a fluoride purity of 43.4 percent. Select the closest answer.

    1. 1.1 gal/day
    2. 2.2 gal/day
    3. 3.3 gal/day
    4. 25 gal/day
    5. 38 gal/day

26. A flow of 0.8 MGD is treated with sodium silicofluoride (Na_2SiF_6) to provide a fluoride ion dose of 1.2 mg/*L*. What is the feed rate in pounds per day? Commercial sodium fluoride has a purity of 98.5 percent and the fluoride ion purity of sodium silicofluoride is 60.7 percent. Select the closest answer.

    1. 6.0 lbs/day
    2. 8.0 lbs/day
    3. 11.7 lbs/day
    4. 13.4 lbs/day
    5. 19.5 lbs/day

27. The feed solution from a saturator containing 1.8 percent fluoride ion is used to treat a flow of 500,000 gallons per day. The desired dose is 1.2 mg/*L* of fluoride ion and the raw water does not have any fluoride. Calculate the feed rate in gallons per day of the saturator solution. Select the closest answer.

    1. 18.0 gal/day
    2. 19.5 gal/day
    3. 26.6 gal/day
    4. 28.9 gal/day
    5. 33.3 gal/day

End of Objective Test

CHAPTER 14

SOFTENING

by

Don Gibson

and

Marty Reynolds

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Chapter 14. Softening

LIME-SODA ASH SOFTENING by Don Gibson

Lesson 1

ION EXCHANGE SOFTENING by Ma[illegible] Reynolds

Lesson 2

OBJECTIVES

Chapter 14. SOFTENING

Following completion of Chapter 14, you should be able to:

1. Explain what makes water hard and the advantages of softening,
2. Describe the processes used to soften water,
3. Prepare chemical doses to soften water with considerations given to coagulants and stability,
4. Safely handle softening chemicals,
5. Dispose of process sludges and brines,
6. Keep neat and accurate softening records,
7. Perform jar tests and apply results,
8. Operate and maintain chemical precipitation and ion exchange softening processes,
9. Start up and shut down water softening units, and
10. Blend softened waters with unsoftened waters (split treatment) for delivery to consumers.

GLOSSARY

Chapter 14. SOFTENING

ALKALINITY (AL-ka-LIN-it-tee) ALKALINITY

The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

ANION (AN-EYE-on) ANION

A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of a difference in electrical potential. Chloride (Cl^-) is an anion.

CALCIUM CARBONATE EQUILIBRIUM CALCIUM CARBONATE EQUILIBRIUM

A water is considered stable when it is just saturated with calcium carbonate. In this condition the water will neither dissolve nor deposit calcium carbonate. Thus, in this water the calcium carbonate is in equilibrium with the hydrogen ion concentration

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CATION (CAT-EYE-on) CATION

A positively charged ion in an electrolyte solution, attracted to the cathode under the influence of a difference in electrical potential. Sodium ion (Na^+) is a cation.

DIVALENT (die-VAY-lent) DIVALENT

Having a valence of two, such as the ferrous ion, Fe^{2+}.

EQUIVALENT WEIGHT EQUIVALENT WEIGHT

That weight which will react with, displace or is equivalent to one gram atom of hydrogen.

GREENSAND GREENSAND

A sand which looks like ordinary filter sand except that it is green in color This sand is a natural ion exchange mineral which is capable of softening water and removing iron and manganese.

HARD WATER HARD WATER

Water having a high concentration of calcium and magnesium ions. A water may be considered hard if it has a hardness greater than the typical hardness of water from the region. Some textbooks define hard water as water with a hardness of more than 100 mg/*L* as calcium carbonate.

HARDNESS, WATER HARDNESS, WATER

A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

HYDRATED LIME HYDRATED LIME

Limestone that has been "burned" and treated with water under controlled conditions until the calcium oxide portion has been converted to calcium hydroxide ($Ca(OH)_2$). Hydrated lime is quicklime combined with water. $CaO + H_2O \rightarrow Ca(OH)_2$. Also see QUICKLIME.

INSOLUBLE (in-SAWL-you-bull) INSOLUBLE

Something that cannot be dissolved.

ION

ION

An electrically charged atom, radical (such as SO_4^{2-}), or molecule formed by the loss or gain of one or more electrons

ION EXCHANGE

ION EXCHANGE

A water treatment process involving the reversible interchange (switching) of ions between the water being treated and the solid resin. Undesirable ions in the water are switched with acceptable ions in the resin.

ION EXCHANGE RESIN

ION EXCHANGE RESIN

Insoluble polymers, used in water treatment, that are capable of exchanging (switching or giving) acceptable cations or anions to the water being treated for less desirable ions

METHYL ORANGE ALKALINITY

METHYL ORANGE ALKALINITY

A measure of the total alkalinity in a water sample The alkalinity is measured by the amount of standard sulfuric acid required to lower the pH of the water to a pH level of 4.5, as indicated by the change in color of methyl orange from orange to pink. Methyl orange alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

NPDES PERMIT

NPDES PERMIT

National Pollutant Discharge Elimination System permit is the regulatory agency document designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

PHENOLPHTHALEIN ALKALINITY (FEE-nol-THAY-leen)

PHENOLPHTHALEIN ALKALINITY

The alkalinity in a water sample measured by the amount of standard acid required to lower the pH to a level of 8.3, as indicated by the change in color of phenolphthalein from pink to clear. Phenolphthalein alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

PRECIPITATE (pre-SIP-uh-TATE)

PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

QUICKLIME

QUICKLIME

A material that is mostly calcium oxide (CaO) or calcium oxide in natural association with a lesser amount of magnesium oxide. Quicklime is capable of combining with water to form hydrated lime. Also see HYDRATED LIME.

RECARBONATION (re-CAR-bun-NAY-shun)

RECARBONATION

A process in which carbon dioxide is bubbled into the water being treated to lower the pH. The pH may also be lowered by the addition of acid Recarbonation is the final stage in the lime-soda ash softening process. This process converts carbonate ions to bicarbonate ions and stabilizes the solution against the precipitation of carbonate compounds.

RESINS

RESINS

See ION EXCHANGE RESINS.

SATURATION

SATURATION

The condition of a liquid (water) when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

SLAKE

SLAKE

To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.

SLAKED LIME SLAKED LIME

See HYDRATED LIME.

SUPERSATURATED SUPERSATURATED

An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction as signaled by the end point.

CHAPTER 14 SOFTENING

Lime-Soda Ash Softening by Don Gibson

(Lesson 1 of 2 Lessons)

14.0 WHAT MAKES WATER HARD?[1]

Water hardness is a measure of the soap or detergent consuming power of water. Technically hardness is caused by *DIVALENT*[2] metallic cations which are capable of reacting (1) with soap (detergent) to form precipitates and (2) with certain anions present in water to form scale.

Cations Causing Hardness	**Most Common Anions**
Calcium, Ca^{2+}	Bicarbonate, HCO_3^-
Magnesium, Mg^{2+}	Sulfate, SO_4^{2-}
Strontium, Sr^{2+}	Chloride, Cl^-
Iron, Fe^{2+}	Nitrate, NO_3^-
Manganese, Mn^{2+}	Silicate, SiO_3^{2-}

Calcium and magnesium are usually the only cations that are present in significant concentrations. Therefore, hardness is generally considered to be an expression of the total concentration of the calcium and magnesium ions that are present in the water. However, if any of the other cations listed are present in significant amounts, they should be included in the hardness determination.

Table 14.1 describes various levels of hardness. Different textbooks will use similar classifications. Hardness levels in source waters, local conditions, and local usage will influence consumers' attitudes towards the hardness of their water.

TABLE 14.1 DESCRIPTION OF VARIOUS LEVELS OF HARDNESS[3]

Description	**Hardness in Terms of mg/*L* as Calcium Carbonate**
1. Extremely soft to soft	0-45
2. Soft to moderately hard	46-90
3. Moderately hard to hard	91-130
4. Hard to very hard	131-170
5. Very hard to excessively hard	171-250
6. Too hard for ordinary domestic use	OVER 250

To help you understand this chapter on water softening, some of the terms used are defined below.

HARD WATER is a water having a high concentration of calcium and magnesium ions. A water may be considered hard if it has a hardness greater than the typical hardness of water from the region. Some textbooks define hard water as a water with a hardness of more than 100 mg/*L* as calcium carbonate.

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[1] *Portions of the material covered in the first three sections of this chapter were provided by Don Gibson, Marty Reynolds, Susumu Kawamura, Terry Engelhardt, Jack Rossum and Mike Curry.*

[2] *Divalent (die-VAY-lent). Having a valence of two, such as ferrous ion,* Fe^{2+}.

[3] *Lipe, L.A. and M.D. Curry "Ion Exchange Water Softening," a discussion for water treatment plant operators, 1974-75 seminar series sponsored by Illinois Environmental Protection Agency.*

HARDNESS is a characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes may cause objectionable tastes in drinking water.

CALCIUM HARDNESS is caused by calcium ions (Ca^{2+}).

MAGNESIUM HARDNESS is caused by magnesium ions (Mg^{2+}).

TOTAL HARDNESS is the sum of the hardness caused by both calcium and magnesium ions.

CARBONATE HARDNESS is caused by the alkalinity present in water up to the total hardness. This value is usually less than the total hardness.

NONCARBONATE HARDNESS is that portion of the total hardness in excess of the alkalinity.

ALKALINITY (AL-ka-LIN-it-tee) is the capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is a measure of how much acid can be added to a water without causing a great change in pH.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT is an expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

14.1 WHY SOFTEN WATER?

The dissolved minerals (calcium and magnesium ions) in water cause difficulties in doing the laundry and in dishwashing in the household. These ions also cause a coating to form inside the hot water heater similar to that in a tea kettle after repeated use.

Hardness, in addition to inhibiting the cleaning action of soaps, will tend to shorten the life of fabrics that are washed in hard water. The scum or curds may become lodged in the fibers of the fabric and cause them to lose their softness and elasticity.

In industry hardness can cause even greater problems. Many processes are affected by the hardness content of the water used. Industrial plants using boilers for processing steam or heat must remove the hardness from their make-up water, even beyond what a water treatment plant would do. The reason for this is that the minerals will plate out on the boiler tubes and form a scale. This scale forms an insulation barrier which prevents proper heat transfer, thus causing excessive energy requirements to fire the boilers. The problems associated with process water softening are too numerous to go into; however, everything from food processing to intricate manufacturing processes is affected by the hardness of water

In addition to the removal of hardness from water, some other benefits of softening include:

1. Removal of iron and manganese,
2. Control of corrosion when proper stabilization of water is achieved,
3. Disinfection due to high pH values when using lime (especially the excess lime softening process),
4. Sometimes a reduction in tastes and odors,
5. Reduction of some total solids content by the lime treatment process, and
6. Removal of radioactivity.

Possible limitations of softening might include:

1. Free chlorine residual is predominantly hypochorite at pH levels above 7.5 and is a less powerful disinfectant.
2. Costs and benefits must be carefully weighed to justify softening.
3. Ultimate disposal of process wastes.
4. At the pH levels associated with softening chemical precipitation, the trihalomethane fraction in the treated water may increase (depends on several other factors).
5. Producing an "aggressive" water which would tend to corrode metal ions from the distribution system piping. Hard waters usually do not corrode pipe. However, excessively hard water can cause scaling on the inside of pipes and thereby restrict flow.

In many cases, the decision to soften the water is left up to each community as softening is done mostly as a customer service. Hard water does not have an adverse effect on health, but can create several unwanted side affects, some of which are:

1. Over a period of time, the detergent-consuming power of hard water can be very costly,
2. Scale problems on fixtures will be more noticeable, and
3. The life cycle of several types of clothing will be reduced with repeated washing in hard water. Also, a residue can be left in clothing, creating a dirty appearance.

Once the decision is made to soften, a method must be selected. The two most common methods used to soften water are chemical precipitation (lime-soda ash) and *ION EXCHANGE*[4]. Ion exchange softening can best be applied to waters high in noncarbonate hardness and where the total hardness does not exceed 350 mg/L. This method of softening can produce a water of zero hardness, as opposed to lime softening where zero hardness cannot be reached.

---

[4] *Ion Exchange. A water treatment process involving the reversible interchange (switching) of ions between the water being treated and the solid resin. Undesirable ions in the water are switched with acceptable ions in the resin.*

Ion exchange softening will also remove noncarbonate hardness without the addition of soda ash which is required with lime softening. Ion exchange is a nonselective method of softening. This means it will remove total hardness (the sum of carbonate and noncarbonate hardness) making it a very desirable means of water softening.

Limitations of the ion exchange softening process include an increase in the sodium content of the softened water if the ion exchanger is regenerated with sodium hydroxide The sodium level should not exceed 20 mg/*L* in treated water because of the potentially harmful effect on persons susceptible to hypertension. Also the ultimate disposal of spent brine and rinse waters from softeners can be a major problem for many installations.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 107.

14.0A What causes hardness in water?

14.1A Why is excessive hardness undesirable in a domestic water supply?

14.1B What are some of the limitations of the ion exchange softening process?

14.2 CHEMISTRY OF SOFTENING

To understand how water hardness is described and also how hardness is removed from water by softening processes, operators need to have an idea of the chemical reactions that take place in water. In this section hardness, pH, and alkalinity reactions in water will be discussed.

14.20 Hardness

Hardness is due to the presence of divalent metallic cations in water, but the Fifteenth Edition of *STANDARD METHODS*[5] identifies only calcium and magnesium as hardness constituents. Hardness is commonly measured by *TITRATION*[6] as described in Volume I on page 513. Individual divalent cations may be measured in the laboratory using an atomic adsorption (AA) spectrophotometer for very accurate work.

Hardness is usually reported as *CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT*.[7] This procedure allows us to combine or add up the hardness caused by both calcium and magnesium and report the results as total hardness.

$$\begin{aligned}\text{Calcium Hardness, mg}/L \text{ as } CaCO_3 &= (\text{Calcium, mg}/L)\left(\frac{\text{Equivalent Weight of } CaCO_3}{\text{Equivalent Weight of Calcium}}\right)\\ &= (\text{Ca, mg}/L)\left(\frac{50}{20}\right)\\ &= 2\ 50(\text{Ca, mg}/L)\end{aligned}$$

This equation indicates that if the calcium concentration in milligrams per liter is multiplied by 2.50, the result is the calcium hardness in milligrams per liter as calcium carbonate. The *EQUIVALENT WEIGHT*[8] of most elements or chemical radicals (SO_4^{2-} is a radical) can be obtained by dividing the molecular weight by the valence.

$$\begin{aligned}\text{Equivalent Weight of Calcium} &= \frac{\text{Atomic Weight}}{\text{Valence}}\\ &= \frac{40}{2}\\ &= 20\end{aligned}$$

To express the magnesium hardness of water as calcium carbonate equivalent use the following formula.

$$\begin{aligned}\text{Magnesium Hardness, mg}/L \text{ as } CaCO_3 &= (\text{Magnesium, mg}/L)\left(\frac{\text{Equivalent Weight of } CaCO_3}{\text{Equivalent Weight of Magnesium}}\right)\\ &= (\text{Mg, mg}/L)\left(\frac{50}{12\ 15}\right)\\ &= 4\ 12\ (\text{Mg, mg}/L)\end{aligned}$$

The total hardness of water is the sum of the calcium and magnesium hardness as $CaCO_3$.

$$\text{Total Hardness, mg}/L \text{ as } CaCO_3 = \text{Calcium Hardness, mg}/L \text{ as } CaCO_3 + \text{Magnesium Hardness, mg}/L \text{ as } CaCO_3$$

EXAMPLE 1

Determine the total hardness as $CaCO_3$ for a sample of water with a calcium content of 30 mg/*L* and a magnesium content of 20 mg/*L*.

Known		Unknown
Calcium, mg/*L*	= 30 mg/*L*	Total Hardness, mg/*L* as $CaCO_3$
Magnesium, mg/*L*	= 20 mg/*L*	

Calculate the total hardness as milligrams per liter of calcium carbonate equivalent.

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[5] *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 16th Edition, 1985. Order No. 10035. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members $72.00; nonmembers $90.00.*

[6] *Titrate (TIE-trate) To TITRATE a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point*

[7] *Calcium Carbonate ($CaCO_3$) Equivalent An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.*

[8] *Equivalent Weight. That weight which will react with, displace or is equivalent to one gram atom of hydrogen. The equivalent weight of an element (such as Ca^{2+}) is equal to the atomic weight divided by the valence.*

$$\begin{aligned}\text{Equivalent Weight of } CaCO_3 &= \frac{\text{Molecular Weight}}{\text{Number of Equivalents}}\\ &= \frac{100}{2}\\ &= 50\end{aligned}$$

$$\text{Total Hardness, mg}/L \text{ as CaCO}_3 = \text{Calcium Hardness, mg}/L \text{ as CaCO}_3 + \text{Magnesium Hardness, mg}/L \text{ as CaCO}_3$$

$$= 2.50(\text{Ca, mg}/L) + 4.12\ (\text{Mg, mg}/L)$$

$$= 2.50(30\text{ mg}/L) + 4.12(20\text{ mg}/L)$$

$$= 75\text{ mg}/L + 82.4\text{ mg}/L$$

$$= 157.4\text{ mg}/L \text{ as CaCO}_3$$

Total hardness is also described as the sum of the carbonate hardness (temporary hardness) and noncarbonate hardness (permanent hardness).

$$\text{Total Hardness, mg}/L \text{ as CaCO}_3 = \text{Carbonate Hardness, mg}/L \text{ as CaCO}_3 + \text{Noncarbonate Hardness, mg}/L \text{ as CaCO}_3$$

The amount of carbonate and noncarbonate hardness depends on the alkalinity of the water. This relationship can be described as follows:

1. When the alkalinity (expressed as calcium carbonate equivalent) is greater than the total hardness, all the hardness is in the carbonate form.

   $$\text{Carbonate Hardness, mg}/L \text{ as CaCO}_3 = \text{Total Hardness, mg}/L \text{ as CaCO}_3$$

2. When the total hardness is greater than the alkalinity, the alkalinity is carbonate hardness and noncarbonate hardness is the difference between total hardness and alkalinity.

   $$\text{Carbonate Hardness, mg}/L \text{ as CaCO}_3 = \text{Alkalinity, mg}/L \text{ as CaCO}_3$$

   $$\text{Noncarbonate Hardness, mg}/L \text{ as CaCO}_3 = \text{Total Hardness, mg}/L \text{ as CaCO}_3 - \text{Alkalinity, mg}/L \text{ as CaCO}_3$$

14.21 pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \text{Log}\frac{1}{(\text{H}^+)}$$

The pH may range from 0 to 14, where zero is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5. Table 14.2 shows the relationship between pH and hydrogen and hydroxide ions.

TABLE 14.2 RELATIONSHIP BETWEEN pH AND HYDROGEN AND HYDROXIDE IONS

pH	Hydrogen Ion (H^+), Moles/Liter	Hydroxide Ion (OH^-), Moles/Liter
0	1.0	0.000 000 000 000 01
1	0.1	0.000 000 000 000 1
2	0.01	0.000 000 000 001
3	0.001	0.000 000 000 01
4	0.000 1	0.000 000 000 1
5	0.000 01	0.000 000 001
6	0.000 001	0.000 000 01
7	0.000 000 1	0.000 000 1
8	0.000 000 01	0.000 001
9	0.000 000 001	0.000 01
10	0.000 000 000 1	0.000 1
11	0.000 000 000 01	0.001
12	0.000 000 000 001	0.01
13	0.000 000 000 000 1	0.1
14	0.000 000 000 000 01	1.0

When treating waters the pH is very important. The pH of water may be increased or decreased by the addition of certain chemicals used to treat water (Table 14.3). In many instances, the effect on pH of adding one chemical is neutralized by the addition of another chemical. When softening water by chemical precipitation processes (lime-soda softening for example), the pH must be raised to 11 for the desired chemical reactions to occur. The levels of carbon dioxide, bicarbonate ion and carbonate ion in waters are very sensitive to pH.

TABLE 14.3 INFLUENCE OF WATER TREATMENT CHEMICALS ON pH

Lowers pH	Increases pH
Aluminum Sulfate (Alum), $Al_2(SO_4)_3 \cdot 18H_2O$	Calcium Hypochlorite, $Ca(OCl)_2$
Carbon Dioxide, CO_2	Caustic Soda, NaOH
Chlorine, Cl_2	Hydrated Lime, $Ca(OH)_2$
Ferric Chloride, $FeCl_3$	Soda Ash, Na_2CO_3
Hydrofluosilicic Acid, H_2SiF_6	Sodium Aluminate, $NaAlO_2$
Sulfuric Acid, H_2SO_4	Sodium Hydrochlorite, NaOCl

The stability of treated water is determined by measuring the pH and calculating the Langelier Index (see Chapter 8, "Corrosion Control," pages 357 to 360). This index reflects the equilibrium pH of a water with respect to calcium and alkalinity.

$$\text{Langelier Index (L.I.)} = \text{pH} - \text{pH}_s$$

where

pH = actual pH of water, and

pH_s = pH at which water having the same alkalinity and calcium content is just saturated with calcium carbonate

A negative Langelier Index indicates that the water is corrosive and a positive index indicates that the water is scale forming. After water has been softened, the treated water distributed to consumers must be stable (neither corrosive nor scale forming).

14.22 Alkalinity

Alkalinity is the capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is measure of how much acid can be added to a liquid without causing a great change in pH.

Alkalinity is measured in the laboratory by the addition of color indicator solutions and the alkalinity is then determined by the amount of acid required to reach a titration end point (specific color change) (see Chapter 11, "Laboratory Procedures," pages 491 to 493). The P (phenolphthalein) end point is at pH 8.3. When the pH is below 8.3, there is no P alkalinity present. When the pH is above 8.3, P alkalinity is present. No carbon dioxide is present when the pH is above 8.3, so there is no carbon dioxide in the water when P alkalinity is present. Also, hydroxide and carbonate alkalinity are not present when pH is below 8.3.

The relationship between the various alkalinity constituents (bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydroxide (OH^-)) can be based on the P (phenolphthalein and T (total or methyl orange) alkalinity as shown in Table 14.4 and Figure 14.1.

TABLE 14.4 ALKALINITY CONSTITUENTS

	Alkalinity, mg/L as $CaCO_3$		
Titration Result	Bicarbonate	Carbonate	Hydroxide
P = 0	T	0	0
P is less than ½T	T-2P	2P	0
P = ½T	0	2P	0
P is greater than ½T	0	2T-2P	2P-T
P = T	0	0	T

where P = phenolphthalein alkalinity
T = total alkalinity

When the pH is less than 8.3, all alkalinity is in the carbonate form and is commonly referred to as natural alkalinity. When the pH is above 8.3, the alkalinity may consist of bicarbonate, carbonate and hydroxide. As the pH increases, the alkalinity progressively shifts to carbonate and hydroxide forms.

Total alkalinity is the sum of the bicarbonate, carbonate and hydroxide. Each of these values can be determined by measuring the P and T alkalinity in the laboratory and referring to Table 14.4. Alkalinity is expressed in milligrams per liter as calcium carbonate equivalence. Alkalinity is influenced by chemicals used to treat water as shown in Table 14.5.

TABLE 14.5 INFLUENCE OF WATER TREATMENT CHEMICALS ON ALKALINITY

Lowers Alkalinity	Increases Alkalinity
Aluminum Sulfate (Alum), $Al_2(SO_4)_3 \cdot 18H_2O$	Calcium Hypochlorite, $Ca(OCl)_2$
Carbon Dioxide, CO_2	Caustic Soda, NaOH
Chlorine Gas, Cl_2	Hydrated Lime, $Ca(OH)_2$
Ferric Chloride, $FeCl_3$	Soda Ash, Na_2CO_3
Ferric Sulfate, $Fe_2(SO_4)_3$	Sodium Aluminate, $NaAlO_2$
Sulfuric Acid, H_2SO_4	

EXAMPLE 2

Results from alkalinity titrations on a raw water sample were as follows:

Known

Sample size, mL	= 100 mL
mL titrant used to pH 8.3, A	= 0 mL
Total mL of titrant used, B	= 8.2 mL
Acid normality, N	= 0.02 N H_2SO_4

Unknown

1. Total Alkalinity, mg/L as $CaCO_3$
2. Bicarbonate Alkalinity, mg/L as $CaCO_3$
3. Carbonate Alkalinity, mg/L as $CaCO_3$
4. Hydroxide Alkalinity, mg/L as $CaCO_3$

See Chapter 11, "Lab Procedures," pages 491-493 for details and formulas.

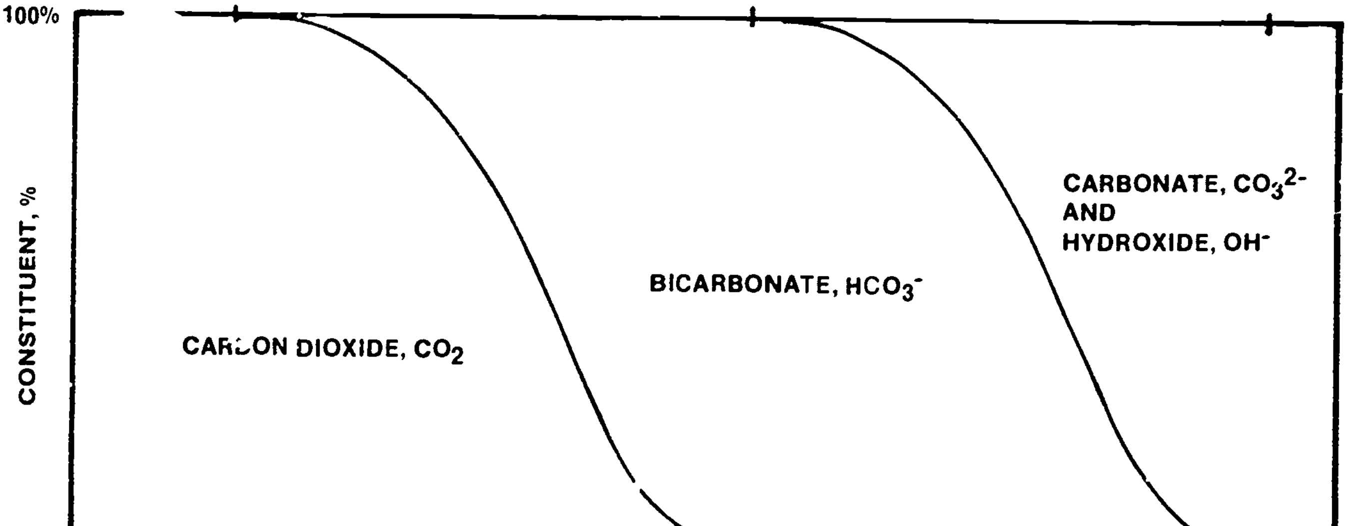

Fig. 14.1 Relationship between pH and alkalinity constituents (HCO_3^-, CO_3^{2-} and OH^-)

1. Calculate the phenolphthalein alkalinity in mg/L as $CaCO_3$.

$$\text{Phenolphthalein Alkalinity, mg/}L\text{ as }CaCO_3 = \frac{A \times N \times 50{,}000}{mL\text{ of sample}}$$

$$= \frac{(0\ mL) \times (0.02\ N) \times (50{,}000)}{100\ mL}$$

$$= 0\ mg/L$$

2. Calculate the total alkalinity in mg/L as $CaCO_3$.

$$\text{Total Alkalinity, mg/}L\text{ as }CaCO_3 = \frac{B \times N \times 50{,}000}{mL\text{ of sample}}$$

$$= \frac{(8.2\ mL) \times (0.02\ N) \times (50{,}000)}{100\ mL}$$

$$= 82\ mg/L$$

3. Refer to Table 14.3 for alkalinity constituents. The first row indicates that since P = 0, the total alkalinity is equal to the bicarbonate alkalinity.

$$\text{Bicarbonate Alkalinity, mg/}L\text{ as }CaCO_3 = \text{Total Alkalinity, mg/}L\text{ as }CaCO_3$$

$$= 82\ mg/L$$

The first row also indicates that since P = 0, the carbonate and hydroxide alkalinities are also zero.

$$\text{Carbonate Alkalinity, mg/}L\text{ as }CaCO_3 = 0\ mg/L$$

$$\text{Hydroxide Alkalinity, mg/}L\text{ as }CaCO_3 = 0\ mg/L$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 107.

14.2A What laboratory procedures are used to measure hardness?

14.2B Determine the total hardness of $CaCO_3$ for a sample of water with a calcium content of 25 mg/L and a magnesium content of 14 mg/L.

14.2C Which water treatment chemicals lower the pH when added to water?

14.2D Results from alkalinity titrations on a sample of water were as follows: sample size, 100 mL; mL titrant used to pH 8.3, 1.2 mL; total mL of titrant used, 5.6 mL, and the acid normality was 0.02 N H_2SO_4. Calculate the total, bicarbonate, carbonate and hydroxide alkalinity as $CaCO_3$.

14.3 HOW WATER IS SOFTENED

14.30 Basic Methods of Softening

The two basic methods of softening a municipal water supply are chemical precipitation and ion exchange. Ion exchange will be discussed in the second portion of this chapter in Sections 14.10 through 14.21. We'll begin here with the chemical precipitation methods, mainly lime-soda ash softening and variations of this process.

Hardness is not completely removed by the chemical precipitation methods used in water treatment plants. That is, hardness is not reduced to zero. Water having a hardness of 150 mg/L as $CaCO_3$ or more is usually treated to reduce the hardness to 80 to 90 mg/L when softening is chosen as a water treatment option.

The minimum hardness that can be achieved by the lime-soda ash process is around 30 to 40 mg/L as $CaCO_3$. The effluent from an ion exchange softener could contain almost zero hardness. Regardless of the method used to soften water, consumers usually receive a blended water with a hardness of around 80 to 90 mg/L as $CaCO_3$ when softening is used in water treatment plants.

Lime-soda softening may produce benefits in addition to the softening of water. These advantages include:

1. Removal of iron and manganese,
2. Reduction of solids,
3. Removal and inactivation of bacteria and virus due to high pH,
4. Control of corrosion and scale formation with proper stabilization of treated water, and
5. Removal of excess fluoride.

Limitations of the lime-soda softening process include:

1. Unable to remove all hardness,
2. A high degree of operator control must be exercised for maximum efficiency in cost, hardness removal and water stability,
3. Color removal may be complicated by the softening process due to high pH levels, and
4. Large quantities of sludge are created which must be handled and disposed of in an acceptable manner.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

14.3A What is the minimum hardness that can be achieved by the lime-soda ash process?

14.3B List some of the benefits that could result from the lime-soda softening process in addition to softening the water.

14.31 Chemical Reactions

In the chemical precipitation process, the hardness causing ions are converted from soluble to insoluble forms. Calcium and magnesium become less soluble as the pH increases. Therefore, calcium and magnesium can be removed from water as insoluble precipitates at high pH levels.

Addition of lime to water increases the hydroxide concentrations, thus increasing the pH. Addition of lime to water also converts alkalinity from the bicarbonate form to the carbonate form which causes the calcium to be precipitated as calcium carbonate ($CaCO_3$). As additional lime is added to the water, the phenolphthalein (P) alkalinity increases to a level where hydroxide becomes present (excess causticity) allowing magnesium to precipitate as magnesium hydroxide.

Following the chemical softening process, the pH is high and the water is *SUPERSATURATED*[9] with excess caustic alkalinity in either the hydroxide or carbonate form. Carbon dioxide can be used to decrease the causticity and scale forming tendencies of the water prior to filtration.

The chemical reactions which take place in water during the chemical precipitation process are described in the remainder of this section. The procedures for softening water depend on whether the hardness to be removed is carbonate or noncarbonate hardness. Carbonate hardness (also called "temporary hardness") can be removed by the use of lime only. Removal of noncarbonate hardness (also called "permanent hardness") requires both lime and soda.

14.310 Lime

The lime used in the chemical precipitation softening process may be from either *HYDRATED LIME*[10] ($Ca(OH)_2$, calcium hydroxide, or "slaked" lime) or calcium oxide (CaO, *QUICKLIME*[11] or "unslaked" lime). The hydrated lime may be used directly. The calcium oxide or quicklime must first be *SLAKED.*[12] This involves adding the calcium oxide (CaO) pellets to water and heating to cause "slaking" (the formation of calcium hydroxide ($Ca(OH)_2$)) before use. Small facilities commonly use hydrated lime ($Ca(OH)_2$). Large facilities may find it more economical to use quicklime (CaO) and slake it on site.

14.311 Removal of Carbon Dioxide

The application of lime for the removal of carbonate hardness also removes carbon dioxide. Carbon dioxide does not contribute to hardness and therefore does not need to be removed. However, carbon dioxide will consume a portion of the lime to be used and therefore must be considered. Equation (1) describes the reaction of carbon dioxide with lime.

$$(1)\ \text{Carbon Dioxide} + \text{Lime} \rightarrow \text{Calcium Carbonate}\downarrow + \text{Water}$$
$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + H_2O$$

14.312 Removal of Carbonate Hardness

The equations below describe the removal of carbonate hardness.

$$(2)\ \text{Calcium Bicarbonate} + \text{Lime} \rightarrow \text{Calcium Carbonate}\downarrow + \text{Water}$$
$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\ CaCO_3\downarrow + 2\ H_2O$$

$$(3)\ \begin{matrix}\text{Magnesium}\\ \text{Bicarbonate}\end{matrix} + \text{Lime} \rightarrow \begin{matrix}\text{Calcium}\\ \text{Carbonate}\downarrow\end{matrix} + \begin{matrix}\text{Magnesium}\\ \text{Carbonate}\end{matrix} + \text{Water}$$
$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + MgCO_3 + 2\ H_2O$$

$$(4)\ \begin{matrix}\text{Magnesium}\\ \text{Carbonate}\end{matrix} + \text{Lime} \rightarrow \begin{matrix}\text{Calcium}\\ \text{Carbonate}\downarrow\end{matrix} + \begin{matrix}\text{Magnesium}\\ \text{Hydroxide}\downarrow\end{matrix}$$
$$MgCO_3 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + Mg(OH)_2\downarrow$$

When lime is added to water, any carbon dioxide present is converted to calcium carbonate if enough lime is added (Equation 1). With the addition of more lime the calcium bicarbonate will be precipitated as calcium carbonate. To remove both the calcium and magnesium bicarbonate, an excess of lime must be used.

14.313 Removal of Noncarbonate Hardness

Magnesium noncarbonate hardness requires the addition of both lime and soda ash (sodium carbonate, Na_2CO_3).

$$(5)\ \text{Magnesium Sulfate} + \text{Lime} \rightarrow \text{Magnesium Hydroxide}\downarrow + \text{Calcium Sulfate}$$
$$MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4$$

$$(6)\ \text{Calcium Sulfate} + \text{Soda Ash} \rightarrow \text{Calcium Carbonate}\downarrow + \text{Sodium Sulfate}$$
$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3\downarrow + Na_2SO_4$$

Equation (6) is also one of the equations for the removal of calcium noncarbonate hardness. Similar equations can be written for the removal of noncarbonate hardness caused by calcium and magnesium chloride.

14.314 Stability

The main chemical reaction products from the lime-soda softening process are $CaCO_3\downarrow$ and $Mg(OH)_2\downarrow$. The water thus treated has been chemically changed and is no longer stable because of pH and alkalinity changes. Lime soda softened water is usually supersaturated with calcium carbonate ($CaCO_3$). The degree of instability and excess calcium carbonate depends on the degree to which the water is softened. Calcium carbonate hardness is removed at a lower pH than magnesium carbonate hardness. If maximum carbonate hardness removal is practiced (thus requiring a high pH to remove the magnesium carbonate hardness), the water will be supersaturated with calcium carbonate and magnesium hydroxide. Under these conditions deposition of precipitates will occur in filters and pipelines.

Excess lime addition to remove magnesium carbonate hardness results in supersaturated conditions and a residual of lime which will produce a pH of about 10.9. The excess lime is called caustic alkalinity since it has the effect of raising the pH. If the pH is then lowered, better precipitation of calcium carbonate and magnesium hydroxide will occur. Alkalinity will be lowered also. This is usually accomplished by pumping carbon dioxide (CO_2) gas into the water. This addition of carbon dioxide to the treated water is called *RECARBONATION.*[13]

Recarbonation may be carried out in two steps. The first addition of carbon dioxide would follow excess lime addition to lower the pH to about 10.4 and encourage the precipitation of calcium carbonate and magnesium hydroxide. A second addition of carbon dioxide would be after treatment to remove noncarbonate hardness. This would again lower the pH to about 9.8 and would encourage precipitation. By

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[9] *Supersaturated. An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.*

[10] *Hydrated Lime. Limestone that has been "burned" and treated with water under controlled conditions until the calcium oxide portion has been converted to calcium hydroxide ($Ca(OH)_2$). Hydrated lime is quicklime combined with water. $CaO + H_2O \rightarrow Ca(OH)_2$. Also called slaked lime.*

[11] *Quicklime. A material that is mostly calcium oxide (CaO) or calcium oxide in natural association with a lesser amount of magnesium oxide. Quicklime is capable of combining with water to form hydrated lime.*

[12] *Slake. To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.*

[13] *Recarbonation (re-CAR-bun-NAY-shun). A process in which carbon dioxide is bubbled into the water being treated to lower the pH. The pH may also be lowered by the addition of acid. Recarbonation is the final stage in the lime-soda ash softening process. This process converts carbonate ions to bicarbonate ions and stabilizes the solution against the precipitation of carbonate compounds.*

carrying out recarbonation prior to filtration, the build up of excess lime and also calcium carbonate and magnesium hydroxide precipitates in the filters will be prevented or minimized. The recarbonation reaction for excess lime removal is shown below.

(7) Calcium Hydroxide + Carbon Dioxide → Calcium Carbonate↓ + Water

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3\downarrow + H_2O$$

Care must be exercised when using recarbonation. Feeding excess carbon dioxide may result in no lowering of the hardness by causing calcium carbonate precipitates to go back into solution and cause carbonate hardness.

(8) Calcium Carbonate + Carbon Dioxide + Water → Calcium Bicarbonate

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$$

14.315 Caustic Soda Softening

An alternate method in the lime-soda softening process is the use of sodium hydroxide (NaOH, often called caustic soda) in place of soda ash. The chemical reactions of sodium hydroxide with carbonate and non-carbonate hardness are listed below.

(9) Carbon Dioxide + Sodium Hydroxide → Sodium Carbonate + Water

$$CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$$

(10) Calcium Bicarbonate + Sodium Hydroxide → Calcium Carbonate↓ + Sodium Carbonate + Water

$$Ca(HCO_3)_2 + 2\,NaOH \rightarrow CaCO_3\downarrow + Na_2CO_3 + 2\,H_2O$$

(11) Magnesium Bicarbonate + Sodium Hydroxide → Magnesium Hydroxide↓ + Sodium Carbonate + Water

$$Mg(HCO_3)_2 + 4\,NaOH \rightarrow Mg(OH)_2\downarrow + 2\,Na_2CO_3 + 2\,H_2O$$

(12) Magnesium Sulfate + Sodium Hydroxide → Magnesium Hydroxide↓ + Sodium Sulfate

$$MgSO_4 + 2\,NaOH \rightarrow Mg(OH)_2 + Na_2SO_4$$

These chemical reactions show that in removing carbon dioxide and carbonate hardness, sodium carbonate (Na_2CO_3, soda ash) is formed which will react to remove the noncarbonate hardness. Not only will sodium hydroxide substitute for soda ash, but it may replace all or part of the lime ($Ca(OH)_2$) requirement for removal of the carbonate hardness. The use of caustic soda (usually as a 50 percent solution) may have several advantages:

1. Stability in storage,
2. Less sludge is formed, and
3. Ease of handling and storage.

Safe handling procedures for caustic soda must be used at all times. A 50 percent caustic solution is very dangerous. Caustic soda is a strong base and will attack fabrics and leather and cause severe burns to the skin. Rubber gloves, respirator, safety goggles and a rubber apron must be worn when handling caustic soda. A safety shower and an emergency eye wash must be readily available at all times.

The decision to use caustic soda rather than soda ash depends on the quality of the source water and the delivered costs of the various chemicals.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

14.3C What causes the pH to increase during the lime-soda softening process?

14.3D Why is the pH increased during the lime-soda softening process?

14.3E How are the scale forming tendencies reduced in water after the chemical softening process?

14.3F Under what conditions might caustic soda softening be used?

14.316 Calculation of Chemical Dosages

There are several different approaches to calculating chemical doses for the lime-soda softening process. This section illustrates one step-by-step procedure. To use this procedure you need to obtain a chemical analysis of the water you are softening. From this analysis obtain the known values for your water similar to the "Knowns" listed in EXAMPLE 2. Then calculate the dosages of chemicals for your water by following the steps in the example.

To help you understand where some of the numbers come from in the formulas, we have listed the molecular weights of the major chemical components involved in the chemical precipitation softening process.

Quicklime, CaO	= 56
Hydrated Lime, $Ca(OH)_2$	= 74
Magnesium, Mg^{2+}	= 24.3
Carbon Dioxide, CO_2	= 44
Magnesium Hydroxide, $Mg(OH)_2$	= 58.3
Soda Ash, Na_2CO_3	= 106
Alkalinity, as $CaCO_3$	= 100
Hardness, as $CaCO_3$	= 100

FORMULAS

1 The lime dosage for softening can be estimated by using the following formula:

$$\text{Quicklime (CaO) Feed, mg/}L = \frac{(A + B + C + D)1.15}{\text{Purity of Lime, as a decimal}}$$

Where A = CO_2 in source water (mg/*L* as CO_2)(56/44)

B = Bicarbonate alkalinity removed in softening (mg/*L* as $CaCO_3$)(56/100)

C = Hydroxide alkalinity in softener effluent (mg/*L* as $CaCO_3$)(56/100)

D = Magnesium removed in softening (mg/*L* as Mg^{2+})(56/24.3)

1.15 = Excess lime dosage (using a 15 percent excess)

NOTE If hydrated lime ($Ca(OH)_2$) is used instead of quicklime substitute 74 for 56 in A, B, C and D.

2 The soda ash dosage to remove noncarbonate hardness can be estimated by using the formula below.

$$\text{Soda Ash }(Na_2CO_3)\text{, Feed, mg/}L = (\text{Noncarbonate Hardness, mg/}L\text{ as }CaCO_3)(106/100)$$

3 The dosage of carbon dioxide required for recarbonation can be estimated using the formula below.

$$\text{Total }CO_2\text{ Feed, mg/}L = (Ca(OH)_2\text{ excess, mg/}L)(44/74) + (Mg(OH)_2\text{ residual, mg/}L)(44/58.3)$$

EXAMPLE 3

Calculate the hydrated lime ($Ca(OH)_2$) with 90 percent purity, soda ash, and carbon dioxide dose requirements in milligrams per liter for the water shown below.

Known

Constituents	Source Water	Softened Water After Recarbonation and Filtration
CO_2, mg/*L*	= 6 mg/*L*	= 0 mg/*L*
Total Alkalinity, mg/*L*	= 170 mg/*L* as $CaCO_3$	= 30 mg/*L* as $CaCO_3$
Total Hardness, mg/*L*	= 280 mg/*L* as $CaCO_3$	= 70 mg/*L* as $CaCO_3$
Mg^{2+}, mg/*L*	= 21 mg/*L*	= 3 mg/*L*
pH	= 7.5	= 8.8
Lime Purity, %	= 90%	

Unknown

1. Hydrated Lime, mg/*L*
2. Soda Ash, mg/*L*
3. Carbon Dioxide, mg/*L*

1. Calculate the hydrated lime ($Ca(OH)_2$) required in milligrams per liter.

$$\begin{aligned} A &= (CO_2,\ mg/L)(74/44) \\ &= (6\ mg/L)(74/44) \\ &= 10\ mg/L \end{aligned}$$

$$\begin{aligned} B &= (\text{Alkalinity},\ mg/L)(74/100) \\ &= (170\ mg/L)(74/100) \\ &= 126\ mg/L \end{aligned}$$

$$C = 0$$

$$\begin{aligned} D &= (Mg^{2+},\ mg/L)(74/24.3) \\ &= (21\ mg/L)(74/24.3) \\ &= 64\ mg/L \end{aligned}$$

$$\begin{aligned} \text{Hydrated Lime } (Ca(OH)_2) \text{ Feed, } mg/L &= \frac{(A + B + C + D)1.15}{\text{Purity of Lime, as a decimal}} \\ &= \frac{10\ mg/L + 126\ mg/L + 0 + 64\ mg/L)1.15}{0.90} \\ &= \frac{(200\ mg/L)(1.15)}{0.90} \\ &= 256\ mg/L \end{aligned}$$

2. Calculate the soda ash required in milligrams per liter.

$$\begin{aligned} \text{Noncarbonate Hardness, } mg/L \text{ as } CaCO_3 &= \text{Total Hardness, } mg/L \text{ as } CaCO_3 - \text{Carbonate Hardness, } mg/L \text{ as } CaCO_3 \\ &= 280\ mg/L - 170\ mg/L \\ &= 110\ mg/L \text{ as } CaCO_3 \end{aligned}$$

$$\begin{aligned} \text{Soda Ash } (Na_2CO_3) \text{ Feed, } mg/L &= (\text{Noncarbonate Hardness, } mg/L \text{ as } CaCO_3)(106/100) \\ &= (110\ mg/L)(106/100) \\ &= 117\ mg/L \end{aligned}$$

3. Calculate the dosage of carbon dioxide required for recarbonation.

$$\begin{aligned} \text{Excess Lime, } mg/L &= (A + B + C + D)(0.15) \\ &= (10\ mg/L + 126\ mg/L + 0 + 64\ mg/L)(0.15) \\ &= (200\ mg/L)(0.15) \\ &= 30\ mg/L \end{aligned}$$

$$\begin{aligned} \text{Total } CO_2 \text{ Feed, } mg/L &= (Ca(OH)_2 \text{ excess, } mg/L)(44/74) + (Mg^{2+} \text{ residual, } mg/L)(44/24.3) \\ &= (30\ mg/L)(44/74) + (3\ mg/L)(44/24.3) \\ &= 18\ mg/L + 6\ mg/L \\ &= 24\ mg/L \end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 108.

14.3G Calculate the hydrated lime ($Ca(OH)_2$) with 90 percent purity, soda ash, and carbon dioxide dose requirements in milligrams per liter for the water shown below.

Constituents	Source Water	Softened Water After Recarbonation and Filtration
CO_2, mg/*L*	= 5 mg/*L*	= 0 mg/*L*
Total Alkalinity, mg/*L*	= 150 mg/*L* as CaCO	= 20 mg/*L* as CaCO
Total Hardness, mg/*L*	= 240 mg/*L* as CaCO	= 50 mg/*L* as CaCO
Mg^{2+}, mg/*L*	= 16 mg/*L*	= 2 mg/*L*
pH	= 7.4	= 8.8
Lime Purity, %	= 90%	

14.32 Lime Softening (Figure 14.2)

Water having hardness caused by calcium and magnesium bicarbonate (carbonate hardness) can usually be softened to an acceptable level using only lime. The lime reacts with the bicarbonate to form calcium carbonate which will precipitate and settle out (convert from soluble to insoluble form) at a pH above 10 and magnesium carbonate which will remain in solution. The magnesium carbonate reacts with additional lime at a pH above 11 to form magnesium hydroxide which will precipitate.

In practice, if enough hardness can be removed by reacting lime with the calcium bicarbonate, softening can be accomplished at less expense. This procedure is sometimes called partial lime softening (no magnesium removal). On the other hand, if some of the magnesium is to be removed, additional lime will be required.

Figure 14.2 is a flow diagram of a typical straight lime softening treatment plant. Settling should be provided after the addition of carbon dioxide (recarbonation) to ease the load on the filters. Recarbonation is used to lower the pH of the water. When properly recarbonated the water is still supersaturated with calcium carbonate ($CaCO_3$). If the pH is much above 9, the water will usually cause scale to form. By recarbonation the pH can be lowered to a range between 8.8 and 8.4 and the Langelier Index will still be positive; therefore there will be little or no corrosion. A polyphosphate is sometimes added to the water to prevent excessively heavy calcium carbonate scale deposits from forming. A polyphosphate may not be necessary if recarbonation is properly controlled. Addition of acid will *NOT* accomplish the same things as recarbonation and the addition of a polyphosphate.

14.33 Split Treatment

The amount of calcium and magnesium in source waters may vary. When the water contains a high level of magnesium, a method known as split treatment may be used (Figure 14.3). Split treatment can be used in lime treatment only or lime-soda ash treatment. In split treatment a portion of the water (say 90 percent) is treated with an excess amount of lime to remove the magnesium at a pH of over 11. Then source water (the other 20 percent) is added in the next basin to neutralize (lower the pH) the excess-lime-treated portion. The percentages will vary depending upon the water hardness, treatment layout, and desired results.

Split treatment softening can eliminate the need for recarbonation as well as offer a significant savings in lime feed. Since the fraction of the water that is treated has a high lime dose, magnesium is almost completely removed from this portion. When this water is mixed with the unsoftened water, the carbon dioxide and bicarbonate in the unsoftened fraction of the water tend to recarbonate in the final blend or mix of the treated water (effluent).

If the water shown in Figure 14.4 was treated by conventional treatment (not split treatment), it would require a lime dose of 400 mg/*L* as $CaCO_3$ which is 25 percent higher and a carbon dioxide dose of 145 mg/*L* as $CaCO_3$ to produce a water having a hardness of 61 mg/*L* as $CaCO_3$ and a pH of 8.63.

While split treatment may be used in the lime-soda process, it is often advantageous to use a lime-ion exchange process (see Section 14.10). The salt used to remove noncarbonate hardness in the ion exchange process is much less expensive than the soda ash required in the lime-soda ash process.

The curves shown in Figure 14.4 assume that carbonate equilibrium has been achieved. In practice, it is not possible to attain equilibrium, but if the reactions take place in solids-contact units the results are very close to carbonate equilibrium.

The proper fraction of water to bypass is rather critically dependent on the lime dose and chemical composition of the unsoftened water. The proper fraction may be calculated, but the calculations are very complex. An experienced water chemist can perform the calculations.

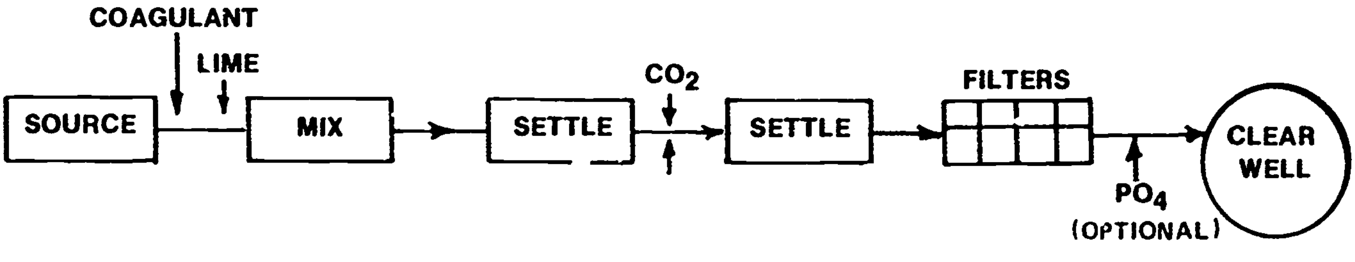


Fig. 14.2 Straight lime treatment

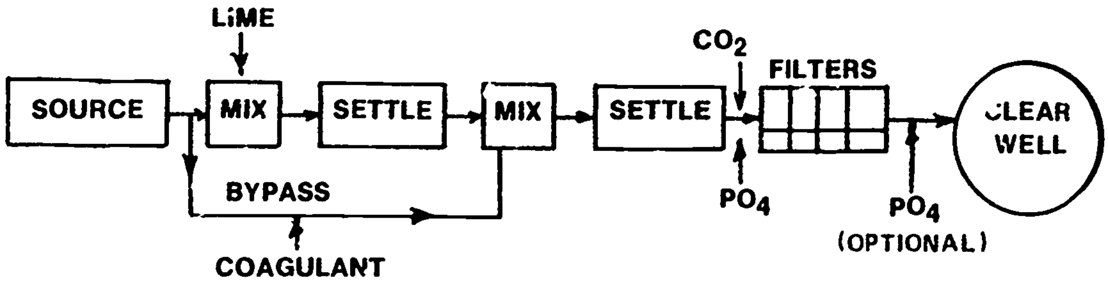


Fig. 14.3 Split lime treatment

UNSOFTENED WATER

TEMPERATURE = 25°C

TDS = 400 mg/L

pH = 7.2

Ca = 150 mg/L as $CaCO_3$

Mg = 100 mg/L as $CaCO_3$

Alk = 250 mg/L as $CaCO_3$

DOSAGE

LIME = 320 mg/L as $CaCO_3$

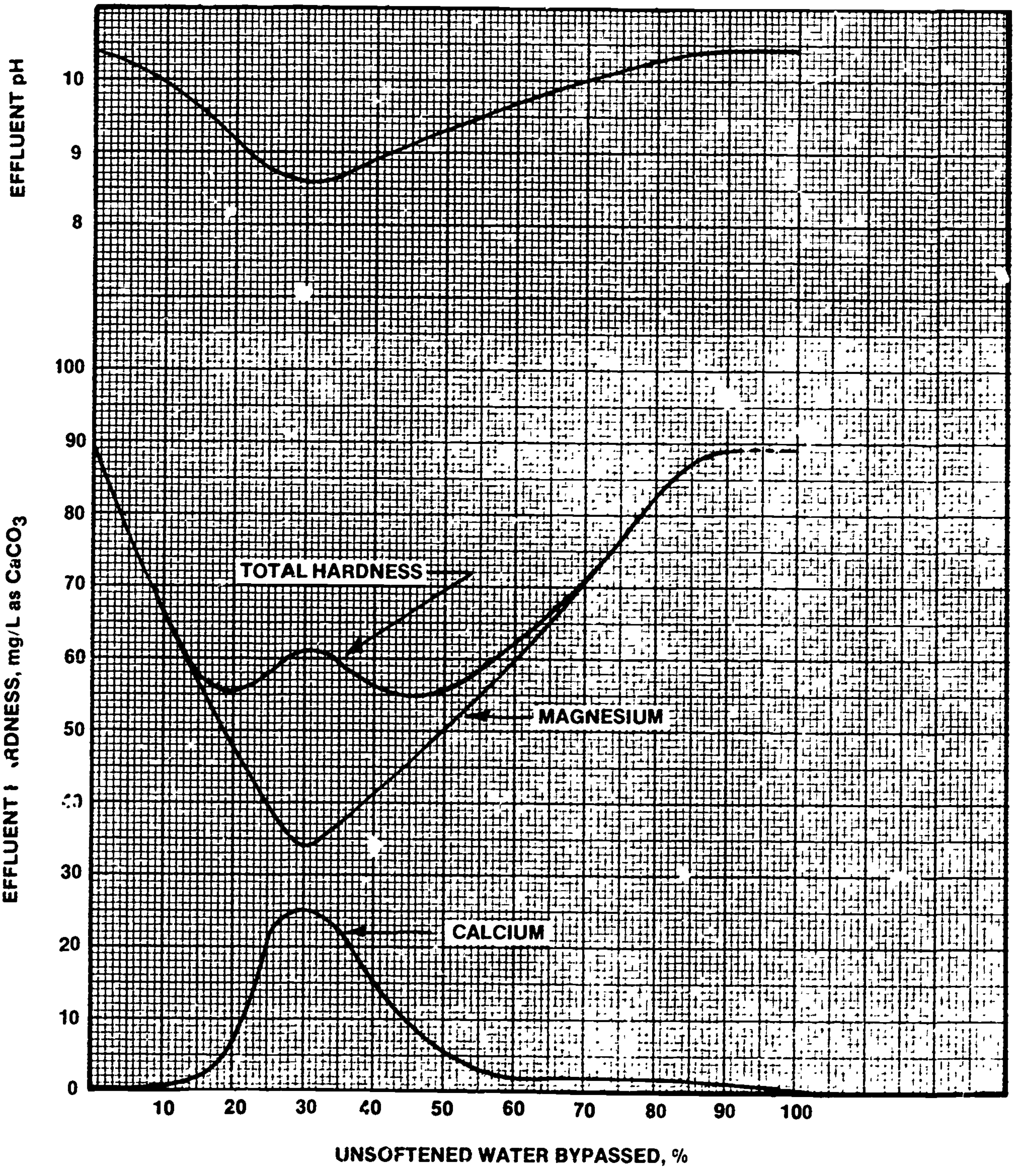


Fig. 14.4 Split treatment softening

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14.3H What compounds are formed when calcium and magnesium are precipitated out of water in the lime softening process?

14.3I What hardness is removed by partial lime softening (no magnesium removal)?

14.3J What is split lime treatment?

14.3K What is recarbonation?

14.34 Lime-Soda Ash Softening

Let's look now at hardness requiring lime-soda ash treatment for removal (Figure 14.5).

When water cannot be softened to the desired level with lime only, it no doubt contains noncarbonate hardness. Noncarbonate hardness requires the addition of a compound which increases carbonate concentration, usually soda ash (sodium carbonate).

A water could contain only calcium hardness, yet require both lime and soda ash treatment. This would occur if the hardness were only calcium bicarbonate, sulfate and/or chloride. In other words, all of the hardness is calcium carbonate and calcium noncarbonate hardness. This would not require split treatment (Figure 14.6).

14.35 Caustic Soda Softening

An alternative to the lime-soda ash process is the use of caustic soda (sodium hydroxide, NaOH) instead of soda ash. The reactions of caustic soda with the carbonate and noncarbonate hardness are given in Section 14.315. Recall that caustic soda reacts with the carbonate hardness to form soda ash (sodium carbonate) which will react with calcium sulfate to form calcium carbonate ($CaCO_3\downarrow$) as shown previously.

The advantages of using liquid caustic soda include ease of handling and feeding, lack of deterioration in storage, and less calcium carbonate sludge to handle and dispose of. Caustic soda is capable of removing both carbonate and noncarbonate hardness. Therefore, caustic soda may be used instead of soda ash, but also in place of part or all of the lime requirement. The use of caustic soda depends on a comparison of the costs of caustic soda, lime and soda ash and the characteristics of the source water.

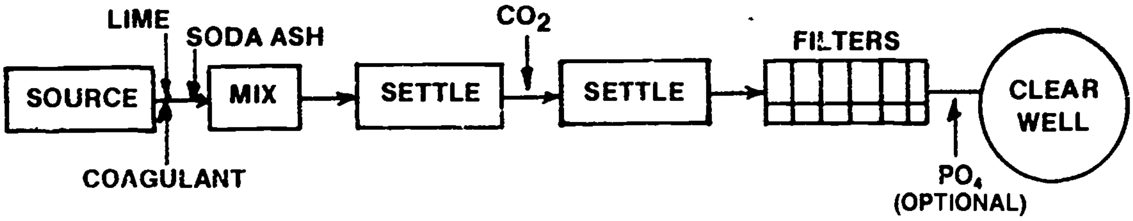


Fig. 14.5 Lime-soda ash treatment

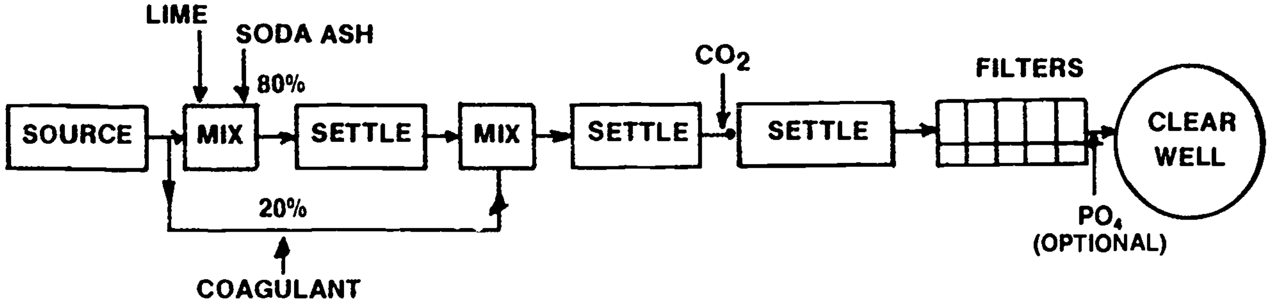


Fig. 14.6 Lime-soda ash split treatment

Two points to observe are that sodium does not contribute to hardness, thus all the reactions having sodium compounds as an end product are non-hardness-producing compounds However, sodium levels in drinking water should be less than 20 mg/*L* The second point is that the precipitated compounds, $CaCO_3\downarrow$ and $Mg(OH)_2\downarrow$ are the desired end products whether lime or lime-soda ash or caustic soda treatment is used.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14.3L Under what conditions would lime-soda ash softening be used?

14.3M What chemical is used to remove noncarbonate hardness in the chemical precipitation softening process?

14.36 Handling, Application and Storage of Lime

Where the daily requirements for lime are small, lime is usually delivered to the water treatment plant in bags. At larger treatment plants either quick (CaO) or hydrated ($Ca(OH)_2$) lime is delivered in bulk quantities. Truck loads of lime are commonly transferred to weather-tight bins or silos by mechanical or pneumatic conveying systems.

Storage areas for bagged lime must be covered to prevent rain from wetting the bags. Bagged quicklime (CaO or calcium oxide) should never be stored close to combustible materials because considerable heat will be generated if the lime accidentally gets wet. Quicklime may be stored as long as six months, but in general should not be stored over three months. Hydrated lime should not be stored for more than three months before using.

Lime may be applied by dry feeding techniques using volumetric or gravimetric feeders. Lime is too insoluble to make "solution feeding" by pump feeders practical because of the accumulation of carbonate precipitation. See Chapter 13, "Fluoridation," for additional details and pictures of the various types of chemical feeders.

Operator safety must be considered before attempting to work with lime. A properly designed lime feeding system can minimize or eliminate lime dust problems. If lime dust is a problem, operators must wear protective clothing to avoid burns from contact with lime. Protective clothing includes long-sleeved shirt with sleeves and collar buttoned, trousers with legs down over tops of shoes or boots, head protection, and gloves. Clothing should not fit too tightly around your neck, wrists or ankles, A protective cream should be applied to exposed parts of the body, especially your neck, face and wrists. You should wear a light-weight filter mask and tight-fitting safety glasses with side shield to protect yourself from the lime dust.

If lime comes in contact with your skin or eyes, immediately flush the affected areas with water and consult a physician if necessary. Do not rub your eyes if they are irritated with lime dust because rubbing will make the irritation worse. Keep any lime burns covered with a bandage during healing to prevent infection.

After handling lime, you should take a shower. If your clothes are covered with dust, or splattered with a lime slurry, take them off and have them washed. If possible, wear clean clothes on every shift.

For additional information regarding lime, contact the National Lime Association, Washington, D.C. 20016, and request a copy of their publication, *LIME HANDLING, APPLICATION, AND STORAGE IN TREATMENT PROCESSES*. Lime, as well as other water treatment chemicals, should comply with the Standards of the American Water Works Association.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14.3N How is lime delivered to plants where the daily requirements are small?

14.3O Why should quicklime be kept dry?

14.3P What types of chemical feeders are used to apply dry lime?

14.4 INTERACTIONS WITH COAGULANTS

Coagulation is discussed in detail in Chapter 4, "Coagulation and Flocculation." However, the interactions of lime and soda ash with metallic coagulants such as alum, iron salts (ferric chloride, ferric sulfate and ferrous sulfate), sodium aluminate, and many polymers are important.

Alum and iron salts are acidic and react with the alkalinity in water to cause a demand the same way that free carbon dioxide will. Therefore, this acidic condition must be met before softening can occur. In other words, extra lime will be required as the alum or iron feed rate goes up and therefore, less lime will be required as the alum or iron feed rate is reduced. Cationic polymers are not very pH sensitive and are often used as coagulant aids in softening plants rather than alum or iron salts.

On the other hand, when sodium aluminate (a basic rather than an acidic compound) is the coagulant, the lime required to achieve a specific hardness reduction will be less, and will vary the opposite of alum or iron salts.

The proportion of lime required in either instance is directly related to the coagulant dosage as well as the hardness removal desired. Approximate relationships can be calculated; however, experimentation is in order since plant equipment and source water variations are primary factors in the efficiencies of each waterworks. Jar tests are discussed later in Section 14.9.

If you are treating. highly colored waters, these waters must be coagulated for color removal at low pH values. Alum is a good coagulant under these conditions. Ozone, permanganate and chlorine may be tried along with alum to oxidize color. The high pH values required during softening tend to "set" the color which then becomes very difficult to remove.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14.4A What happens to the lime dose when the alum dose is increased for coagulation?

14.4B How can color be removed from water?

14.5 STABILITY

In nature, most waters are more or less stable. That is, they are in chemical balance. When lime is added, the chemical balance is changed. The calcium carbonate ($CaCO_3$) formed in lime treatment is scale forming unless the exact chemical balance is achieved, which is seldom the case.

Under most conditions, a slight excess of lime is fed to cause a caustic condition to insure complete reactions and achieve the desired results In order to prevent scale formation on the filter sand, distribution mains, and household plumbing, the excess caustic and unprecipitated carbonate ions (pin floc) must be converted to soluble forms. Recarbonation is the most common way to do this Again, as with all chemical treatment, recarbonation must be controlled to achieve the desired results.

Recarbonation lowers the pH to about 8.8 and thus converts some of the carbonate (CO_3^{2-}) back to the original bicarbonate (HCO_3^-) that existed in the source water. Recarbonation can be accomplished, to a degree, by using the source water in the split treatment mode discussed earlier. Usually this is not adequate so further recarbonation is required. One reason for using source water as a neutralizing agent is that the recarbonation process is much less costly than if a high caustic water (high pH) is neutralized by chemical addition.

Use of carbon dioxide gas is the most common method of recarbonation. The reactions are:

1. $Ca(OH)_2 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$ and
2. $CaCO_3 + CO_2 + H_2O \rightarrow Ca(HCO_3)_2$.

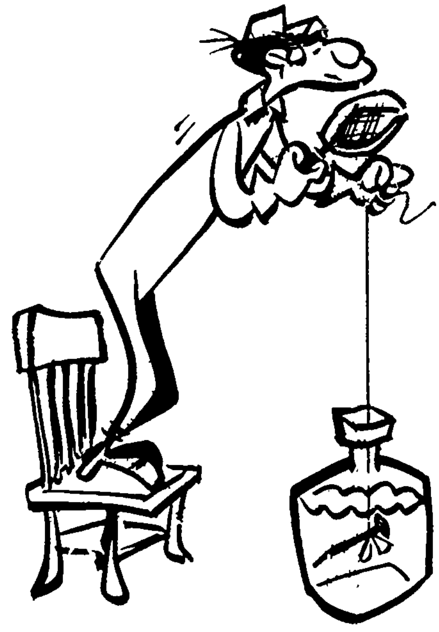
These reactions may be looked at as lime softening in reverse and will increase the hardness slightly. In these reactions you are producing bicarbonate ions which were removed in softening as carbonate hardness. This process tends to move the water back toward its original state, thus rendering it more stable.

The use of acids such as sulfuric or hydrochloric instead of recarbonation with carbon dioxide (CO_2) does not produce the same results. When carbon dioxide is added to a water containing calcium ions (Ca^{2+}) and hydroxide ions (OH^-), a calcium carbonate ($CaCO_3$) precipitate will form and the water will be saturated (or supersaturated) with calcium carbonate. If a strong acid is added to neutralize the softened water which is highly basic, these reactions will not take place.

The marble test is the simplest method of measuring stability in the laboratory. Run the marble test[14] as outlined below:

1. Collect a sample of tap water that has been softened and stopper the sample bottle (avoid splashing into the flask).
2. To an identical sample, add one gram of powdered calcium carbonate. Mix and let stand for an hour or so.
3. Filter both samples (so they are both exposed to the same conditions).
4. Run pH and alkalinity tests on both samples.
5. The goal is to have the sample of softened tap water as nearly matched to the softened sample treated with calcium carbonate as possible. Then stability is near. The plant treatment must be controlled to permit this condition to exist. If the pH and alkalinity in the softened sample are higher than in the softened sample treated with calcium carbonate, you are probably over-treating your supply and have scale-forming water. But, if the pH and alkalinity in your untreated softened sample are lower than in the treated one (calcium carbonate added), you are undertreating your supply. If they are similar, then stability is near.

Another way to check your water is to suspend a couple of nails on strings in your filter. Observe the nails occasionally to see if they are rusting or scaling up. To further protect the distribution system as well as prevent scale formation in the filter bed, 0.7 to 1.0 mg/*L* polyphosphate could be fed ahead of the filters at such a distance to allow mixing before it goes on to the filters. Addition of polyphosphate can *PREVENT THE FORMATION OF SCALE* on filter media and in distribution system mains, but polyphosphate does *NOT* prevent corrosion. The Langelier Index (see pages 357 to 360 in Volume I) is another approach to determining the corrosivity of water.



Caution should be exercised when using polyphosphate compounds. If they are converted to the orthophosphate form, they will lose their effectiveness. With the addition of phosphorous to water, there could be an increase in bacterial growths in the distribution system. Also some wastewater treatment plants have phosphorous discharge limitations and polyphosphates added to drinking water can cause wastewater treatment plants to violate their discharge requirements.

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[14] *For additional information on the marble test, see Chapter 21, "Advanced Laboratory Procedures," Test Procedure 9, Marble Test.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14.5A What problems are sometimes created when a slight excess of lime is fed during softening to cause a caustic condition to insure complete reactions?

14.5B How can excess caustic and unprecipitated carbonate ions (pin floc) be removed from softened water?

14.5C What test is used to determine if a water is stable?

14.5D How can nails be used to determine if a water is stable?

14.6 SAFETY

When quicklime reacts with water in the slaking process (Figure 14.7), it gets hot enough to cause serious burns. Also, being caustic in nature, it can harm your eyes and skin. *ALWAYS* wear goggles or a face shield when working with lime that has been or is in the process of slaking. Flush with water if exposed to lime. Seek medical attention if it gets in your eyes. As for hands or face burns, immediately wash the affected areas and consult a physician if the burns appear serious.

Feeding equipment has moving parts. All moving machinery is a potential safety hazard. A paste-type slaker is particularly dangerous. This type of slaker will "eat you alive." Never put your hand in or near the slaker paddles while the slaker is running. Use wooden paddles as cleaning tools on any slaker in operation. A metal tool will damage the slaker and could even injure the operator if dropped by accident However, a wooden paddle is less likely to damage the equipment or the operator.

Types of equipment vary greatly. Usually the operator has little or no input in this area. Engineers usually design a plant and specify the type of chemical feed equipment.

Equipment suppliers are usually quite cooperative in advising any operator in the use and care of their equipment in your treatment plant.

Detailed startup and shutdown and maintenance procedures are available in the equipment manuals.

Another important safety precaution is to avoid using the same conveyor or bin for alternately handling both quicklime and one of the coagulants containing water, such as alum, ferric sulfate or copperas. This water may be withdrawn by the quicklime and could generate enough heat to cause a fire Explosions have been reported to have been caused by lime-alum mixtures in enclosed bins. Therefore, always clean facilities before switching from one chemical to another

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14 6A Why should wooden paddles be used as cleaning tools on any slaker in operation?

14.6B Where would you look for information on how to safely maintain equipment?

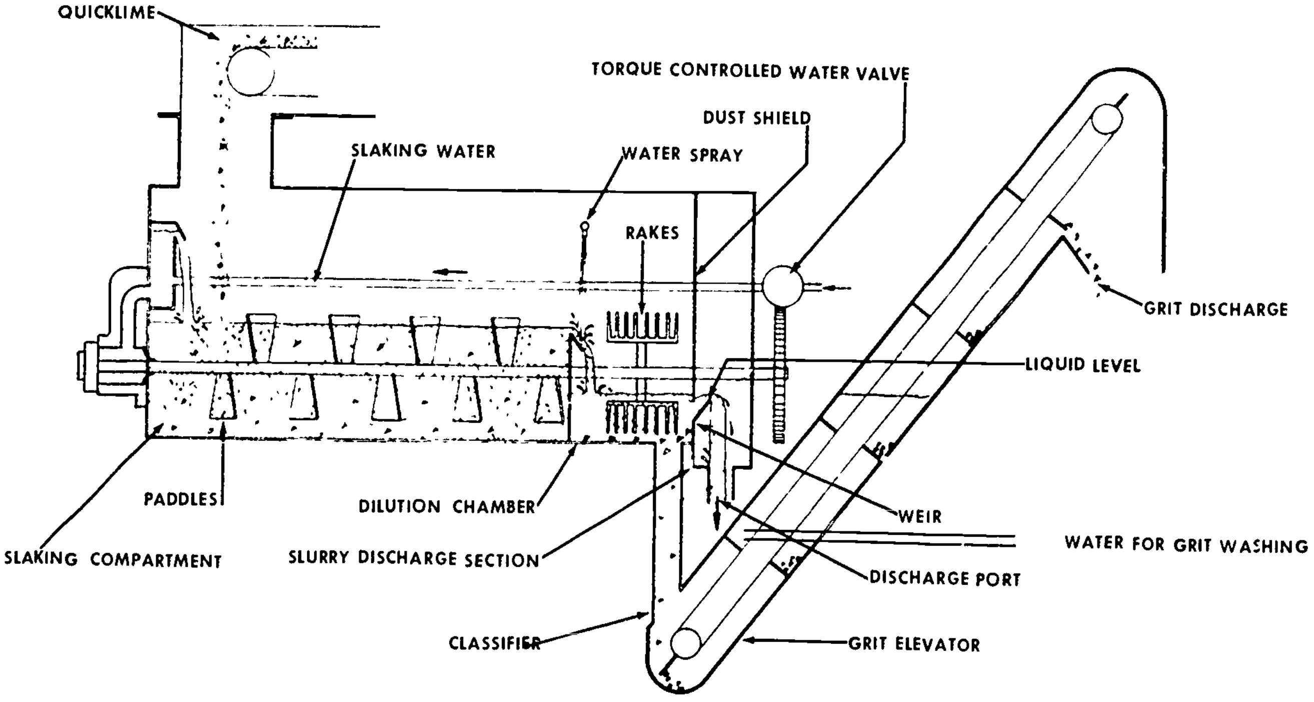

Fig. 14.7 Lime-slaking system

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

14.7 SLUDGE RECIRCULATION AND DISPOSAL

Considerable sludge may be produced by the lime and lime-soda softening processes. When calcium and magnesium hardness are converted from soluble forms to insoluble precipitates (calcium carbonate and magnesium hydroxide), these precipitates form sludge. This sludge is removed from the bottom of settling basins and may be recirculated or must be disposed of by an acceptable procedure.

In some instances, sludge is recirculated back into the primary mix area of conventional plants to help "seed" the process. The advantages are (1) recirculation speeds up the precipitation process and (2) some reduction of chemical requirements may result. One disadvantage is that an increase in magnesium could result. Only trial and error will really determine if sludge recirculation will serve a useful purpose in your plant.

Sludge disposal is a problem everywhere. Perhaps the most common method is landfill disposal. This is accomplished by dewatering the sludge (drying beds or mechanical means) and then hauling the sludge to landfill sites developed solely for sludge disposal or sanitary landfills. Generally, a sludge with a Ca Mg ratio of less than 2.1 will be difficult to dewater, whereas a sludge with a Ca Mg ratio of greater than 5:1 will dewater relatively easily. The less water in the sludge, the less volume to transport to the disposal site and the less space required in the landfill.

To a lesser degree, sanitary sewer disposal is sometimes used. This only moves the sludge to another location for someone else to deal with. Some work has also been done with land application as a substitute for agriculture lime to increase the pH of highly acid soils. The lime sludge is applied at a rate which will produce the optimum soil pH for the crops to be planted. For additional information on sludge disposal, see Chapter 17, "Handling and Disposal of Process Wastes."

14.8 RECORDS

Records should be kept on the amounts of chemicals ordered and the amounts fed Laboratory results should be recorded in a permanent lab book. See Chapter 18, "Maintenance," for details on how to keep equipment maintenance schedules and records.

Again, every plant is different. However, records will help a good operator be a better operator

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14.7A What is a disadvantage of recirculating sludge back to the primary mix area?

14.7B How could you determine if sludge recirculation will serve a useful purpose in your plant?

14.8A What types of records should be kept regarding treatment plant chemicals?

14.9 JAR TESTS

14.90 Typical Procedures

Approximate amounts of chemicals required can be calculated (see Section 14.316, "Calculation of Chemical Dosages"), however, the best method of determining the proper dosages is by the use of the jar test. See Chapter 11, "Laboratory Procedures," for details on the equipment and procedures required to run jar tests.

Chemical reagents may be made up by adding one gram of reagent to a liter of water.[15] This will produce a 0.1 percent chemical solution. When 1.0 gram/liter of lime, soda ash or coagulant is made up as the stock solution, one *mL* of the stock solution in a one liter sample of water equals one mg/*L* dosage. If large doses of lime are required, add 10 grams of lime per liter. With this stock solution, one *mL* of stock solution in a one liter sample of water equals ten mg/*L* dosage

Set up 6 samples and estimate the dosage required by adding varying amounts to each sample. Trial and error will put you in the "ball park." To refine the dosage, pick the best looking sample from the settling properties of the floc to establish the optimum lime dose. Then do the same with varying amounts of soda ash, leaving the lime dosage constant. By running pH, alkalinity, and hardness tests you can find the optimum dosages that give the desired softened water results.

The exact procedures used to soften water by chemical precipitation using the lime-soda ash process depend on the hardness and other chemical characteristics of the water being treated. A series of jar tests are commonly used to determine optimum dosages. In many cases, the feed rates determined by jar tests do not produce the exact same results in an actual plant. This is because of differences in water temperature, size and shape of jar as compared with plant basins, mixing equipment, and influence of coagulant (a heavy alum feed will neutralize more of the lime). You must remember that jar test results are a starting point. You may have to make additional adjustments to the chemical feeders in your plant based on actual analyses of the treated water.

Convert the jar test results to plant feed rates Always feed enough chemical to achieve the desired results, but don't overfeed. Overfeeding is a waste of money and quality control will suffer.

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[15] *Some operators add 10 grams of reagent to a liter of water. This will produce a one percent solution. One mL of the stock solution in one liter will produce a ten mg/L dosage.*

14.91 Examples

Let's set up some jar tests to determine the optimum dosages for lime or lime-soda treatment to remove hardness from a municipal water supply. To get started, add 10.0 grams of hydrated lime to a one-liter graduated cylinder or flask and fill to the one-liter mark with tap water. Thoroughly mix this stock solution in order to thoroughly suspend all of the lime. One m*L* of this solution (which has been thoroughly mixed) in a liter of water is the same as a lime dose of ten mg/*L*, or 0.5 m*L* in 500 m*L* is still the same as a ten mg/*L* lime dose.

Set up a series of hardness tests by adding 5.0 m*L*, 10.0 m*L*, 15.0 m*L*, 20.0 m*L*, 25.0 m*L*, 30.0 m*L*, 35.0 m*L* and 40.0 m*L* to one-liter (1000 m*L*) beakers or jars. Fill the beakers to the 1000 m*L* mark with the water being tested. Mix thoroughly for as long as normal mixing will occur in your plant. Allow the precipitate to settle (20 minutes if this is the settling time in your plant) and measure the hardness remaining in the water above the precipitate. A plot of the hardness remaining against the lime dosage will reveal the optimum dosage. Examination of Figures 14.8, 14.9 and 14.10[16] reveals that the water of all three cities responded differently to the increasing lime dosage. City 1 (Figure 14.8) should be providing a lime dose of 100 mg/*L*. The cost of increasing the dosage to 150 mg/*L* is not worth the slight reduction in hardness from 110 to 100 mg/*L* as $CaCO_3$. Note that an overfeed of lime will actually increase the hardness.

City 2 (Figure 14.9) should be providing a lime dose of 200 mg/*L*. A dose of 300 mg/*L* will reduce hardness, but the increase in lime costs is too great. City 3 (Figure 14.10) should be dosing lime between 200 and 250 mg/*L*. Note that the greater the lime dose, the less the hardness, but the greater the quantities of sludge that must be handled and disposed of.

If lime added to the water does not remove sufficient hardness, select the optimum lime dose and then add varying amounts of soda ash. From Figure 14.9 we found that the optimum lime dose was 200 mg/*L* (300 mg/*L* would have reduced the hardness slightly). Let's take six one-liter containers and add 20 m*L* of our lime stock solution (a dosage of 200 mg/*L*). Prepare a stock solution of soda ash similar to our lime solution by adding 10 grams of soda ash to a one-liter container, fill with distilled water and mix thoroughly. Add zero, 2.5 m*L* (25 mg/*L* dose), 5 m*L*, 7.5 m*L*, 10 m*L* and 12.5 m*L* to the one-liter containers. Mix thoroughly, allow the precipitate to settle and measure the hardness remaining in the water above the precipitate. A plot of hardness remaining against the soda ash dosage will reveal the desired dosage. We would like the final hardness to be in the 80 to 90 mg/*L* as $CaCO_3$ range in this example.

To select the optimum doses of lime and soda ash, consider the items discussed below.

1 Optimum dosage of lime was based on increments of 50 mg/*L*. You should refine this test by trying at least two-10 mg/*L* increments above and below the optimum dose. From Figure 14.8 we found that 100 mg/*L* was the optimum dose. Try lime doses of 80, 90, 100, 110 and 120 mg/*L*.
2 Optimum dosage of soda ash can be refined by trying smaller increments also.
3 Try slightly increasing the actual lime dose in your plant to see if there is any decrease in the remaining hardness. Is the decrease in hardness worth the increase in lime costs?
4. Try slightly increasing and decreasing both lime and soda ash dosages at your plant one at a time, and evaluate the results.
5. If you are treating well water or a water of constant quality, all you have to do to maintain proper treatment is to make minor adjustments to keep the system fine tuned.
6. If you are treating water from a lake or a river and the water quality (including temperature) changes, you'll have to repeat these procedures whenever the raw water quality changes. Water quality changes of concern include raw water hardness, alkalinity, pH, turbidity and temperature.
7. *REMEMBER*, you do not want to produce water of zero hardness. If you can get the hardness down to around 80 to 90 mg/*L*, that usually will be low enough for most domestic consumers. When selecting a target hardness level for your plant, consider the uses of your softened water and the cost of softening.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14 9A What items should be considered when determining the hardness of the treated water from a water softening plant?

14.9B If lime added to water does not reduce the hardness of a water sufficiently, what would you do?

14.92 Calculation of Chemical Feeder Settings

After chemical doses have been calculated or determined from jar tests, convert the results to plant chemical feed rates. Depending on the type of chemical feeder, you may have to calculate the feed rates in pounds per day, pounds per hour or pounds per minute. Always feed enough chemical to achieve the desired results, but don't over feed Over treating is a waste of money and quality control will suffer.

EXAMPLE 4

The optimum lime dosage from the jar tests is 230 mg/*L*. If the flow to be treated is 6 MGD, what is the feeder setting in pounds per day and the feed rate in pounds per minute?

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[16] *These figures were adapted from an article titled, "Use of Softening Curve for Lime Dosage Control," by Michael D. Curry, P.E., which appeared in THE DIGESTER/OVER THE SPILLWAY, published by the Illinois Environmental Protection Agency.*

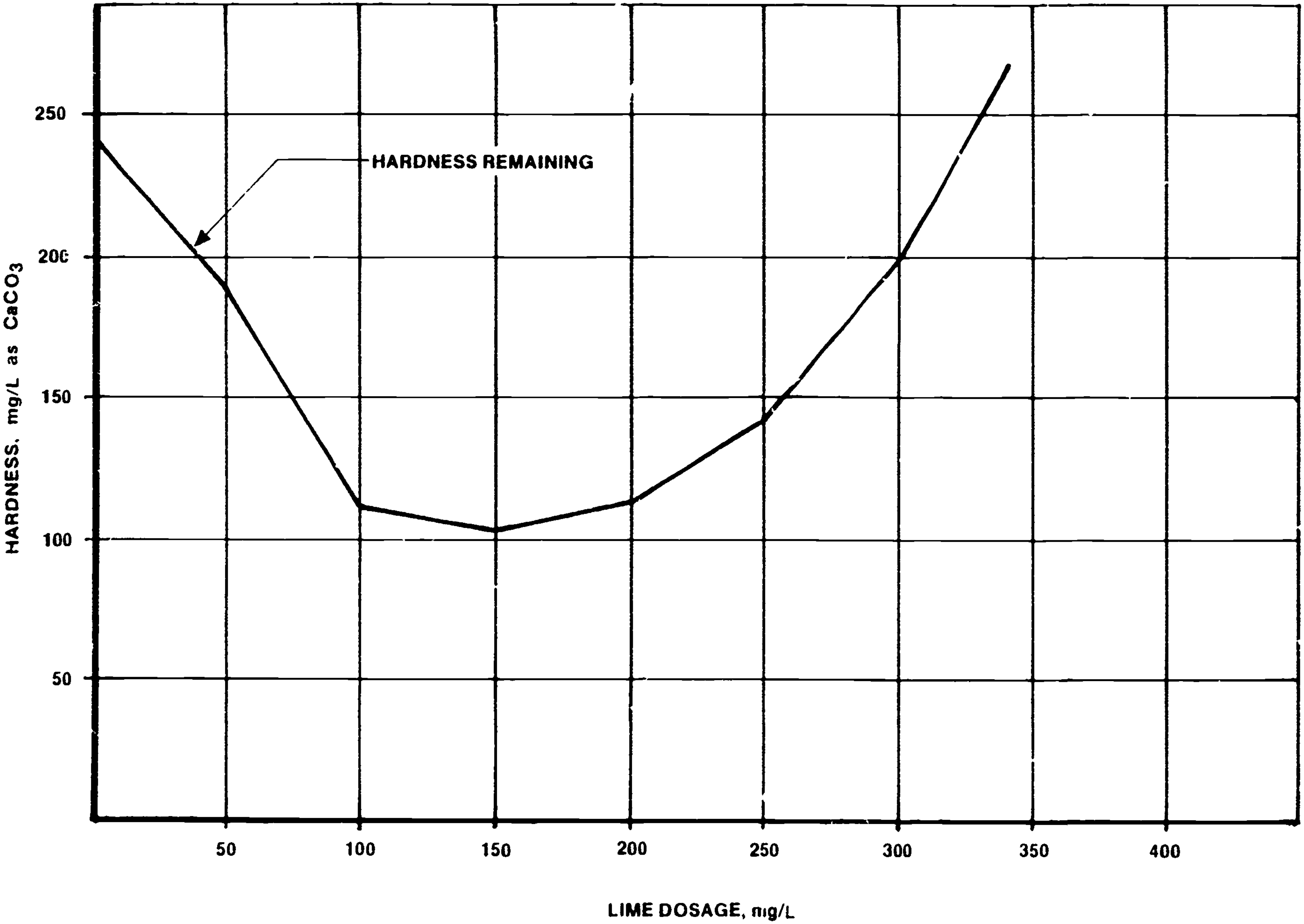


Fig. 14.8 Softening curve for City 1

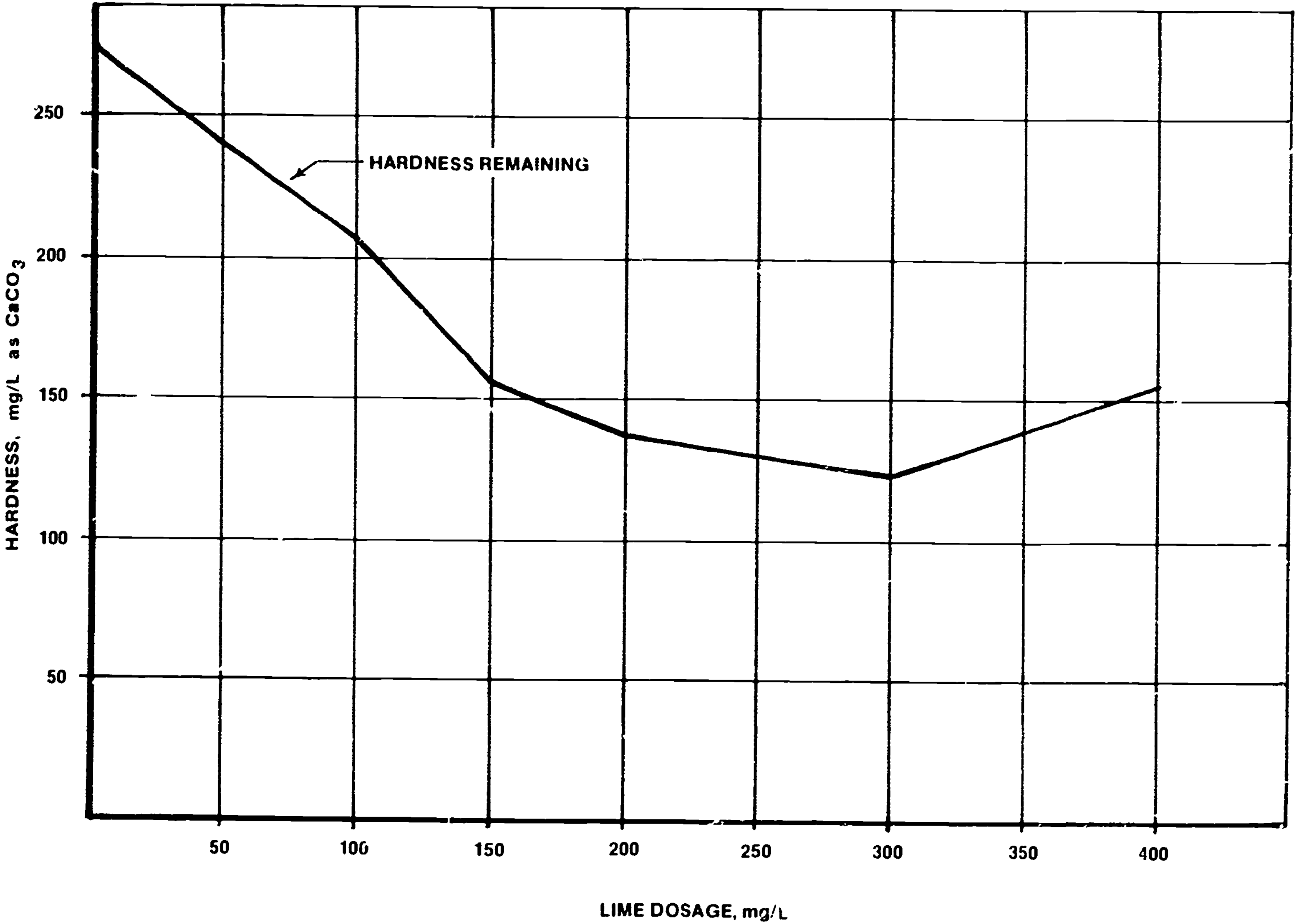


Fig. 14.9 Softening curve for City 2

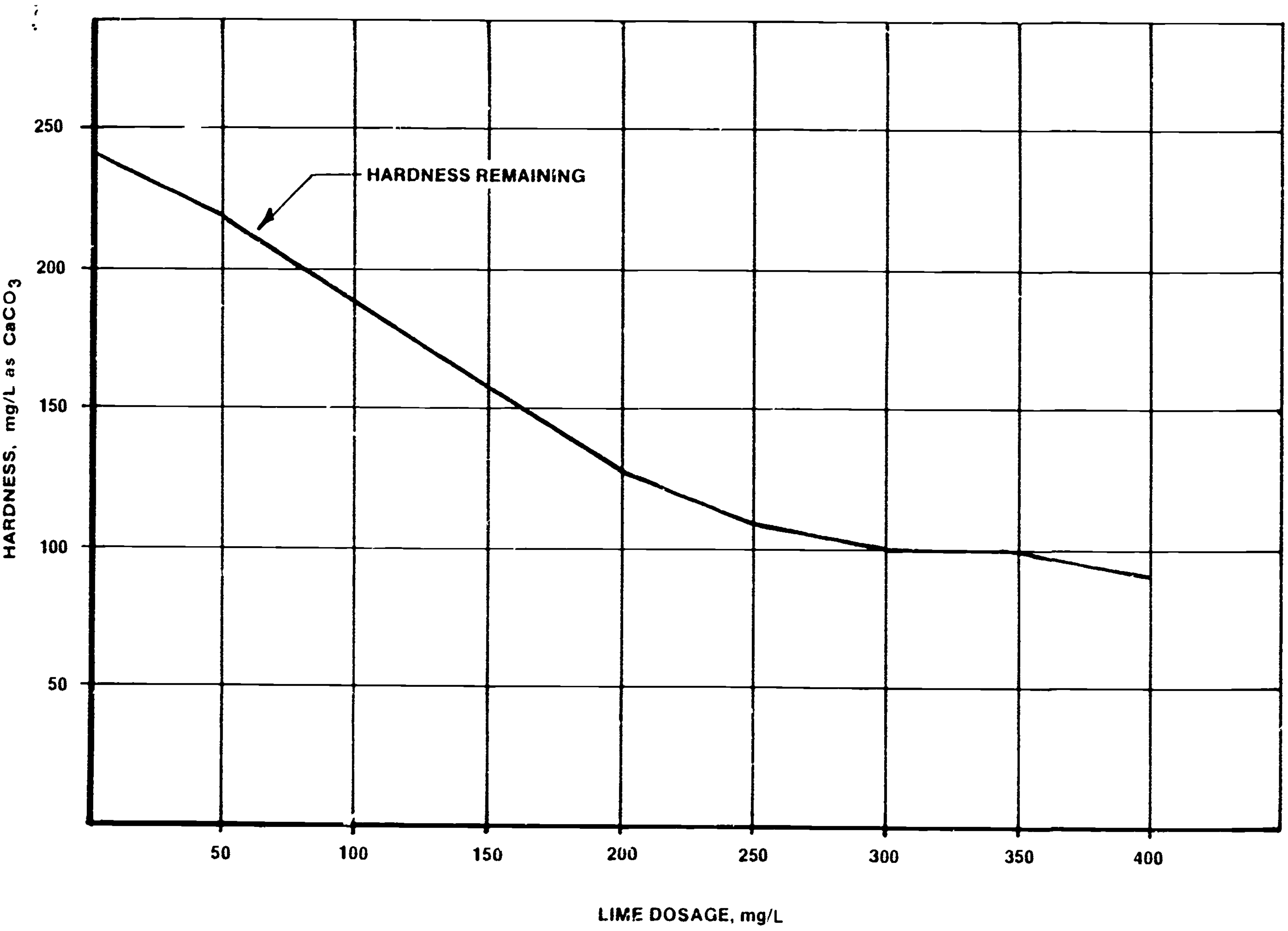


Fig. 14.10 Softening curve for City 3

Known	Unknown
Lime Dose, mg/L = 230 mg/L	1. Feeder Setting, lbs/day
Flow, MGD = 6 MGD	2. Feed Rate, lbs/min

1. Calculate the feeder setting in pounds per day

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Lime, mg}/L)(8.34\ \text{lbs/gal})$$
$$= (6\ \text{MGD})(230\ \text{mg}/L)(8.34\ \text{lbs/gal})$$
$$= 11{,}509\ \text{lbs/day}$$

2. Calculate the feed rate in pounds per minute.

$$\text{Feed Rate, lbs/min} = \frac{\text{Feeder Setting, lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$
$$= \frac{11{,}509\ \text{lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$
$$= 8.0\ \text{lbs/min}$$

When the calculated feed rate of eight pounds of lime per minute is put into the plant process, observations and tests will determine if optimum levels are met. In many instances, jar tests and actual plant feed rates do not agree exactly. This is because of temperature, size and shape of jars vs. size and shape of plant facilities, mixing time, and influence of the coagulant (a heavy alum feed would neutralize more of the lime). Jar tests are merely indicators or a point of beginning.

If underfeeding results, reactions will not be complete and the results will be undertreated water having a hardness higher than that desired.

If overfeeding results, chemicals are being wasted. Also, it is quite possible to have excessive calcium in the water This results in unstable conditions which cause buildup on the sand grains and the interior of the water mains. This is where the stability test enters the picture (refer to Section 14.5. "Stability").

The above discussion has dealt with establishing the proper lime feed. The same process would be used to determine the soda ash requirements if you are removing noncarbonate hardness Set up the lime feeds as discussed. Pick the optimum dosage. Then set up another series of jars using the same lime feed rate in all jars. Now, vary the soda ash feed rate.

EXAMPLE 5

How much soda ash is required (pounds per day and pounds per minute) to remove 50 mg/L noncarbonate hardness as $CaCO_3$ from a flow of 6 MGD?

Known		Unknown
Noncarbonate Hardness Removed, mg/L as $CaCO_3$	= 50 mg/L	1 Feeder Setting, lbs/day
Flow, MGD	= 6 MGD	2 Feed Rate, lbs/min

1 Calculate the soda ash dose in milligrams per liter. See Section 14 316. "Calculation of Chemical Dosages" for the following formula.

$$\text{Soda Ash, mg}/L = (\text{Noncarbonate Hardness, mg}/L \text{ as } CaCO_3)(106/100)$$
$$= (50\ \text{mg}/L)(106/100)$$
$$= 53\ \text{mg}/L$$

2. Determine the feeder setting in pounds per day.

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Soda Ash, mg}/L)(8.34\ \text{lbs/gal})$$
$$= (6\ \text{MGD})(53\ \text{mg}/L)(8.34\ \text{lbs/gal})$$
$$= 2652\ \text{lbs/day}$$

3 Calculate the soda ash feed rate in pounds per minute.

$$\text{Feed Rate, lbs/min} = \frac{\text{Feeder Setting, lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$
$$= \frac{2652\ \text{lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$
$$= 1.8\ \text{lbs/min}$$

After you determine the proper feed rates and implement them, if you are treating well water or other water of constant quality, all you have to do to maintain proper treatment is make minor adjustments to keep the system fine tuned.

On the other hand, if you treat a river or lake supply subject to constant and frequent changes in water quality, it's an entirely different set of circumstances. Until you learn from experience to judge the chemical changes necessary by the fluctuations in raw water hardness, alkalinity and turbidity, you almost have to check yourself daily by the jar test method.

When your treatment process does not work properly, the first thing to check is whether or not the feeder is feeding properly If it is, the next step is to check your source water quality Generally, one of these two will be the cause of your problem

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 109.

14 9C Why should the overfeeding of chemicals be avoided?

14 9D What should be the lime feeder setting in pounds per day to treat a flow of 2 MGD when the optimum lime dose is 160 mg/L?

14 9E How much soda ash is required in pounds per day to remove 40 mg/L of noncarbonate hardness from a flow of 2 MGD?

End of Lesson 1 of 2 Lessons on SOFTENING

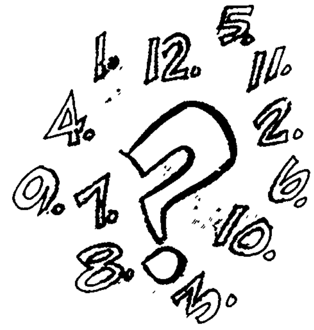
DISCUSSION AND REVIEW QUESTIONS

Chapter 14. SOFTENING

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing

1. Why should water be softened?
2. What are the benefits of softening water in addition to hardness removal?
3. Why is settled water recarbonated after the precipitation of calcium carbonate?
4. What are the advantages of using liquid caustic to soften water?
5. Why should quicklime never be stored close to combustible material?
6. How can operators protect themselves from lime?
7. Why is the stability of a water important?
8. Why is a paste-type slaker dangerous?
9. Why should you avoid using the same conveyor or bin for alternately handling both quicklime and one of the coagulants containing water, such as alum?
10. Why is sludge sometimes recirculated back into the primary mix area of conventional plants?
11. When running jar tests, how would you determine the optimum dosage for a coagulant, lime and soda ash?
12. When your lime-soda ash softening plant does not perform properly, what is the first thing you should check?



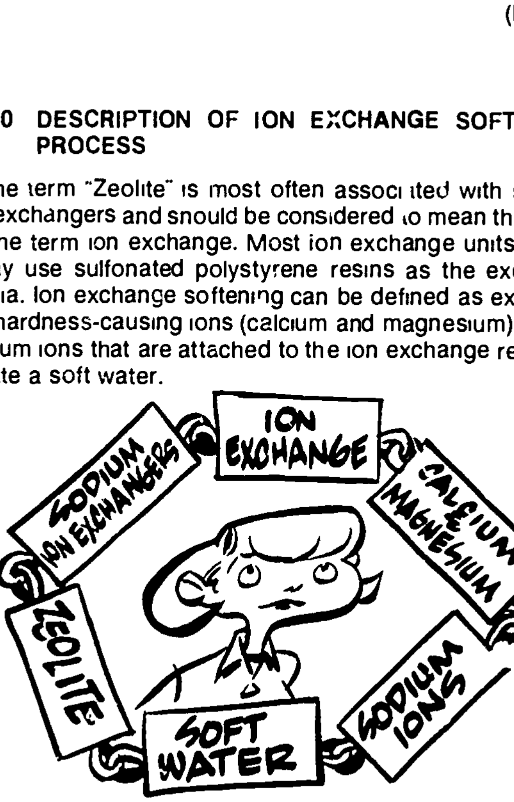
CHAPTER 14. SOFTENING

Ion Exchange Softening by Marty Reynolds

(Lesson 2 of 2 Lessons)

14.10 DESCRIPTION OF ION EXCHANGE SOFTENING PROCESS

The term "Zeolite" is most often associated with sodium ion exchangers and should be considered to mean the same as the term ion exchange. Most ion exchange units in use today use sulfonated polystyrene resins as the exchange media. Ion exchange softening can be defined as exchanging hardness-causing ions (calcium and magnesium) for the sodium ions that are attached to the ion exchange resins to create a soft water.

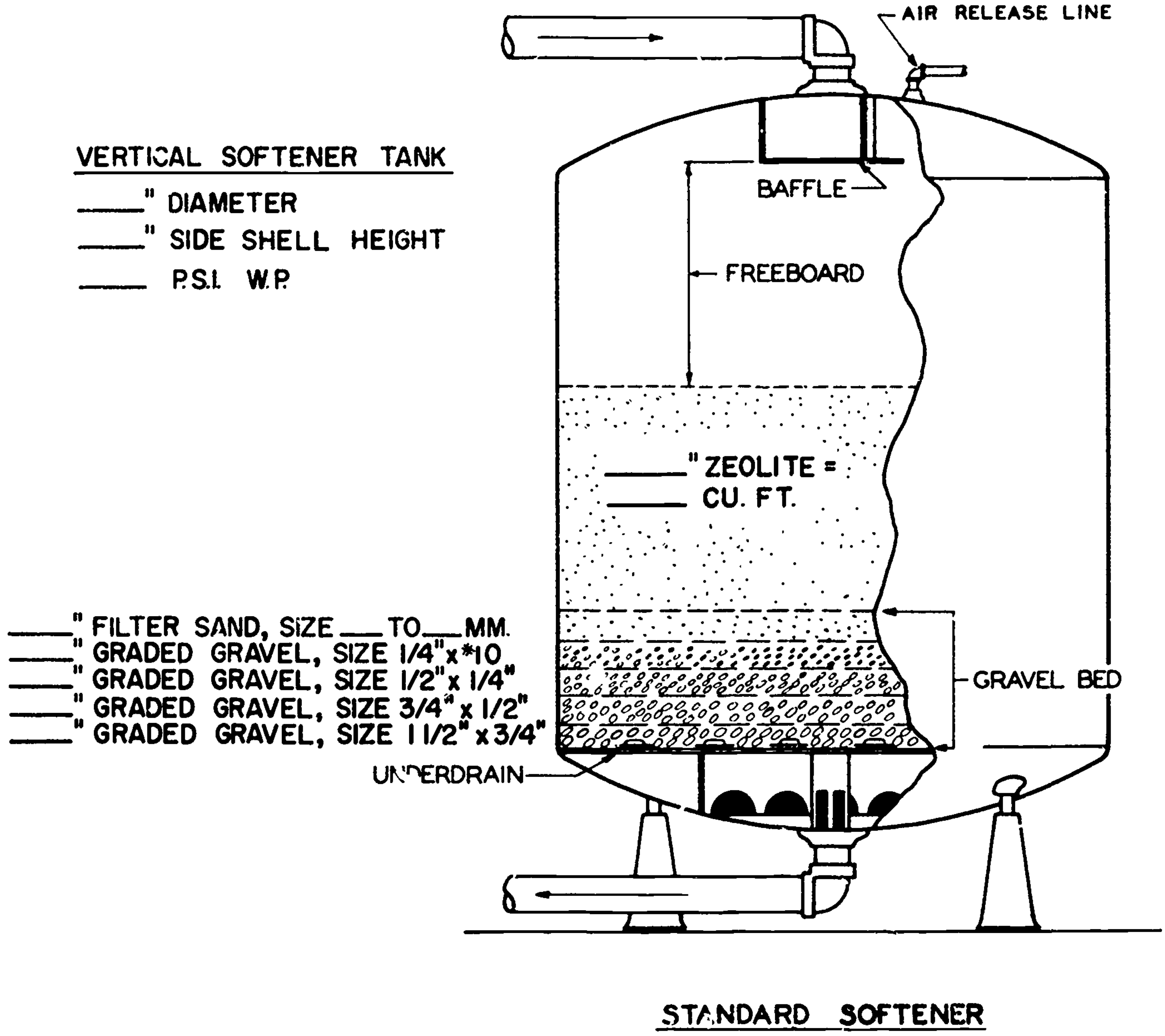


The treatment plant operator should be aware of the three basic types of softeners on the market.

1. An upflow unit in which the water enters from the bottom and flows up through the ion exchange bed and out the top
2. A unit which is constructed and operated like a gravity rapid sand filter The water enters the top, flows down through the ion exchange bed and out the bottom.
3. The pressure downflow ion exchange softener, which is the most common will be covered by this chapter. See Figures 14.11 and 14.12. Pressure filters may be either horizontal or vertical units. Vertical units are preferred because there is less chance of short-circuiting.

To help explain the construction and activity that occurs in an ion exchanger, let's compare it to a pressure filter. The water enters the unit through an inlet distributor located in the top; it is forced (usually pumped) down through a bed of some type of media into an underdrain structure. From the underdrain structure, the treated water flows out of the unit and into storage or into the distribution system.

The flow pattern through a filter and softener are similar, the key difference being the action that takes place in the media or bed of each unit. The filter bed may be considered



UNDERDRAIN:-
RIGIDLY SUPPORTED PLATE OVER 100 % FILTER AREA WITH STAINLESS STEEL BAFFLE ASSEMBLIES.

ZEOLITE:- ____ CUBIC FEET.

SUPPORTING GRAVEL:- ______ "GRADED.

STAINLESS STEEL
BAFFLE ASSEMBLY

Figure 14.11 Pressure downflow ion exchange softener
(Permission of General Filter Company)

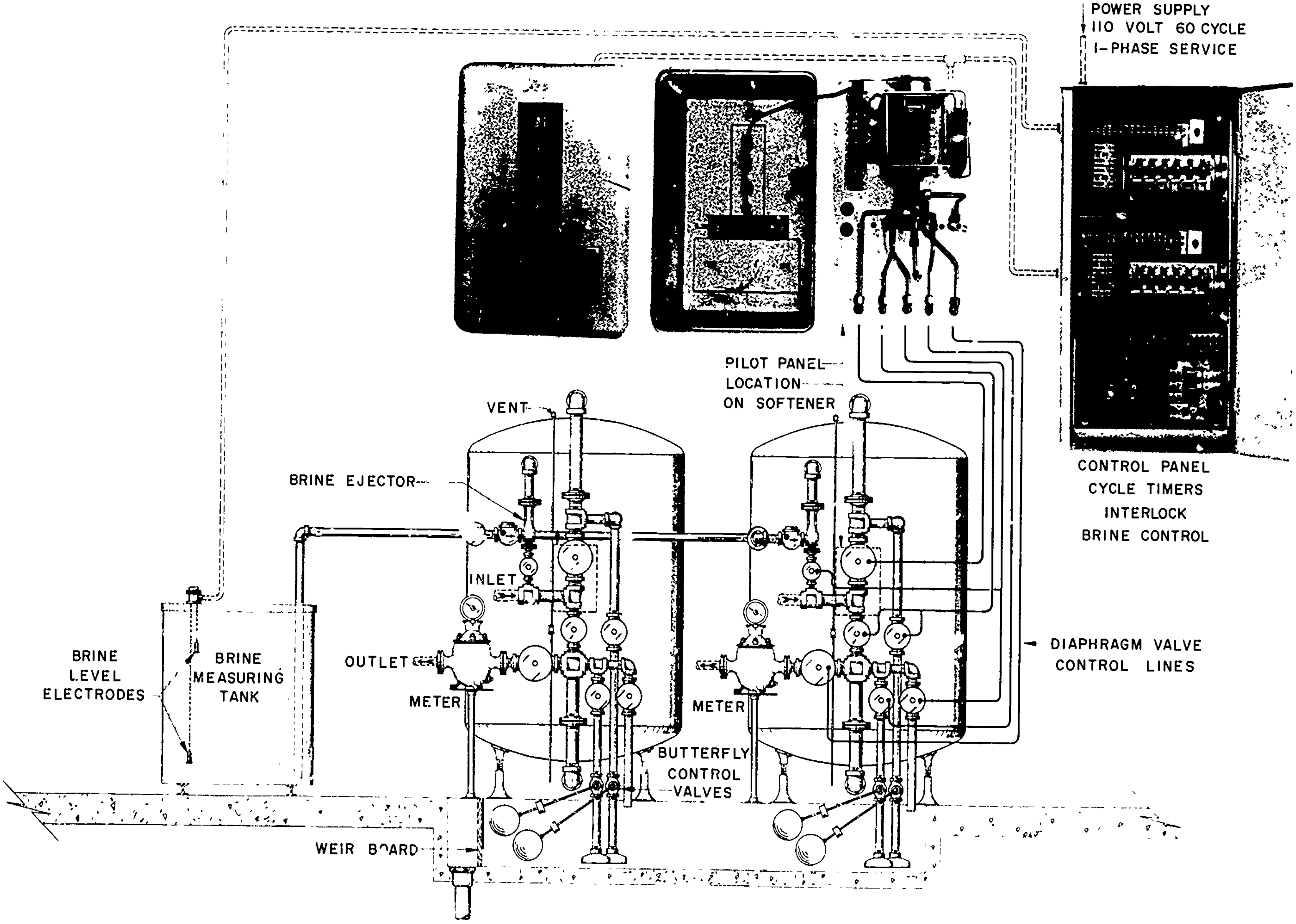


Figure 14.12 Semi-automatic controls for ion exchanger
(Permission of General Filter Company)

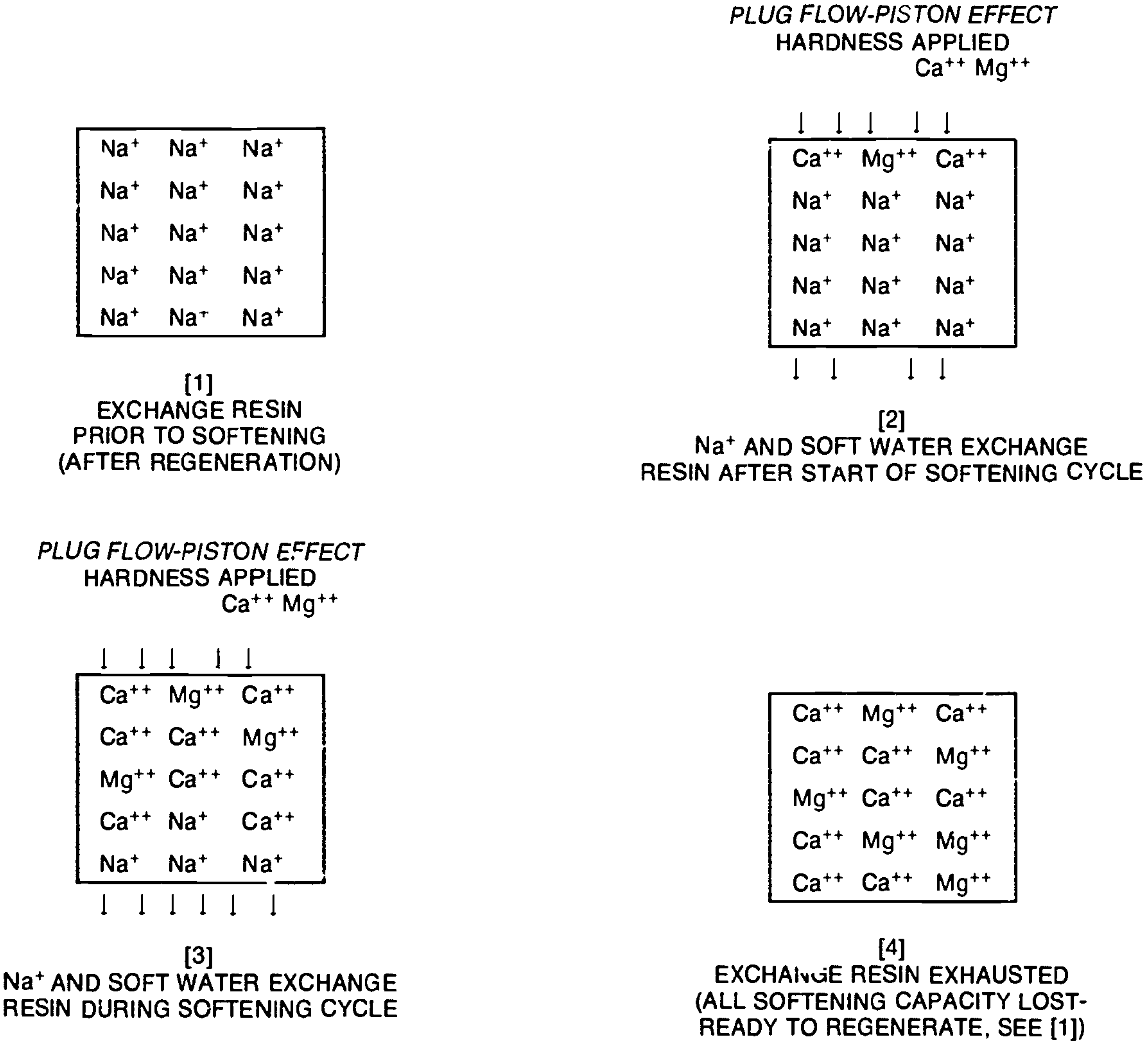
an adsorption and mechanical straining device used to remove suspended solids from the water. The bed usually consists of sand, anthracite (crushed coal) or a combination of both. Once the bed becomes saturated with the insoluble material (usually clay, suspended solids and iron manganese hydroxide), the filter is taken out of service, backwashed and returned to service. This pressure filter will continue to operate until the condition reoccurs and the procedure is repeated.

The bed, media or resin in an ion exchange softener, however, is much more complex. This resin serves as a medium in which an ion exchange takes place. As hard water is passed through the resin, the sodium ions on the resin are exchanged for the calcium and magnesium ions (in the case of sodium exchange resins). The sodium ions are released from the exchange resin and remain in the water which flows out of the softener. The calcium and magnesium ions, however, are retained by the resin. The softener effluent is free from calcium and magnesium ions and therefore is softened (Figure 14.13).

Once a softener has exchanged all of its sodium ions and the resin is saturated with calcium and magnesium, it will no longer produce soft water. At this time the unit must be taken out of service, the calcium and magnesium removed from the resin by exchange with sodium ions. This process is referred to as a regeneration cycle.

In a regeneration cycle, the calcium and magnesium ions that have been retained by the resin must be removed and the sodium ions restored. In order for the exchange to take place, the resin must hold all ions loosely. If the calcium and magnesium ions cannot be removed, the resin will not accept the addition of new sodium ions that are necessary for additional softening

Salt in the form of a concentrated brine solution is used to regenerate (recharge) the ion exchange resin. When salt is added to water it changes into or ionizes to form sodium cation (Na^+) and chloride anions (Cl^-). When the brine solution is fed into the resin, the sodium cations are exchanged for calcium and magnesium cations. As the brine



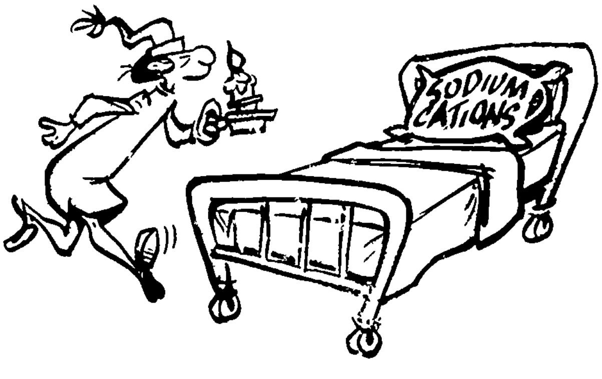
[1]
EXCHANGE RESIN
PRIOR TO SOFTENING
(AFTER REGENERATION)

[2]
Na^+ AND SOFT WATER EXCHANGE
RESIN AFTER START OF SOFTENING CYCLE

[3]
Na^+ AND SOFT WATER EXCHANGE
RESIN DURING SOFTENING CYCLE

[4]
EXCHANGE RESIN EXHAUSTED
(ALL SOFTENING CAPACITY LOST-
READY TO REGENERATE, SEE [1])

Fig. 14.13 Ion exchange resin condition during softening cycle solution travels down through the resin, the sodium cations are attached to the resin while the calcium, magnesium and chloride (from the salt) ions flows to waste After the regeneration has taken place, the bed is ready to be placed in service again to remove calcium and magnesium by ion exchange.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14.10A List the three basic types of softeners on the market.

14 10B What happens during the regeneration cycle of an ion exchange softener?

14.11 OPERATIONS

Many factors influence the procedures used to operate an ion exchange unit and the efficiency of the softening process. These factors include·

1. Characteristics of the ion exchange resin,
2. Quality of the source water,
3. Rate of flow applied to the softener,
4. Salt dosage during regeneration,
5. Brine concentration, and
6. Brine contact time.

Each ion exchange softener, regardless of manufacturer, will have at least four common stages of operation. These stages are listed below and will be explained as each occurs in the softener operation (see Figure 14.14).

1. Service,
2. Backwash,
3. Brine, and
4. Rinse.

14.110 Service

The service stage of each unit is where the actual softening of the water occurs. Hard water is forced into the top of the unit and allowed to flow down through the exchange resin. As this takes place, the calcium and magnesium ions exchange with sodium on the resin. The sodium ions are released into the water and the exchange capacity of the unit is slowly exhausted.

The length of each service stage is dependent on several factors, source water hardness is a main consideration. The harder the water, the more calcium and magnesium must be removed to reach a level of zero hardness. Simply stated, the harder the water, the less water you can treat before the resin becomes exhausted. As long as the design flow for the ion exchange unit is not exceeded, changes in the hardness of the source water may be automatically adjusted for in the ion exchange unit. The effluent from the unit usually will have zero hardness until the unit needs regeneration. If the total dissolved solids (TDS) in the water supply is fairly high (above 500 mg/*L*), there may be some leakage. If a high TDS water has a high sodium content, the sodium may hinder the process by causing a local exchange on the media of calcium and magnesium (hardness leakage) for some of the sodium The amount of hardness leakage depends on the TDS and the salt dosage (percent salt) used for regeneration.

Other factors involved are the size of the softener and the exchange capacity of the resin Softeners can vary in size from a few cubic feet to several hundred cubic feet. The size of the unit will generally be consistent with regard to the overall treatment plant design. In other words, the softener should be capable of producing enough softened water so that the mix or blend of softened and unsoftened water will produce a treated water with the desired level of hardness.

The exchange resin will also vary in its removal capacity. There are many types of strong acid cation exchange resins on the market today. Most will range in capacity from 20,000 to 30,000 grains of hardness removal per cubic foot (0.011 to 0.016 kg/cu m) resin. The removal ability of the resin is usually expressed in grains of hardness removal per cubic foot of material or resin.

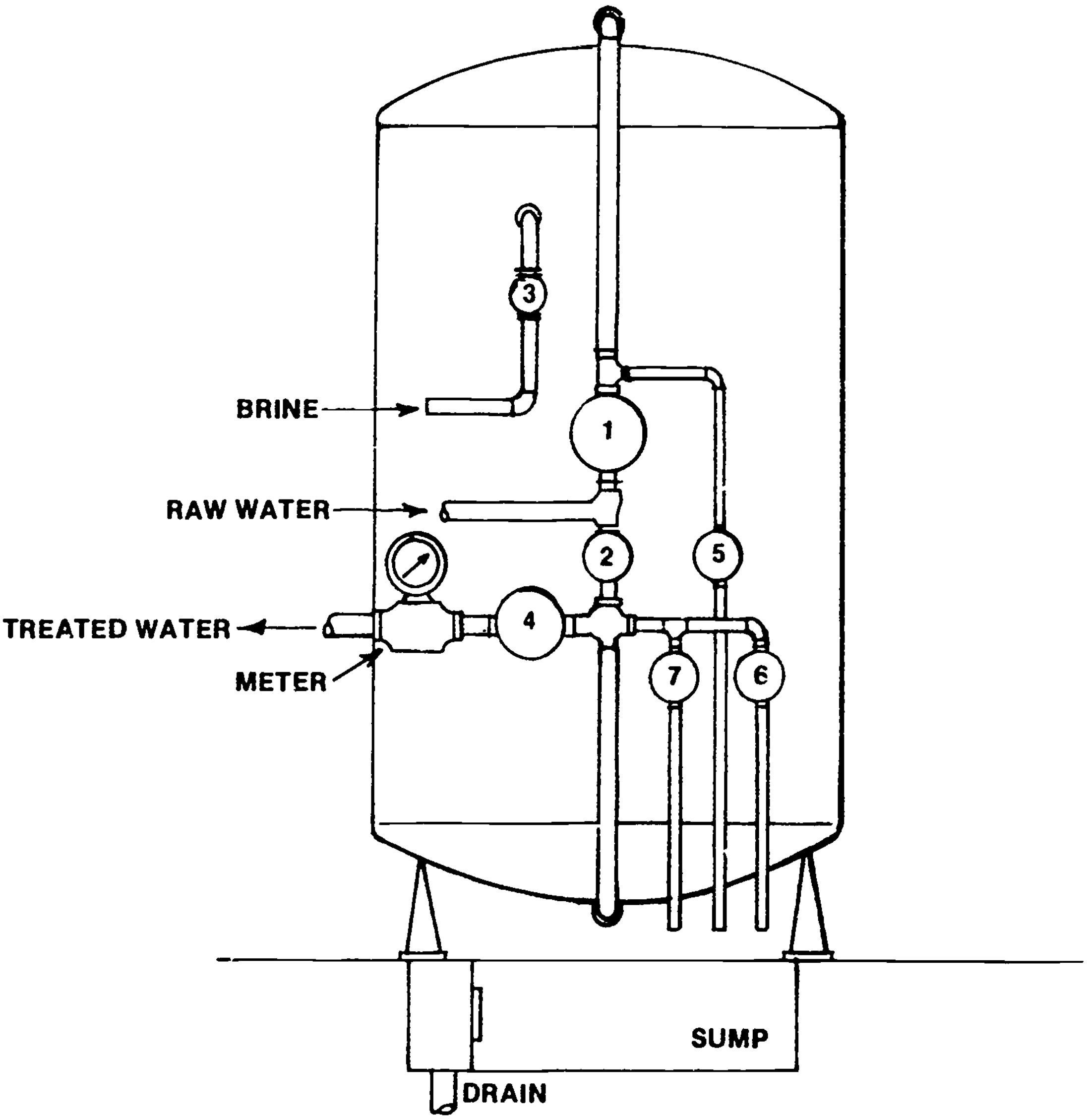
The source water hardness, size and the removal capacity of the resin will determine the amount of water that can be treated before the softener must be regenerated. With a few simple calculations, an operator can determine the softening capacity of the units. Calculations and examples will be given at the end of the chapter. See Example 8 in Section 14 18, "Ion Exchange Arithmetic."

14.111 Backwash

The second stage of the ion exchange softener process is the backwash. In this stage, the unit is taken out of service and the flow pattern through the unit is reversed. The purpose of this is to expand and clean the resin particles and also to free any material such as iron, manganese and particulates that might have been removed during the softening stage. The backwash water entering the softener at the beginning of this stage should be applied at a slow steady rate If the water enters the unit too quickly, it could create a surge in the resin and wash it out of the unit with the water going to waste.

Ideal bed expansion during the softener backwash should be 75 to 100 percent. In other words, when the unit is backwashed, the resin should expand to occupy a volume from 75 to 100 percent greater than when in normal service. An example of this would be an ion exchange softener with 24 inches (60 cm) of resin while in service. When the unit is backwashed, the resin should expand to 48 inches (120 cm) for a 100 percent expansion of the bed. As the bed expands a shearing action due to the backwash water and some scrubbing action will free any material that might have formed on the resin particles during the softening stage.

During the backwash a small amount of resin could be lost. This amount, however, should be minimal and you



OPERATION	VALVE NUMBER						
	1	2	3	4	5	6	7
SERVICE	OPEN	CLOSE	CLOSE	OPEN	CLOSE	CLOSE	CLOSE
BACK WASH	CLOSE	OPEN	CLOSE	CLOSE	OPEN	CLOSE	CLOSE
BRINE	CLOSE	CLOSE	OPEN	CLOSE	CLOSE	OPEN	CLOSE
RINSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	OPEN

Fig. 14.14 Valve positions for each stage of ion exchange softener operation
(Permission of General Filter Company)

should check the backwash effluent at different intervals to insure that the resin is not being lost. A glass beaker can be used to catch a sample of the effluent while the unit is backwashing. A trace amount of resin should cause no alarm, but a steady loss of resin could indicate a problem in the unit and the cause should be located and corrected as soon as possible. Too much loss of resin may be caused by an improper freeboard on the tank or wash troughs.

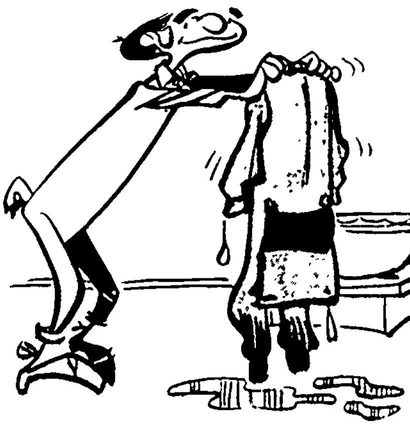
The backwash duration and flow rate will vary depending on the manufacturer and the type and size of resin used and the water temperature.

14.112 Brine

The third stage is most often termed the regeneration or brine stage. At this point, the sodium ion concentration of the resin is recharged by pumping a concentrated brine solution onto the resin. The solution is allowed to circulate through the unit and displace all water from the resin in order to provide full contact between the brine solution and the resin.

Most treatment plants use a brine solution to regenerate their softening units. The optimum brine concentration coming in contact with the ion exchange resin is around 10 to 14 percent sodium chloride solution. Concentrated brine is only used when the water within the softener tank serves as the dilution water. A 26 percent brine solution (fully concentrated or saturated) causes too great of an osmotic shock on the ion exchange resin and can cause it to break up. The salt dosage used to prepare the brine solution is one of the most important factors affecting the ion exchange capacity and ranges from 5 to 15 pounds of salt per cubic foot (80 to 240 kg/cu m) of resin. See *EXAMPLE 10* on page 104 for procedures on how to calculate the salt dosage and gallons of brine solution required. Brine concentrations less than saturated require longer contact time and more solution must be applied to the unit to achieve a successful regeneration.

The regeneration stage of the softener is very important and the operator should be certain it is properly carried out. In the regeneration stage, the sodium ions present in the brine solution are exchanged with the calcium and magnesium ions on the resin. The ions on the resin were exchanged during the service or softening stage. The regeneration rate is usually one to two GPM per cubic foot (2.2 to 4.4 liters per second per cubic meter) of resin for the first 55 minutes and then three to five GPM per cubic foot (6.6 to 11 liters per second per cubic meter) for the last five minutes of fast drain. If the regeneration process is performed correctly, the result is a bed that is completely recharged with sodium ions and will again soften water when the unit is returned to service.



14.113 Rinse

The fourth and final stage of softener operations is the rinse stage. After adequate contact time has been allowed between the brine solution and resin, a clear rinse is applied from the top of the unit to remove the waste products and excess brine solution from the softener. The flow pattern is very similar to the service stage except that the softener effluent goes to waste instead of storage. The waste discharge contains high concentrations of calcium and magnesium chloride. Most rinse stages will last between 20 and 40 minutes, depending on the size of the unit and the manufacture. See Section 14.14, "Disposal of Spent Brine," for procedures on how to dispose of the waste discharge.

Again, the operator should pay close attention to the softener while it rinses. The rinse must be long enough to remove the heavy concentration of waste from the unit. If the rinse is not of the correct length and the unit returns to service, a salty taste will be very noticeable in the softener effluent. Taste the waste effluent near the end of the rinse stage to determine if the majority of chloride ions have been removed. The chloride ion concentration may also be measured by titration as outlined in Chapter 21, "Advanced Laboratory Procedures" or by measuring the conductivity of the water. If the water still has a strong salty taste or excessive chloride ions are present, check the rinse rate and timer settings. The unit may need adjustment to increase the duration of the rinse stage.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14.11A What is the main consideration in determining the length of the service stage of an ion exchange softener?

14.11B What is the purpose of the backwash stage of an ion exchange softener?

14.11C How are ion exchange softeners regenerated?

14.11D Where does the softener effluent go during the rinse stage?

14.12 CONTROL TESTING OF ION EXCHANGE SOFTENERS

In most small treatment plants, the operator has to perform many jobs and may not always have time to monitor the softening units as they should be monitored. If a few simple test procedures are learned and carried out on a regular basis the operator can feel confident the ion exchange units are operating properly. Control tests the operator should perform are listed in this section.

1. Softener Influent

   Be aware of the iron and manganese levels entering the softener. These levels should be kept to a minimum to prevent fouling of the media bed as the unit will remove a certain amount of iron and manganese before becoming plugged. Insoluble particles of iron and manganese will plug the filter media. Soluble ionic iron (Fe^{2+}) and manganese (Mn^{2+}) will exchange onto the media and will not be fully removed by regeneration. If the source water entering the plant is high in iron and manganese, proper oxidation and filtration of the water *BEFORE* the softener should reduce the levels and prevent problems from developing in the softeners.

Monitor source water hardness on a routine basis. Generally, hardness will not vary, but if it changes, you will need to adjust the amount of water treated by each softener before the media becomes exhausted and the unit must be regenerated

2. Softener Effluent

   At the end of a regeneration stage, as the unit goes back into service, check the effluent for hardness. This one test will tell you if the regeneration of the softener has been properly conducted. Allow a few minutes to ensure that all of the rinse water in the unit has been purged (removed). Run a hardness test on the effluent side of the unit. The results should indicate a water of zero hardness. Several test kits are available on the market today that are fairly quick and simple to use to measure water hardness.

14.13 LIMITATIONS CAUSED BY IRON AND MANGANESE

Ion exchange units are very versatile. The primary purpose of the unit is to remove calcium and magnesium from the water thus making the water soft. Ion exchange softeners, however, will also remove iron and manganese in either the soluble or precipitated form. If this occurs, the iron and manganese will seriously affect the life of the exchange capacity of the resin. If water high in iron and manganese is applied to the ion exchange resin for very long, iron fouling or the loss of exchange capacity will result.

When the softeners remove iron in the ferrous (soluble) or ferric (solid) form, the two problems discussed below could result

1. If water with iron in the ferrous form is applied to the softener, the resin will remove the iron from the water. The iron can be retained on the surface of the resin or is sometimes captured deep inside the resin itself. As this happens, the resin or bed will develop an orange or rusty appearance. If the resin becomes iron coated, the efficiency of the softener will be reduced greatly.

2. The second problem associated with high iron levels is a plugging or clogging of the resin bed. When water containing iron in the ferric form (solid) is applied to the unit, it will act like a filter and strain the iron from the water, leaving the iron trapped in the bed. If high iron loadings continue, the upper layer of the bed could become plugged, forcing the water to channel or short-circuit through the bed. The result is incomplete contact between the water and media thus creating hardness leakage and loss of softening efficiency.

   IRON AND MANGANESE MUST BE REDUCED TO THEIR LOWEST POSSIBLE LIMITS BEFORE APPLYING WATER TO THE SOFTENER. Oxidation of iron and manganese (see Chapter 12, "Iron and Manganese Control") *BEFORE* applying water to ion exchange units is very helpful. You should also be aware of the chlorine levels applied to the softening units. Normal chlorine dosages will not present a problem, but high residuals could damage the resin and reduce its life span.

14.14 DISPOSAL OF SPENT BRINE

One of the largest problems associated with the design and operation of ion exchange softening plants is the disposal of the softener waste.

The waste discharge from softeners consists mostly of calcium, magnesium and sodium chlorides. These by-products are corrosive to material they contact and possess varying toxic levels in relationship to the environment.

Many water treatment plants discharge spent brine into nearby sewers. This procedure may be approved if the downstream wastewater treatment plant and receiving waters can handle the brine. Usually the water treatment plant must have some type of holding tank to store the spent brine. The brine is slowly discharged into the sewer at a rate which will not upset (or be toxic to) the biological treatment processes at the wastewater treatment plant. Also the salt level in the effluent from the wastewater treatment plant must not adversely impact the aquatic life in the receiving waters nor cause a violation of the wastewater treatment plant's *NPDES PERMIT.*[17]

Some water treatment plants may be issued an NPDES Permit to discharge spent brine into receiving waters. This could happen only if the flow in the receiving waters was very high (plenty of dilution) and the flow of spent brine was very low. A holding tank would be needed for the spent brine and the brine could be discharged very slowly. The receiving waters would have to be monitored to be sure that the discharge of brine will not cause a significant increase in the level of brine

Sanitary landfills also may be an acceptable means of disposing of spent brine. See Chapter 17, "Handling and Disposal of Process Wastes," for additional information.

Each ion exchange treatment plant probably has only one approved method of waste disposal. Very few options are available to plants discharging this type of waste. Alternate waste disposal methods available for spent brine are covered in Chapter 17, "Handling and Disposal of Process Wastes."

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[17] *NPDES Permit.* ***N****ational* ***P****ollutant* ***D****ischarge* ***E****limination* ***S****ystem permit is the regulatory agency document issued by either a federal or state agency which is designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.*

The operator needs to be aware of the seriousness involved with softener waste. If a problem develops at the treatment plant, the operator should be working with the agency in the area that governs waste disposal as several considerations must be studied when changing a disposal method

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14 12A Which water quality indicators should be monitored in the effluent of an ion exchange softener?

14 13A What happens when high chlorine residual levels are applied to the softening units?

14.14A Why is the disposal of spent brine a problem?

14.15 MAINTENANCE

Most of the ion exchange water softening equipment on the market today is fully automated (Figure 14.12). The reason for most of this automation is to reduce the time an operator must spend with each unit. Automation is fine for operational control, but it does not mean a unit is maintenance free. Systems like this have a tendency to lead operators astray. A small routine maintenance item can go unnoticed until it becomes a full scale problem if the operator does not run a regular maintenance schedule on the equipment. For example, most valves on ion exchange units are pneumatic or are equipped with some type of self-operating device (valve actuators). This does not mean, however, the valve will operate each time it is required to do so without a regular examination and overhaul. The operator must check the equipment to insure it is always in proper working order One valve that fails to open or to close during a regeneration stage could mean trouble (a storage tank full of salty water or no brine at all).

The components of an ion exchange softening system that should receive constant attention are the brine pumps and piping. A saturated brine solution is very corrosive and will attack any unprotected metallic surface it comes in contact with. Try to keep the system as tight as possible. An uncontained brine leak will only get worse.

If you must change the pipe work in the brine system, give serious consideration to installing PVC pipe. The material is much cheaper than bronze and will outlast steel or galvanized pipe when properly installed and supported. Future repairs are also much easier to make if PVC pipe is used.

The pump on the brine system is most often made of brass which offers some additional protection from the brine solution. The impeller should be bronze and the shaft stainless steel. A strainer or screen device should be installed ahead of the pump on the suction side.

Most treatment plants buy salt to make their brine solution in bulk form. Regardless of the salt supplier, a certain amount of insoluble material will accompany each bulk delivery This insoluble material will consist of rocks, coal, sand and other particles that can clog or destroy an impeller if they reach the pump. Check the strainer assembly on the brine pumps quite often and keep spare parts on hand in case replacement is required.

The use of packing on the pumps is recommended over mechanical seals. Regardless of how well the strainers perform, a small amount of sand will usually end up in the pump The combination of sand and mechanical seals will most often result in high repair and maintenance costs Packing is cheaper and easier to install and maintain than mechanical seals and packing will usually outlast mechanical seals in this type of installation

The brine pump motor should have a "heavy duty" rating and a body made of cast iron is preferable. Aluminum or mild steel motor housings do not hold up as well as cast iron when subjected to the corrosive environment around the brine pumping station.

An area most often neglected until problems arise is the bulk brine storage area of the treatment plant. Most storage areas are underground pits equipped with rock or gravel strainers above some type of underdrain collection system. Over a period of time, the strainers will silt in with sand and impurities received with salt deliveries. The best way to prevent this from occurring is to regularly shut down, drain and replace the strainer systems in the pit. This is a great deal of work, but it is a necessity if the brine system is to stay in operation.

Some brine storage areas have become so clogged that the brine solution could not penetrate the strainer media and reach the underdrain system. Like the head loss on a filter, the strainers can become so clogged that the solution cannot seep through to the underdrain system. If this happens and the system cannot be shut down for cleaning, a pipe can be driven down through the sand and impurities into the gravel layers. If enough holes are driven through the zones of impurities, the solution will eventually seep into the underdrains and can be pumped into the softeners. This is a temporary repair measure only and the storage area should be cleaned as soon as possible.

Inspect the brine solution make-up water line while the storage area is shut down. This line must be kept in good working order because it provides potable water to the salt supply This water makes the saturated brine solution that is used to regenerate the softener PVC pipe would provide excellent service in a corrosive environment such as a storage area.

Wet salt storage brine tanks are another location at a water treatment plant where sanitary defects may develop. The make-up water line must have a free fall or air gap someplace in the system to prevent the backflow of a brine solution into the potable water supply. The brine tanks must be protected from contamination just like any other water storage facility. The cover and access hatches must be of the raised-lip, overlapping-cover type. All vents must be properly screened to keep out insects, birds, and rodents.

All areas of maintenance in an ion exchange softening plant cannot be covered here because each plant will differ with the type of equipment used and its method of operation Set up a maintenance routine that is characteristic of your treatment plant The objective of the maintenance routine must be to keep the plant operating and hold repair costs to a minimum

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14 15A What could happen if a valve fails to open or close during a regeneration stage?

14 15B Why should the brine pumps and piping receive constant attention?

14 15C Why is packing on brine pumps recommended over mechanical seals?

14.16 TROUBLESHOOTING

14.160 Test Units

Ion exchange softeners. if properly operated and maintained. will usually provide years of trouble-free service. If problems arise. however. the operator should be able to identify and correct the situation without a great deal of difficulty.

The best way to insure that a softener will continue to operate properly is to occasionally test the unit during various stages of operation Learn to recognize minor problems as they develop and make the necessary repairs before a full scale problem exists

Items an operator should check on in each stage are discussed in this section

14.161 Service Stage

In the service stage. while the unit is producing soft water. hardness tests should be run on the softener effluent to insure the water has a hardness of zero. One grain hardness per gallon of water (17 1 mg/*L*) showing up in the effluent should not cause alarm. but concentrations of hardness higher than one grain hardness per gallon signal the need to investigate the softener s operation more closely.

14.162 Backwash Stage

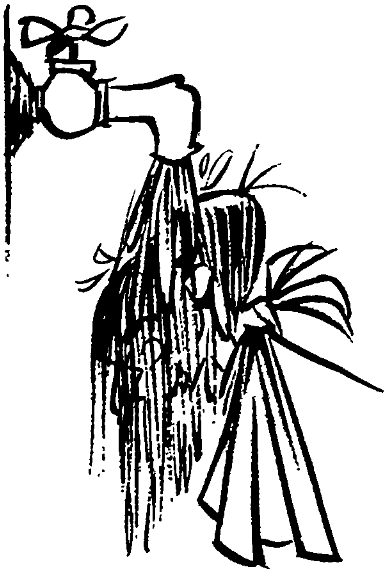
Check the backwash stage for adequate flow rates and full extent of the time required to complete the stage Unless the rate is high enough to remove trapped turbidity particles and other insoluble material that is trapped in the resin. a loss of softener efficiency could result

Check the timer on the backwash stage to make sure the unit is washed for the required length of time.

If high iron concentrations have been applied to the softener. check the condition of the resin by visually inspecting the top layer of the bed Color is a key factor to watch for in units beginning to show signs of an iron-fouled resin. The resin will be an orange. rusty color. while the backwash effluent will appear a light orange at the end of the backwash stage Also. the head loss on the unit will run higher than normal as the bed becomes plugged with iron.

If iron fouling appears to be a problem. the length of the backwash stage should be increased to wash as much of the particulate matter from the resin as possible. A means of surface washing the resin must be provided for this procedure to be effective Avoid exceeding recommended manufacturer s flow rates to prevent washing resin from the unit

A chemical cleaner can be used to remove heavy iron coatings from the resin itself. These cleaners are mostly sodium bisulfite and can be mixed in solution form and poured into the softener. The bisulfite could also be added to the resin during the regeneration stage by dumping a concentrated powder form in with the brine solution. Consult the resin supplier or manufacturer before using any cleaner on the resin



14.163 Rinse Stage

The rinse stage of the softener should be checked when tests indicate problems are developing. The rinse rate is a key factor in keeping the softener functioning properly. If the rinse starts too soon. the brine solution could be forced out of the unit before adequate contact time has elapsed. If the rinse rate is too low. all the waste material might not be removed from the unit before it goes into the service stage.

The rate settings on the unit should be compared. on all stages. against the actual manufacturer's recommended settings As equipment ages. it wears. Over a period of time. valves might need adjustment to keep the unit operating within the manufacturer's guidelines.

14.164 Brine Injection Stage

The brine injection stage of the softener sequence must be correctly applied or the unit will not perform satisfactorily when it returns to service. If the resin is not regenerated during this stage. there will be no sodium ions to exchange with the hardness ions in the water when the water is applied to the unit

The brine storage area should always contain enough salt to provide a brine solution when make-up water is added.

Also check the amount of salt solution that is pumped into the softener This is usually done with a meter that is preset to deliver the exact amount of brine solution required to regenerate the softener. If a brine solution is less than saturated. longer contact time is required between the media and the solution

The required amount of solution must be delivered consistently to achieve a successful regeneration of the unit. If hardness leakage appears early in the service or softening stage, check the amount and saturation of brine solution in the brine system since these are the main reasons for hardness leakage.

If hardness leakage is excessive immediately following a regeneration stage, shut the unit down and check the media level. The bed could be disrupted from excessive backwash or rinse rates. Iron fouling could also cause a channeling condition to occur and cause the water to short-circuit through the media without contacting the complete bed volume.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14.16A What is the maximum hardness level expected in the effluent of a properly operating ion exchange softener before the operator should investigate the operation?

14.16B What is the purpose of the backwash stage of an ion exchange softener operation?

14.16C What problems may occur if the rinse rate starts too soon or is too slow?

14 16D What would you do if hardness leakage is excessive immediately following a regeneration stage?

14.17 STARTUP AND SHUTDOWN OF UNIT

At times it becomes necessary to shut a unit down and take it out of service for repairs or inspection. If the operator will follow common sense guidelines, no problems should arise from unit shutdowns.

When dealing with these units, drain and fill them slowly. This will prevent surging of the media which will either wash it out of the unit or disrupt it, thus making the media uneven and creating channeling problems. If you suspect problems with a unit, the last thing you want to do is make the situation worse by rapidly backfilling or backwashing the softener.

Most units are equipped with automatic air release valves (Figure 14.15). Be certain these valves are operating properly, because the venting of trapped air is an important step in filling a unit after it has been shut down.

During unit shutdown, make a complete visual inspection. Now is the time to detect and correct minor problems that might otherwise develop into bigger ones. Check the brine inlet distributors while the unit is down. They should be visible from the top hatch on most softeners.

Make sure the pipe work is level and the nozzles or openings are not clogged. The distributors play an important role in the regeneration stage by applying the brine solution evenly to the top of the resin bed If the pipe work is deteriorating from the brine solution, PVC pipe should be used as a replacement.

If the resin and gravel support material is removed from the softener, check the underdrain structures in the unit and repair any problems you discover. In filling the unit with gravel and resin, each zone of the bed should be leveled and sized according to manufacturer's specifications.

The procedure for filling a unit with water after a total shutdown is very important. The flow into the unit should be from the bottom at a slow, controlled rate. This is done by putting the unit in the backwash position, running water into the unit from the bottom and out the backwash effluent valve. The purpose of this procedure is to fill the unit with water and purge the air that was trapped in the resin and softener during the replacement process.

After the unit is filled the backwash rate should be increased to normal and continued until the effluent is clear. Again, care should be taken when bringing the rates up to the manufacturer's recommendations, to prevent disrupting or displacing resin from the bed.

Once the unit has been satisfactorily backwashed, the bed should be regenerated. This can be accomplished by running the softener through a normal brine and rinse procedure before it is returned to service. Run a hardness test on the effluent to insure all stages have performed correctly and the unit is softening water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14.17A Why must ion exchange softeners be drained and filled slowly during startup and shutdown?

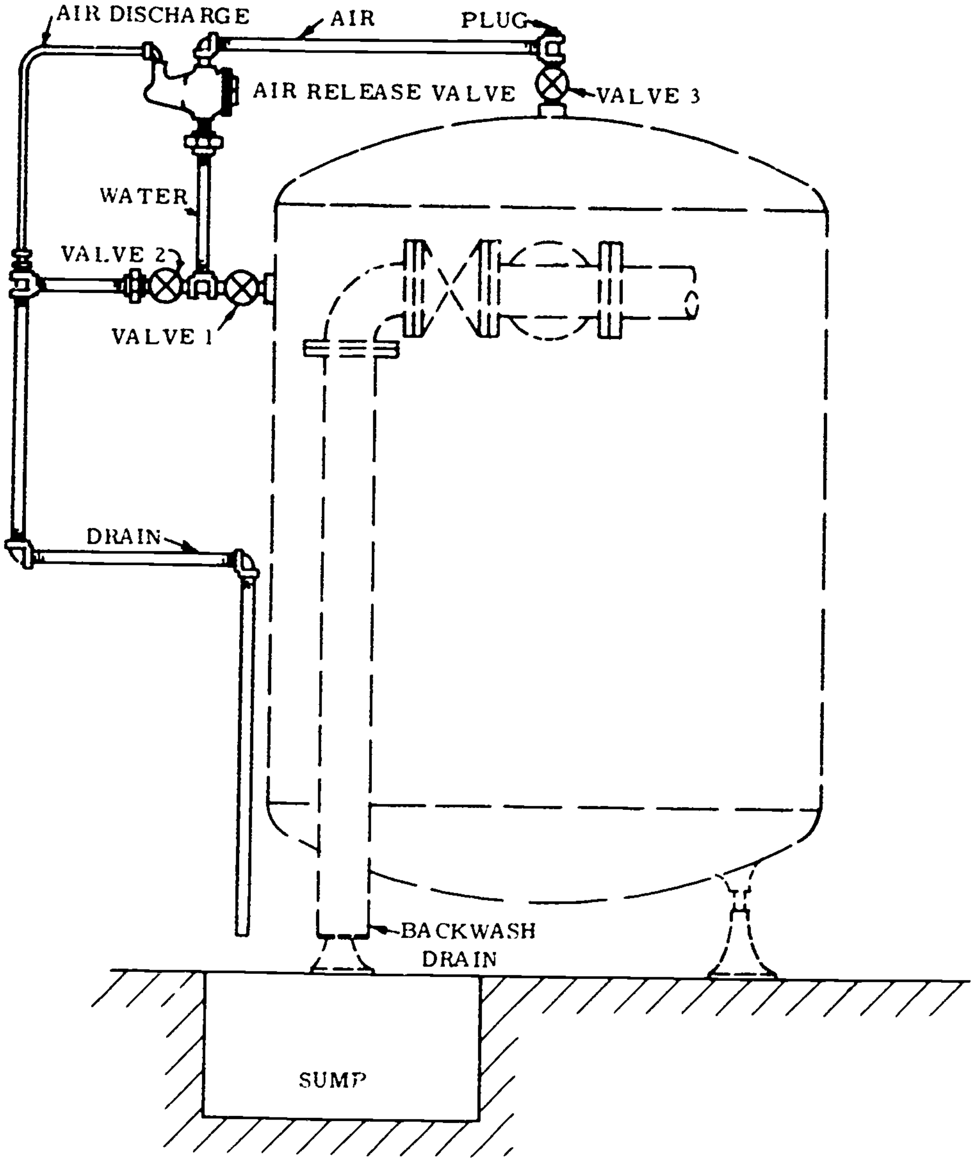
14.17B What should be done if the pipe work in an ion exchange softener is deteriorating from the brine solution?

14.18 ION EXCHANGE ARITHMETIC

Hardness is usually expressed as mg/L of $CaCO_3$. In ion exchange softening, however, hardness is most often expressed in terms of grains per gallon or grains of hardness removed from the water being treated.

The exchange capacity of most softeners is expressed as kilograins (1000 grains) of hardness removed per each cubic foot of resin.

AIR RELEASE ASSEMBLY



Pressure aeration and pressure filtration type filter plants require an automatic air release assembly to prevent accumulation of an excessive volume of air in the pressure filter tanks. This air release assembly consists of an automatic air release valve, and necessary pipe, valves and fittings to install on filter tank. The air release valve is a float operated type and must be installed with center line of valve level with or above top of filter tank. Air from top of filter enters air release valve at top connection and water from filter inlet pipe enters valve at bottom connection. Excessive air from filter fills valve body with air forcing water level down and thereby allowing float to drop. Downward movement of float allows excessive air to escape through the needle valve until an air-water pressure balance is restored.

In normal operation valves 1 and 3 are open and valve 2 is closed. To flush air release valve close valve 1 and open valve 2 which allows water from top of filter to flush down through the valve to the drain. Valve 3 is left open at all times unless it is necessary to remove air release valve.

Figure. 14.15 Air release assembly

(Permission of General Filter Company)

Salt in solution form is used to regenerate ion exchange softeners. The theoretical salt requirement is 0.17 pounds of salt for 1000 grains of hardness removed. Most regenerations, however, require 0.3 to 0.5 pounds of salt per 1000 grains of hardness removal.

In this section you will learn how to calculate the volume of the brine solution required to regenerate the softening unit as well as the pounds of salt required for regeneration. The concentration of brine solution used at each treatment plant may vary. Table 14.6 lists the pounds of salt present in the percentage of brine solution being used.

FORMULAS AND CONVERSION FACTORS

Hardness is usually expressed as milligrams of hardness per liter of water as $CaCO_3$.

Treatment for hardness is often discussed as grains of hardness per gallon of water.

1 grain per gallon = 17.1 milligrams per liter

or 1 gpg = 17.1 mg/*L*

7000 grains = 1 pound

To convert grains per gallon to milligrams per liter,

$$\text{Hardness, mg}/L = \frac{(\text{Hardness, grains/gallon})(17.1\ \text{mg}/L)}{1\ \text{gpg}}$$

To convert milligrams per liter to grains per gallon,

$$\text{Hardness, grains/gallon} = \frac{(\text{Hardness, mg}/L)(1\ \text{gpg})}{17.1\ \text{mg}/L}$$

To find the exchange capacity of a softener, you need to know the removal capacity of the softener in grains per cubic foot of resin or in kilograins per cubic foot of resin and the volume of the resin in cubic feet.

TABLE 14.6 SALT SOLUTION CHARACTERISTICS

Percent NaCl or grams per 100 grams of solution	Specific Gravity at 15°C or 59°F	Salameter Degree	Lbs NaCl per U.S. gal	Lbs NaCl per Cu Ft
1.0	1.0073	4	0.084	0.63
2 0	1.0145	8	0.169	1.27
3.0	1 0217	11	0.255	1.91
4.0	1.0290	15	0 343	2.57
5.0	1 0362	19	0 432	3.23
6.0	1.0437	23	0.522	3.90
7 0	1.0511	27	0.612	4.59
8.0	1.0585	30	0.705	5.28
9 0	1.0659	34	0.799	5.98
10 0	1.0734	38	0.874	6.69
11.0	1.0810	42	0.990	7.41
12 0	1 0885	45	1.09	8.14
13.0	1.0962	49	1.19	8.83
14.0	1.1038	53	1 29	9.63
15.0	1.1115	67	1.39	10.4
16.0	1.1194	60	1 49	11.2
17 0	1.1273	65	1.60	12.0
18.0	1.1352	68	1.70	12.7
19.0	1.1432	72	1.81	13.5
20.0	1.1511	76	1.92	14.4
21.0	1.1593	80	2.03	15.2
22.0	1.1676	84	2.14	16.0
23 0	1 1758	87	2.25	16.9
24.0	1.1840	91	2.37	17.7
25.0	1.1923	95	2.48	18.6
26.0	1.2010	99	2.60	19.5
26.4	1.2040	100	2.65	19.8

$$\text{Exchange Capacity, grains} = (\text{Removal Capacity, grains/cu ft})(\text{Media Vol, cu ft})$$

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness Removed, grains/gal}}$$

$$\text{Operating Time, hr (At a Given Flow Rate Before Regeneration)} = \frac{(\text{Water Treated, gal})(24\ \text{hr/day})}{\text{Ave Daily Flow, gal/day}}$$

To determine the amount of salt required for regeneration, you need to know the pounds of salt per 1000 grains required for regeneration. To calculate the gallons of brine required for regeneration, you need to know the percent brine solution or the pounds of salt per gallon of brine.

$$\text{Salt Needed, lbs} = (\text{Salt Required, lbs/1000 gr})(\text{Hardness Removed, gr})$$

$$\text{Brine, gallons} = \frac{\text{Salt Needed, lbs}}{\text{Salt Solution, lbs salt/gallon of brine}}$$

EXAMPLE 6

How many milligrams of hardness per liter are there in a water with 16 grains of hardness per gallon of water?

Known	Unknown
Hardness, gpg = 16 gpg	Hardness, mg/*L*

1 Calculate the hardness of the water in milligrams per liter.

$$\text{Hardness, mg}/L = \frac{(\text{Hardness, grains/gallon})(17.1\ \text{mg}/L)}{1\ \text{grain/gallon}}$$

$$= \frac{(16\ \text{grains/gallon})(17.1\ \text{mg}/L)}{1\ \text{grain/gallon}}$$

$$= 274\ \text{mg}/L$$

EXAMPLE 7

Convert the hardness of a water at 290 mg/*L* to grains per gallon

Known	Unknown
Hardness, mg/*L* = 290 mg/*L*	Hardness, grains/gallon

1. Convert the hardness from milligrams per liter to grains per gallon

$$\text{Hardness, grains/gallon} = \frac{(\text{Hardness mg}/L)(1\ \text{grain/gallon})}{17.1\ \text{mg}/L}$$

$$= \frac{(290\ \text{mg}/L)(1\ \text{grain/gallon})}{17.1\ \text{mg}/L}$$

$$= 17\ \text{grains/gallon}$$

EXAMPLE 8

An ion exchange softener contains 50 cubic feet of resin with a hardness removal capacity of 20 kilograins per cubic foot of resin. The water being treated has a hardness of 300 mg/*L* as $CaCO_3$. How many gallons of water can be softened before the softener will require regeneration?

Known		Unknown
Resin Volume, cu ft	= 50 cu ft	Water Treated, gal
Removal Capacity, gr/cu ft	= 20,000 grains/cu ft	
Hardness, mg/*L*	= 300 mg/*L*	

1 Convert the hardness from mg/L to grains per gallon

$$\text{Hardness, grains/gallon} = \frac{(\text{Hardness mg/L})(1\text{ grain/gallon})}{17.1\text{ mg/L}}$$

$$= \frac{(300\text{ mg/L})(1\text{ grain/gallon})}{17.1\text{ mg/L}}$$

$$= 17.5\text{ grains/gallon}$$

2 Calculate the exchange capacity of the softener in grains

$$\text{Exchange Capacity, grains} = (\text{Resin Vol cu ft})(\text{Removal Capacity grains/cu ft})$$

$$= (50\text{ cu ft})(20\,000\text{ grains/cu ft})$$

$$= 1{,}000\,000\text{ grains of removal capacity}$$

3 Calculate the volume of water in gallons that may be treated before regeneration

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}$$

$$= \frac{1{,}000{,}000\text{ grains}}{17.5\text{ grains/gallon}}$$

$$= 57{,}143\text{ gallons}$$

Therefore, 57,C00 gallons of water with 17.5 grains of hardness per gallon of water can be treated before the resin becomes exhausted

EXAMPLE 9

An ion exchange softening plant has two softeners that are eight feet in diameter and the units have a resin depth of six feet. The resin has a 20 kilograin removal ability. How many gallons of water can be treated if the hardness is 14 grains per gallon? If the flow rate to the softeners is 500 gallons per minute, how long will they operate before regeneration is required?

Known		Unknown
Number of Softeners	= 2 Softeners	1. Water Treated, gal
Diameter, ft	= 8 ft	
Resin Depth, ft	= 6 ft	2. Operating Time, hr
Exchange Capacity, gr/cu ft	= 20,000 grains/cu ft	
Hardness, grain/gallon	= 14 grains/gallon	
Flow, gallons/min	= 500 gallons/min	

1. Calculate the total volume of softener media

$$\text{Resin Vol, cu ft} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(\text{No. Softeners})$$

$$= (0.785)(8\text{ ft})^2(6\text{ ft})(2\text{ Softeners})$$

$$= 603\text{ cu ft}$$

2. Calculate the total exchange capacity of the two softeners in grains.

$$\text{Exchange Capacity, grains} = (\text{Resin Vol, cu ft})(\text{Removal Capacity, grains/cu ft})$$

$$= (603\text{ cu ft})(20{,}000\text{ grains/cu ft})$$

$$= 12{,}060{,}000\text{ grains, removal capacity of the beds}$$

3. Calculate the volume of water in gallons that may be treated before the resin is exhausted.

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}$$

$$= \frac{12{,}060{,}000\text{ grains}}{14\text{ grains/gallon}}$$

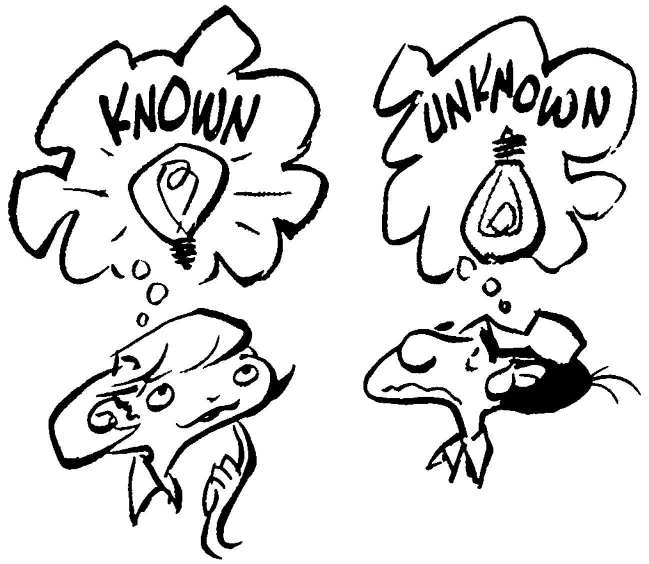
$$= 861{,}429\text{ gallons can be treated before resin is exhausted}$$

4. Find the length of time the softeners can run before requiring regeneration.

$$\text{Operating Time, hr} = \frac{(\text{Water Treated, gal})}{(\text{Ave Daily Flow, gal/min})(60\text{ min/hr})}$$

$$= \frac{(861{,}429\text{ gal})}{(500\text{ gal/min})(60\text{ min/hr})}$$

$$= 28.7\text{ hours of operation before regeneration is required}$$



EXAMPLE 10

An ion exchange softener will remove 1,000,000 grains of hardness before the resin becomes exhausted. If 0.3 pounds of salt are required per 1000 grains of hardness, how many pounds of salt are needed? If a 15 percent salt solution is used to regenerate the unit, how many gallons of brine are required? Table 14.6 indicates that 1.39 pounds of salt is present in each gallon of 15 percent brine solution.

Known		Unknown
Hardness Removal, grains	= 1,000,000 grains	1 Salt Needed, lbs
Salt Required, lbs/1000 gr	= 0.3 lbs/1000 gr	2 Brine, gal
Salt Solution, lbs/gal	= 1.39 lbs/gal	

1 Determine the pounds of salt needed for regeneration.

$$\text{Salt Needed, lbs} = (\text{Salt Required, lbs/1000 gr})(\text{Hardness Removed, gr})$$

$$= \frac{(0.3\text{ lbs Salt})(1{,}000{,}000\text{ grains})}{(1000\text{ grains})}$$

$$= 300\text{ lbs of salt}$$

2. Find the gallons of brine solution required.

$$\text{Brine, gal} = \frac{\text{Salt Needed, lbs}}{\text{Salt Solution, lbs/gallon of brine}}$$

$$= \frac{300\text{ lbs of Salt}}{1.39\text{ lbs of salt/gallon of brine}}$$

$$= 216\text{ gallons of brine (15 percent salt solution)}$$

EXAMPLE 11

Use the same information as in Example 10, except use a 12 percent brine solution. Table 14.6 indicates that 1.09 pounds of salt are present in each gallon of 12 percent brine solution. Three hundred pounds of salt are needed for regeneration. How many gallons of 12 percent brine solution is required?

Known	Unknown
Salt Needed, lbs = 300 lbs	Brine, gal
Salt Solution, lbs/gal = 1.09 lbs/gal	

1. Find the gallons of brine solution required.

$$\text{Brine, gal} = \frac{\text{Salt Needed, lbs}}{\text{Salt Solution, lbs/gallon of brine}}$$

$$= \frac{300 \text{ lbs}}{1.09 \text{ lbs/gal}}$$

$$= 275 \text{ gallons of 12 percent brine solution}$$

NOTE: More gallons of brine solution are required when using a 12 percent brine solution than when using a 15 percent solution. The weaker concentration requires more gallons to achieve the same results.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 110.

14.18A A source water has a hardness of 150 mg/*L* as $CaCO_3$. What is the hardness in grains per gallon?

14.18B An ion exchange softener contains 60 cubic feet of resin with a hardness removal capacity of 25 kilograins per cubic foot of resin. The water being treated has a hardness of 250 mg/*L* as $CaCO_3$. How many gallons of water can be softened before the softener will require regeneration?

14.19 BLENDING

Ion exchange softeners will produce a water with zero hardness. Water with zero hardness must not be sent into a distribution system. Water with zero hardness is very corrosive and over a period of time will attack steel pipes in the system and create red water problems. Also, to provide a water supply with zero hardness water would be very expensive.

At most softening plants, the zero hardness effluent from the softeners is mixed with filtered water having a known hardness concentration. In other words, a certain amount of water the treatment plant produces will bypass the softening units (split treatment). This water has a known hardness concentration and is mixed in various proportions with the softener effluent to arrive at a desired level of hardness in the finished water (Figure 14.16).

An example would be a treatment plant that has a filtered water hardness of 16 grains/gallon. If the desired plant effluent hardness is 8 grains/gallon, fifty percent of the plant influent must be softened and the other fifty percent would be filtered water mixed together with the softener effluent. The result would be water that has a hardness of 8 grains per gallon.

The blending of water is very simple and is usually controlled by a valve and meter. The operator adjusts the exact gallons per minute bypassing the softener to produce the desired hardness

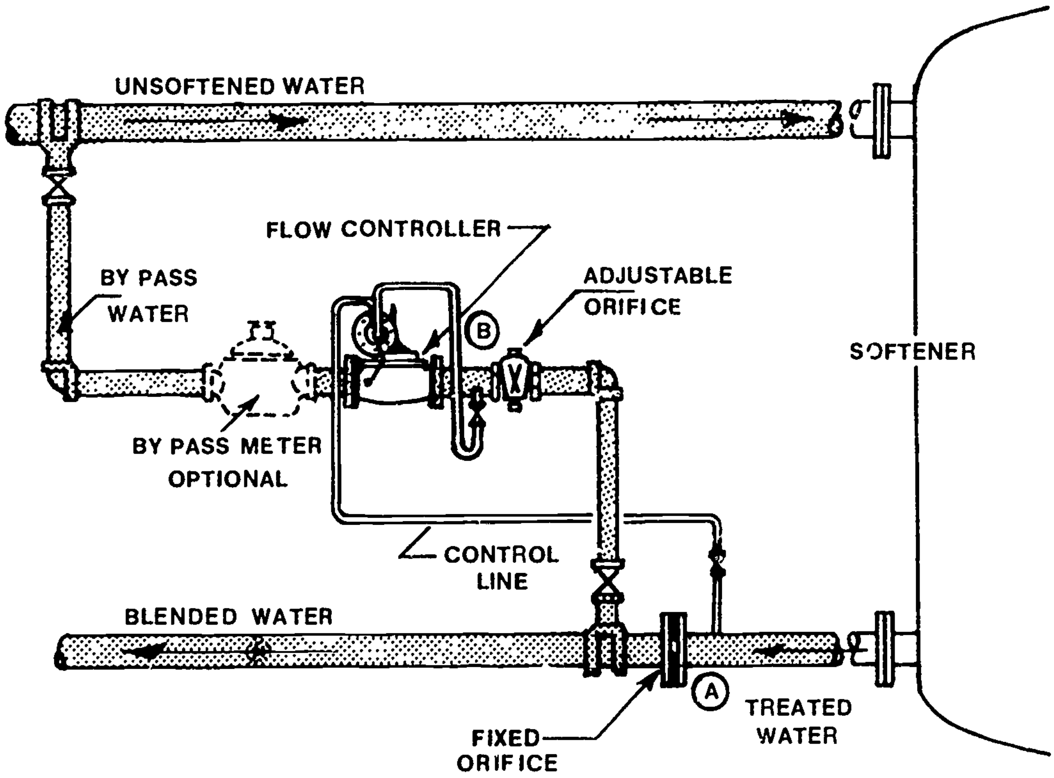


Fig. 14.16 Automatic softener bypass

(Permission of General Filter Company)

FORMULAS

To calculate the bypass flow in gallons per day to blend water, determine the total flow, the filtered water hardness and the desired effluent hardness.

The softener capacity in gallons and both the softener and bypass flows in gallons per day are needed to determine the volume of bypass water.

The total flow produced by the plant before regeneration is the sum of the flows through the softener and the bypass flow.

$$\text{Bypass Flow, GPD} = \frac{(\text{Total Flow, GPD})(\text{Plant Effl Hardness, gpg})}{\text{Filtered Hardness, gpg}}$$

$$\text{Bypass Water, gal} = \frac{(\text{Softener Capacity, gal})(\text{Bypass Flow, GPD})}{\text{Softener Flow, GPD}}$$

$$\text{Total Flow, gal} = \text{Softener Capacity, gal} + \text{Bypass Water, gal}$$

EXAMPLE 12

A softener plant treats 120,000 gallons per day. The filtered water has a hardness of 15 grains per gallon (256 mg/*L*) and the desired hardness in the plant effluent is 5 grains per gallon (86 mg/*L*) How much water in gallons per day must bypass the softener to produce the desired level of hardness?

Known		Unknown
Total Flow, GPD	= 120,000 GPD	Bypass Flow, GPD
Filtered Hardness, gpg	= 15 gpg	
Effl Hardness, gpg	= 5 gpg	

1. Calculate the bypass flow in gallons per day.

$$\text{Bypass Flow, GPD} = \frac{(\text{Total Flow, GPD})(\text{Plant Effl Hardness, gpg})}{\text{Filtered Hardness, gpg}}$$

$$= \frac{(120{,}000\ \text{GPD})(5\ \text{gpg})}{(15\ \text{gpg})}$$

$$= 40{,}000\ \text{GPD}$$

EXAMPLE 13

Using the information in Example 12, how many gallons of water will be bypassed before the softener requires regeneration? The softener has the capacity to treat 105,000 gallons. From Example 12 the bypass flow is 40,000 GPD and the total flow is 120,000 GPD. Therefore the softener flow is 80,000 GPD (120,000 GPD − 40,000 GPD). What is the total flow produced by the plant per regeneration?

Known		Unknown
Softener Capacity, gal	= 105,000 gal	1. Bypass Water, gal
Softener Flow, GPD	= 80,000 GPD	2. Total Flow, gal
Bypass Flow, GPD	= 40,000 GPD	

1. Calculate the gallons of water that will be bypassed before the softener requires regeneration.

$$\text{Bypass Water, gal} = \frac{(\text{Softener Capacity, gal})(\text{Bypass Flow, GPD})}{(\text{Softener Flow, GPD})}$$

$$= \frac{(105{,}000\ \text{gal})(40{,}000\ \text{GPD})}{80{,}000\ \text{GPD}}$$

$$= 52{,}500\ \text{gallons}$$

2. Determine the total flow produced by the plant per regeneration.

$$\text{Total Flow, gal} = \text{Softener Capacity, gal} + \text{Bypass Water, gal}$$

$$= 105{,}000\ \text{gal} + 52{,}500\ \text{gal}$$

$$= 157{,}500\ \text{gallons}$$

14.20 RECORDKEEPING

Keeping correct and up-to-date records is as important as performing scheduled maintenance on a regular routine. The recordkeeping system should be set up to record data on a daily basis. Record the total flow through the softener each day, along with the blend rates and gallons that have bypassed the unit. The total gallons of brine used each day, along with the pounds of salt used to keep the ion exchange softener in good working order should be recorded. Records of the tests performed on the softeners should be kept up-to-date in order to warn the operator of any problems that might be developing with the softening unit. Good records are an important part of a successful treatment plant operation Many problems can be avoided or solved with an adequate recordkeeping system if you review your daily records and compare them with the normal records to determine operating problems.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 111.

14.19A Why is source water blended with the effluent from an ion exchange softener?

14.20A What records should be kept by the operator of an ion exchange softening plant?

14.21 ARITHMETIC ASSIGNMENT

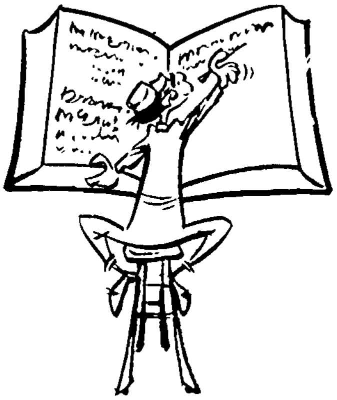
Turn to the Appendix at the back of this manual on "How to Solve Water Treatment Plant Arithmetic Problems." In Section A.52, "Softening," read the material, work the example problems and check the arithmetic using your calculator.

14.22 ADDITIONAL READING

1 *NEW YORK MANUAL*, Chapter 11, "Softening."

2 *TEXAS MANUAL*, Chapter 11, Special Water Treatment (Softening and Ion Exchange).

3 *NOTES ON WATER CHEMISTRY*, prepared for "Advanced Water Works Operations," by Michael D. Curry, P E, President Curry and Associate Engineers, Inc., P.O. Box 246, Nashville, Illinois 62263.



14.23 ACKNOWLEDGMENTS

Portions of the material discussed on ion exchange softening came from the sources listed below.

1. Bowers, Eugene, "Ion Exchange Softening" in *WATER QUALITY AND TREATMENT*, 3rd Ed., American Water Works Association, Computer Services, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10008. Price, members, $41.00; nonmembers, $51.00
2. Lipe, L.A. and M.D. Curry, "Ion Exchange Water Softening," a discussion for water treatment plant operators, 1974-75 seminar series sponsored by Illinois Environmental Protection Agency, and
3. Riehl, Merrill L., *WATER SUPPLY AND TREATMENT*, National Lime Association, 3601 North Fairfax Drive, Arlington, Virginia 22201. Price, $10.00.

End of Lesson 2 of 2 Lessons
on
SOFTENING

DISCUSSION AND REVIEW QUESTIONS

Chapter 14. SOFTENING

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 111. The problem numbering continues from Lesson 1.

13. What happens in the resin or media in an ion exchange softener during the softening stage?
14. How would you insure that large amounts of resin are not being lost during the backwash stage?
15. How would you determine if an ion exchange softener rinse stage has been successful?
16. What happens if an ion exchange softener removes iron in the ferrous (soluble) or ferric (solid) form?
17. What types of insoluble material may be found in salt? What problems can be caused by this material and how can these problems be prevented?
18. How would you prevent the strainers under the bulk brine storage area from silting in with sand and impurities?
19. How would you determine if iron has fouled the resin of an ion exchange softener?
20. How are ion exchange units filled with water after total shutdown?
21. Why is water with zero hardness not delivered to consumers?

SUGGESTED ANSWERS

Chapter 14. SOFTENING

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 72.

14.0A Hardness is caused mainly by the calcium and magnesium ions in water.

14.1A Excessive hardness is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes may cause objectionable tastes in drinking water.

14.1B Limitations of the ion exchange softening process include (1) an increase in the sodium content of the softened water and (2) ultimate disposal of spent brine and rinse waters.

Answers to questions on page 75.

14.2A Hardness is commonly measured by titration. Individual divalent cations may be measured by using an atomic adsorption (AA) spectrophotometer.

14.2B Determine the total hardness as $CaCO_3$ for a sample of water with a calcium content of 25 mg/*L* and a magnesium content of 14 mg/*L*

Known	Unknown
Calcium, mg/*L* = 25 mg/*L*	Total Hardness,
Magnesium, mg/*L* = 14 mg/*L*	mg/*L* as $CaCO_3$

Calculate the total hardness as milligrams per liter of calcium carbonate equivalent.

$$\text{Total Hardness, mg/}L\text{ as CaCO}_3 = \text{Calcium Hardness, mg/}L\text{ as CaCO}_3 + \text{Magnesium Hardness, mg/}L\text{ as CaCO}_3$$

$$= 2.50\ (\text{Ca, mg/}L) + 4.12\ (\text{Mg, mg/}L)$$

$$= 2.50\ (25\text{ mg/}L) + 4.12\ (14\text{ mg/}L)$$

$$= 62.5\text{ mg/}L + 57.7\text{ mg/}L$$

$$= 120.2\text{ mg/}L\text{ as CaCO}_3$$

14.2C Water treatment chemicals which lower the pH when added to water include alum, carbon dioxide, chlorine (Cl_2), ferric chloride, hydrofluosilicic acid and sulfuric acid.

14.2D Results from alkalinity titrations on a sample of water were as follows:

Known

Sample Size, mL = 100 mL
mL titrant used to pH 8.3, A = 1.2 mL
Total mL of titrant used, B = 5.6 mL
Acid normality, N = 0.02 N H_2SO_4

Unknown

1. Total Alkalinity, mg/L as $CaCO_3$
2. Bicarbonate Alkalinity, mg/L as $CaCO_3$
3. Carbonate Alkalinity, mg/L as $CaCO_3$
4. Hydroxide Alkalinity, mg/L as $CaCO_3$

1. Calculate the phenolphthalein alkalinity in mg/L as $CaCO_3$.

$$\text{Phenolphthalein Alkalinity, mg}/L \text{ as } CaCO_3 = \frac{A \times N \times 50{,}000}{mL \text{ of sample}}$$

$$= \frac{(1.2\ mL) \times (0.02\ N) \times 50{,}000}{100\ mL}$$

$$= 12\ mg/L \text{ as } CaCO_3$$

2. Calculate the total alkalinity in mg/L as $CaCO_3$.

$$\text{Total Alkalinity, mg}/L \text{ as } CaCO_3 = \frac{B \times N \times 50{,}000}{mL \text{ of sample}}$$

$$= \frac{(5.6\ mL) \times (0.02N) \times (50{,}000)}{100\ mL}$$

$$= 56\ mg/L \text{ as } CaCO_3$$

3. Refer to Table 14.3 for alkalinity constituents.

From Table 14.3 we want the second row because P = 12 mg/L which is less than ½T[(½) (56 mg/L) = 28 mg/L].

Therefore,

a. Bicarbonate Alkalinity $= T - 2P$
$= 56\ mg/L - 2(12\ mg/L)$
$= 32\ mg/L$ as $CaCO_3$

b. Carbonate Alkalinity $= 2P$
$= 2\ (12\ mg/L)$
$= 24\ mg/L$ as $CaCO_3$

c. Hydroxide Alkalinity $= 0\ mg/L$ as $CaCO_3$

Answers to questions on page 75.

14.3A The minimum hardness that can be achieved by the lime-soda ash process is around 30 to 40 mg/L as $CaCO_3$.

14.3B Benefits that could result from the lime-soda softening process in addition to softening include:

1. Removal of iron and manganese,
2. Reduction of solids,
3. Removal and inactivation of bacteria and virus due to high pH,
4. Control of corrosion and scale formation with proper stabilization of treated water, and
5. Removal of excess fluoride.

Answers to questions on page 77.

14.3C The addition of lime to water increases the hydroxide concentration, thus increasing the pH.

14.3D The pH is increased because calcium and magnesium become less soluble as the pH increases. Therefore, calcium and magnesium can be removed from water as insoluble precipitates at high pH levels.

14.3E After the chemical softening process, the scale forming tendencies of water are reduced by bubbling carbon dioxide (recarbonation) through the water.

14.3F Caustic soda softening might be used in place of soda ash. The decision to use caustic soda rather than soda ash depends on the quality of the source water and the delivered costs of various chemicals.

Answers to questions on page 78.

14.3G Calculate the hydrated lime ($Ca(OH)_2$) with 90 percent purity soda ash, and carbon dioxide dose requirements in milligrams per liter for the water shown below.

Known

Constituents	Source Water	Softened Water After Recarbonation and Filtration
CO_2, mg/L	= 5 mg/L	= 0 mg/L
Total Alkalinity, mg/L	= 150 mg/L as $CaCO_3$	= 20 mg/L as $CaCO_3$
Total Hardness, mg/L	= 240 mg/L as $CaCO_3$	= 50 mg/L as $CaCO_3$
Mg^{2+}, mg/L	= 16 mg/L	= 2 mg/L
pH	= 7.4	= 8.8
Lime Purity, %	= 90%	

Unknown

Hydrated Lime, mg/L
Soda Ash, mg/L
Carbon Dioxide, mg/L

1 Calculate the hydrated lime ($Ca(OH)_2$) required in milligrams per liter.

$A = (CO_2\ mg/L)\ (74/44)$
$= (5\ mg/L)\ (74/44)$
$= 8\ mg/L$

$B = (\text{Alkalinity, } mg/L)\ (74/100)$
$= (150\ mg/L)\ (74/100)$
$= 111\ mg/L$

$C = 0$ Hydroxide Alkalinity = 0

$D = (Mg^{2+},\ mg/L)\ (74/24.3)$
$= (16\ mg/L)\ (74/24.3)$
$= 49\ mg/L$

$$\text{Hydrated Lime } (Ca(OH)_2) \text{ Feed, } mg/L = \frac{(A + B + C + D)\ 1.15}{\text{Purity of Lime, as a decimal}}$$

$$= \frac{(8\ mg/L + 111\ mg/L + 0 + 49\ mg/L)\ 1.15}{0.90}$$

$$= \frac{(168\ mg/L)\ (1.15)}{0.90}$$

$$= 215\ mg/L$$

2 Calculate the soda ash required in milligrams per liter.

$$\text{Noncarbonate Hardness, } mg/L \text{ as } CaCO_3 = \text{Total Hardness, } mg/L \text{ as } CaCO_3 - \text{Carbonate Hardness, } mg/L \text{ as } CaCO_3$$

$$= 240\ mg/L - 150\ mg/L$$

$$= 90\ mg/L \text{ as } CaCO_3$$

$$\text{Soda Ash } (Na_2CO_3) \text{ Feed, } mg/L = (\text{Noncarbonate Hardness, } mg/L \text{ as } CaCO_3)\ (106/100)$$

$$= (90\ mg/L)\ (106/100)$$

$$= 95\ mg/L$$

3. Caculate the dosage of carbon dioxide required for recarbonation.

Excess Lime, mg/L $= (A + B + C + D)(0.15)$

$= (8\ mg/L + 111\ mg/L + 0 + 49\ mg/L)(0.15)$

$= (168\ mg/L)(0.15)$

$= 25\ mg/L$

Total CO_2 Feed, mg/L $= (Ca(OH)_2$ excess, mg/L$)(44/74) + (Mg^{+2}$ residual, mg/L$)(44/24.3)$

$= (25\ mg/L)(44/74) + (2\ mg/L)(44/24.3)$

$= 15\ mg/L + 4\ mg/L$

$= 19\ mg/L$

Answers to questions on page 81.

14.3H In the lime softening process, calcium is precipitated out as calcium carbonate and magnesium hydroxide.

14.3I Partial lime softening (no magnesium removal) removes hardness caused by calcium ions. This may be referred to as calcium hardness.

14.3J In split lime treatment, a portion of the water is treated with excess lime to remove the magnesium at a high pH. The source water (the remaining portion) is added in the next basin to neutralize (lower the pH) the excess-lime-treated portion.

14.3K Recarbonation is a process in which carbon dioxide is bubbled into the water being treated to convert carbonate ions to bicarbonate ions to stabilize the solution against the precipitation of carbonate compounds. The pH may also be lowered by the addition of acid.

Answers to questions on page 82.

14.3L Lime-soda ash softening is used when lime alone will not remove enough hardness.

14.3M Noncarbonate hardness is removed by the addition of soda ash in the chemical precipitation softening process.

Answers to questions on page 82.

14.3N Where the daily requirements for lime are small, lime is usually delivered to the water treatment plant in bags.

14.3O Considerable heat is generated if quicklime accidentally gets wet.

14.3P Lime may be applied by dry feeding techniques using volumetric or gravimetric feeders.

Answers to questions on page 83.

14.4A When the alum dose increases for coagulation, the lime dose must be increased also.

14.4B Color can be removed from water by coagulation with alum at low pH values. The high pH values required during softening tend to "set" the color which then becomes very difficult to remove.

Answers to questions on page 84.

14.5A A slight excess of lime can cause a scale to form on the filter sand, distribution mains, and household plumbing.

14.5B Excess caustic and unprecipitated carbonate ions (pin floc) can be removed from softened water by recarbonation. Recarbonation is the bubbling of carbon dioxide through the water being treated to lower the pH. Recarbonation can be accomplished, to a degree, by using source water in the split treatment mode.

14.5C The marble test is used to determine if a water is stable. The Langelier Index is also used to determine the corrosivity of water.

14.5D Suspending a couple of nails on strings in a filter can indicate if the water is stable. If the nails are rusting, the water is corrosive. If a scale forms on the nails, then scale is forming on your filter media and in your distribution system.

Answers to questions on page 84.

14.6A Wooden paddles should be used as cleaning tools on any slaker in operation. A metal tool will damage the slaker and could even injure the operator if dropped by accident. However, a wooden paddle will likely be broken up with no damage to the equipment or operator.

14.6B Information on how to safely maintain equipment may be found in equipment manuals provided by equipment suppliers and manufacturers.

Answers to questions on page 85.

14.7A A disadvantage of recirculating sludge back to the primary mix area is that an increase in magnesium could result.

14.7B Only trial and error will really determine if sludge recirculation will serve a useful purpose in your plant.

14.8A Records should be kept on the amounts of treatment plant chemicals ordered and the amounts fed.

Answers to questions on page 86.

14.9A When selecting the target hardness for a water softening plant, consider the uses of the softened water and the cost of softening.

14.9B If lime added to water does not reduce the hardness of a water sufficiently, use the optimum lime dose and run jar tests with varying soda ash doses. Select the soda ash dose that will produce a water with a softness of around 80 to 90 mg/L.

Answers to questions on page 90.

14.9C The overfeeding of chemicals is a waste of money and quality control will suffer.

14.9D What should be the lime feeder setting in pounds per day to treat a flow of 2 MGD when the optimum lime dose is 160 mg/L?

Known		**Unknown**
Flow, MGD	= 2 MGD	Feeder Setting, lbs/day
Lime Dose, mg/L	= 160 mg/L	

Calculate the lime feeder setting in pounds per day.

Feeder Setting, lbs/day = (Flow, MGD) (Lime, mg/L) (8.34 lbs/gal)

= (2 MGD) (160 mg/L) (8.34 lbs/gal)

= 2669 lbs/day

14.9E How much soda ash is required in pounds per day to remove 40 mg/L hardness from a flow of 2 MGD?

Known		Unknown
Flow, MGD	= 2 MGD	Feeder Setting, lbs/day
Hardness Removed, mg/L	= 40 mg/L	

1 Calculate the soda ash dose in milligrams per liter.

$$\text{Soda Ash, mg/}L = (1.1)(\text{Hardness Removed, mg/}L)$$
$$= (1.1)(40\text{ mg/}L)$$
$$= 44\text{ mg/}L$$

2 Determine the soda ash feeder setting in pounds per day.

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Soda Ash, mg/}L)(8.34\text{ lbs/gal})$$
$$= (2\text{ MGD})(44\text{ mg/}L)(8.34\text{ lbs/gal})$$
$$= 734\text{ lbs/day}$$

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 95.

14.10A The three basic types of softeners on the market are:

1. An upflow unit,
2. A gravity flow unit, and
3. A pressure downflow unit (the most common).

14.10B During the regeneration cycle the softener is taken out of service. Salt in the form of a concentrated brine solution is used to regenerate (recharge) the ion exchange media. When the brine solution is fed into the media, the sodium cations are exchanged for calcium and magnesium cations. As the brine solution travels down through the media, the sodium cations are attached to the media while the calcium, magnesium and chloride (from the salt) ions flow to waste. After the regeneration has taken place, the bed is ready to be placed in service again to remove calcium and magnesium by ion exchange.

Answers to questions on page 97.

14.11A The source water hardness is the main consideration in determining the length of the service stage of an ion exchange softener.

14.11B The purpose of the backwash stage is to expand and clean the media or resin particles and also to free any material such as iron and manganese that might have been removed during the softening stage.

14.11C Ion exchange softeners are regenerated by the use of a saturated brine solution

14.11D During the rinse stage the softener effluent goes to waste.

Answers to questions on page 99.

14.12A Hardness should be monitored in the effluent from an ion exchange softener.

14.13A High chlorine residual levels applied to softening units could damage the resin and reduce its life span.

14.14A The disposal of spent brine is a problem because the brine is very corrosive and toxic to many living things in the environment.

Answers to questions on page 100.

14.15A One valve that fails to open or close during a regeneration stage could mean a storage tank full of salty water or no brine.

14.15B Brine pumps and piping must receive constant attention because a saturated brine solution is very corrosive. An uncontained brine leak will only get worse.

14.15C Packing is recommended over mechanical seals on brine pumps because sand in mechanical seals will result in high repair and maintenance costs.

Answers to questions on page 101.

14.16A The maximum expected hardness level in the effluent from an ion exchange softener should not exceed one grain hardness per gallon (17.1 mg/L).

14.16B The purpose of the backwash stage is to remove trapped turbidity particles and other insoluble material that is trapped in the resin.

14.16C If the rinse rate starts too soon, the brine solution could be forced out of the unit before adequate contact time has elapsed. If the rinse rate is too low, all the waste material might not be removed from the unit before it goes into the service stage.

14.16D If hardness leakage is excessive immediately following a regeneration stage, shut the unit down and check the media level. The bed could be disrupted from excessive backwash or rinse rates. Iron fouling could also cause a channeling condition to occur and cause the water to short-circuit through the media without contacting the complete bed area.

Answers to questions on page 101.

14.17A Ion exchange softeners must be drained and filled slowly during startup and shutdown to prevent surging of the media which will either wash it out of the unit or disrupt it, thus making the media uneven and creating a channeling problem.

14.17B If the pipe work is deteriorating from the brine solution, PVC pipe should be used as a replacement.

Answers to questions on page 105.

14.18A A source water has a hardness of 150 mg/L as $CaCO_3$. What is the hardness in grains per gallon?

Known	Unknown
Hardness, mg/L = 150 mg/L	Hardness, grains/gallon

Calculate the source water hardness in grains per gallon.

$$\text{Hardness, grains/gallon} = \frac{(\text{Hardness, mg/}L)(1\text{ gpg})}{17.1\text{ mg/}L}$$
$$= \frac{(150\text{ mg/}L)(1\text{ gpg})}{17.1\text{ mg/}L}$$
$$= 8.8\text{ grains/gallon}$$

14.18B An ion exchange softener contains 60 cubic feet of resin with a hardness removal capacity of 25 kilograins per cubic foot of media. The water being treated has a hardness of 250 mg/*L* as $CaCO_3$. How many gallons of water can be softened before the softener will require regeneration?

Known		Unknown
Resin Vol, cu ft	= 60 cu ft	Water Treated, gal
Removal Capacity, gr/cu ft	= 25,000 gr/cu ft	
Hardness, mg/*L*	= 250 mg/*L*	

1. Convert the hardness from mg/*L* to grains per gallon.

$$\text{Hardness, grains/gallon} = \frac{(\text{Hardness, mg}/L)(1\text{ grain/gallon})}{17.1\text{ mg}/L}$$

$$= \frac{(250\text{ mg}/L)(1\text{ grain/gallon})}{17.1\text{ mg}/L}$$

$$= 14.6\text{ grains/gallon}$$

2. Calculate the exchange capacity of the softener in grains.

$$\text{Exchange Capacity, grains} = (\text{Resin Vol, cu ft})(\text{Removal Capacity, gr/cu ft})$$

$$= (60\text{ cu ft})(25,000\text{ grains/cu ft})$$

$$= 1,500,000\text{ grains of hardness removal capacity}$$

3. Calculate the volume of water in gallons that may be treated before regeneration

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gallon}}$$

$$= \frac{1,500,000\text{ grains}}{14.6\text{ grains/gallon}}$$

$$= 102,700\text{ gallons}$$

Therefore, 102,700 gallons of water with 14.6 grains of hardness per gallon of water can be treated before the resin becomes exhausted.

Answers to questions on page 106.

14.19A Source water is blended with the effluent from an ion exchange softener so the consumers will receive water with an acceptable hardness. Delivering water with zero hardness is very expensive and the water is very corrosive.

14.20A Records that should be kept by the operator of an ion exchange softening plant include:

1. Total daily flow through unit,
2. Blend rates,
3. Total daily gallons that have bypassed unit,
4. Gallons of brine used each day,
5. Pounds of salt used each day, and
6. Results of tests performed on source water, softener effluent and blended water

OBJECTIVE TEST

Chapter 14. SOFTENING

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1 Most of the hardness in water is caused by iron.
   1 True
   2. False

2 Some industrial processes require softer water than is produced by municipal water treatment plants which soften water
   1. True
   2. False

3 The lime-soda ash softening process produces water with zero hardness.
   1. True
   2. False

4. Water having a hardness caused by calcium and magnesium bicarbonate ion can usually be softened to an acceptable level using lime only.
   1. True
   2. False

5 Recarbonation is a process which causes the precipitation of calcium carbonate
   1 True
   2. False

6 Water which cannot be softened by lime contains carbonate hardness
   1 True
   2. False

7 Noncarbonate hardness requires the addition of a compound containing carbonate to soften the water.
   1. True
   2. False

8 The addition of caustic soda to water can remove both carbonate and noncarbonate hardness.
   1 True
   2. False

9. Carbonate hardness is caused by the presence of sulfate and chloride ions.
   1. True
   2. False

10 All three forms of alkalinity can exist at once in a sample of water

1 True
2. False

11 Quicklime should never be stored close to combustible materials.

1. True
2. False

12 Do not rub your eyes if they become irritated with lime dust.

1. True
2. False

13 When the alum dose is decreased for coagulation, the lime dose for softening can be ______.

1. Decreased
2. Increased.

14 Recarbonation will actually increase the hardness of the water slightly.

1. True
2. False

15. Always wear goggles or a face shield when working with lime that has been or is in the process of slaking.

1. True
2. False

16 Records will help a good operator to be a better operator

1. True
2. False

17. An overfeed of lime to some waters will actually increase the hardness.

1 True
2. False

18. Ion exchange water softening is a process in which the hardness-causing sodium ions are replaced by calcium and magnesium ions.

1. True
2. False

19 Hard water has an adverse effect on health.

1. True
2. False

20. Lime softening will remove noncarbonate hardness.

1 True
2. False

21. Changes in the hardness of the source water are automatically treated by an ion exchange unit.

1. True
2. False

22. At the beginning of the backwash stage, the backwash water should be applied at a slow steady rate.

1. True
2. False

23. The ion exchange softener regeneration and brine stages are two different stages.

1 True
2. False

24. During the rinse stage the softener effluent goes to storage.

1 True
2. False

25 Ion exchange softening will remove iron and manganese in either the soluble or precipitated form.

1 True
2. False

26 A saturated brine solution will attack any unprotected metallic surface it comes in contact with.

1. True
2 False

27 The use of mechanical seals on brine pumps is recommended over packing.

1. True
2 False

28 The brine tanks must be protected from contamination just like any other water storage facility.

1. True
2. False

29. If iron fouling appears to be a problem with an ion exchange softener, the duration of the backwash stage should be decreased.

1. True
2. False

30. If the rinse rate of an ion exchange softener is too low, all of the waste material might not be removed from the unit before it goes into the service stage.

1. True
2. False

MULTIPLE CHOICE

31. Carbonate hardness is caused by

1. Calcium chloride.
2. Calcium sulfate.
3. Magnesium bicarbonate.
4. Magnesium chloride.
5. Magnesium sulfate.

32. The two basic methods of softening a municipal water supply are

1. Ion exchange and chemical precipitation.
2. Ion exchange and lime.
3. Ion exchange and excess lime.
4. Lime and soda ash.
5. Lime-soda ash and caustic soda.

33. Regardless of the method used to soften water, consumers usually receive a softened water with a hardness of around ______.
    1. 30 to 40 mg/*L*.
    2. 50 to 60 mg/*L*.
    3. 80 to 90 mg/*L*.
    4. 140 to 150 mg/*L*.
    5. 150 to 200 mg/*L*.

34. Removal of noncarbonate hardness by chemical precipitation requires the addition of a compound containing
    1. Bicarbonate
    2. Calcium.
    3. Carbonate.
    4. Chloride.
    5. Sulfate.

35. Items to be considered when deciding whether to use caustic soda or the lime-soda ash process to soften water include
    1. Amounts of sludge produced.
    2. Costs.
    3. Disposal of sludge.
    4. Handling and feeding of chemicals.
    5. Source water characteristics.

36. Alkalinity exists as
    1. Bicarbonate.
    2. Carbonate.
    3. Hydroxide.
    4. pH.
    5. Sulfate.

37. How frequently should alkalinity be measured if the source water for a lime-soda ash process is subject to change? Every
    1. 2 hours.
    2. 4 hours.
    3. 8 hours.
    4. 16 hours.
    5. 24 hours.

38. Which of the following protective devices could be used to protect you from lime?
    1. Filter mask
    2. Gloves
    3. Long-sleeved shirt
    4. Safety glasses
    5. Skin cream

39. How can the pH of softened water be lowered after lime softening? By the use of
    1. Carbon dioxide gas.
    2. Caustic soda.
    3. Hydrochloric acid.
    4. Source water.
    5. Sulfuric acid.

40. The most common method of sludge disposal is ______ disposal.
    1. Drying bed
    2. Land application
    3. Landfill
    4. Sewer
    5. Sludge recirculation

41. The chemical feed rates produced by jar tests may not produce the exact same results in an actual plant because of differences in
    1. Coagulant feed
    2. Mixing equipment.
    3. Sizes and shapes of jars and basins.
    4. Water quality.
    5. Water temperature.

42. Source water quality changes of concern to the operator of a lime-soda ash softening plant include changes in
    1. Alkalinity
    2. Hardness.
    3. pH.
    4. Temperature.
    5. Turbidity.

43. A soft to moderately hard water will have a hardness of ______ mg/*L* as calcium carbonate.
    1. 0 to 45
    2. 46 to 90
    3. 91 to 130
    4. 131 to 170
    5. 171 to 250

44. The common stages of operation of an ion exchange softener include
    1. Backwash
    2. Brine.
    3. Recarbonation.
    4. Rinse.
    5. Service

45. Most ion exchange resins on the market will range in exchange capacity from ______ grains of hardness removed per cubic foot of resin.
    1. 100 to 500
    2. 500 to 1000
    3. 1000 to 5000
    4. 5000 to 20,000
    5. 20,000 to 30,000

46. The backwash duration and flow rate of an ion exchange softener will vary depending on the
    1. Amount of alkalinity being removed.
    2. Amount of hardness being removed.
    3. Manufacturer.
    4. Temperature of the water.
    5. Type of resin used.

47. Which water quality indicators should be monitored in the influent to an ion exchange softener?
    1. Alkalinity
    2. Hardness
    3. Iron and manganese
    4. pH
    5. Temperature

48. What type of pipe material should be used in a brine system?
    1. Boron
    2. Galvanized
    3. Iron
    4. PVC
    5. Steel

49 What can the operator do if iron fouling appears to be a problem on an ion exchange softener?

1. Apply a chemical cleaner such as sodium bisulfate
2. Decrease the strength of the brine used in the regeneration stage
3. Increase backwash flow rates
4. Increase duration of backwash stage
5. Increase duration of service stage

50 Hardness may be expressed as

1. Grains per gallon.
2. Milligrams per liter
3. Milliliters per liter.
4. Pounds per day.
5. Pounds per million gallons

51 How many gallons of water with a hardness of 14 grains per gallon may be treated by an ion exchange softener with an exchange capacity of 20,000 kilograins?

1 0.70 M Gal
2 1 07 M Gal
3. 1 24 M Gal
4 1.43 M Gal
5 1.67 M Gal

52. How many hours will an ion exchange softening unit operate when treating an average flow of 500 GPM? The unit is capable of softening 1,500,000 gallons of water before requiring regeneration

1 25 hours
2. 30 hours
3. 35 hours
4. 40 hours
5. 50 hours

End of Objective Test

CHAPTER 15

TRIHALOMETHANES

by

Mike McGuire

TABLE OF CONTENTS

Chapter 15. Trihalomethanes

OBJECTIVES

Chapter 15. TRIHALOMETHANES

Following completion of Chapter 15, you should be able to:

1. Describe how trihalomethanes are formed,
2. Explain why trihalomethanes are a problem in drinking water,
3. Collect samples for trihalomethane analysis,
4. Identify control strategies for trihalomethanes,
5. Describe treatment processes capable of controlling trihalomethanes, and
6. Select and implement a cost-effective means of controlling trihalomethanes.

GLOSSARY

Chapter 15. TRIHALOMETHANES

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce a cancer in an organism.

MAXIMUM CONTAMINANT LEVEL (MCL) MAXIMUM CONTAMINANT LEVEL

The largest allowable amount. MCLs for various water quality indicators are specified in the National Interim Primary Drinking Water Regulations (NIPDWR).

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters. These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs), they *MUST* be present in order for THMs to form.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms Often formed during chlorination by reactions with natural organic materials in the water. The resultant compounds (THMs) are suspected of causing cancer.

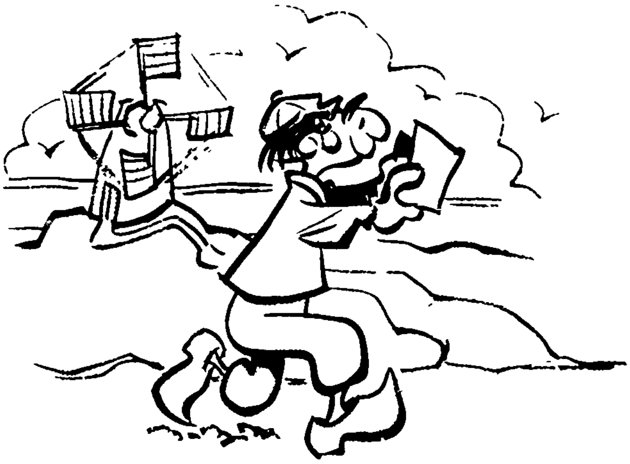
VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid

CHAPTER 15. TRIHALOMETHANES

15.0 THE TRIHALOMETHANE (THM) PROBLEM

For the past few decades water utilities have been concerned about the presence of organic compounds in drinking water. The analytical methods for detecting inorganic compounds such as calcium, magnesium, and iron have been known for many decades. However, the ability to analyze for organic compounds in water has been developed only recently. What are organic compounds? Organic compounds are defined as those compounds that contain a carbon atom. Carbon is one of the basic chemical elements. Examples of organic compounds include: proteins, carbohydrates, fats, vitamins, and a wide variety of compounds that modern technology has created.



In 1974, researchers with the U.S. Environmental Protection Agency (EPA) and in the Netherlands published their findings that trihalomethanes are formed in drinking water when free chlorine comes in contact with naturally occurring organic compounds (*THM PRECURSORS*[1]). Trihalomethanes are a class of organic compounds where there has been a replacement of three hydrogen atoms in the methane molecule with three halogen atoms (chlorine or bromine). The four most commonly found THMs are chloroform, bromodichloromethane, dibromochloromethane, and bromoform (Figure 15.1). While it is theoretically possible to form iodine-substituted THMs, they are rarely found in treated water and they are not regulated at this time. In general, methane is not involved in the THM reaction. The production of THMs can generally be shown as:

EQUATION 1

$$\text{Free Chlorine} + \underset{\text{(precursor)}}{\text{Natural Organics}} + \text{Bromide} \rightarrow \text{THMs} + \text{Other Products}$$

Free chlorine is added to drinking water as a disinfectant. The naturally occurring organics get into water when the water partially dissolves organic materials from algae, leaves, bark, wood, soil and other similar materials. This dissolved action is similar to what happens when a teabag is placed in hot water; the water dissolves those parts of the tea leaves which are soluble organic and inorganic compounds. While it is possible to form THMs by reactions between chlorine and industrial organic chemicals, the overwhelming bulk of THM precursors in water are from natural organic compounds

One source of bromide is sea water. Water agencies whose supplies are subject to sea water intrusion can expect THMs in their treated water to have high levels of bromide. Bromide reaction products can be found in most surface waters, even where bromide concentrations are low. The "other products" formed in this reaction are very poorly understood and are not regulated at this time.

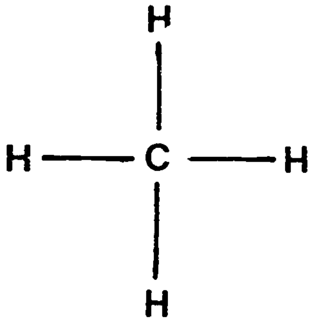
After THMs were discovered in drinking waters around the country, several studies were made of the possible health effects of THMs in general and chloroform (a THM) in particular. The results of these tests indicated that chloroform caused cancer in laboratory animals (rats and mice) and was suspected of causing cancer in humans. Further studies comparing people who used different sources of drinking water suggested that there may be a link between the presence of man-made organic compounds like THMs and increased levels of cancer. Animal feeding experiments and population studies are not definite proof that THMs in drinking water cause cancer. Under the Safe Drinking Water Act, EPA may pass a regulation for any contaminant which *MAY HAVE* any adverse health effect.

On November 29, 1979, the THM regulations were published in the *FEDERAL REGISTER*. These regulations were amended on February 28, 1983 (see Section 15.7, "Regulatory Update"). The details of the regulation are covered in Chapter 22, "Drinking Water Regulations," and general aspects of the regulation are outlined below:

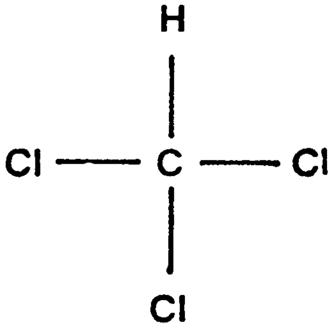
MAXIMUM CONTAMINANT LEVEL: 0.10 mg/*L* total trihalomethanes (TTHMs) — sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

---

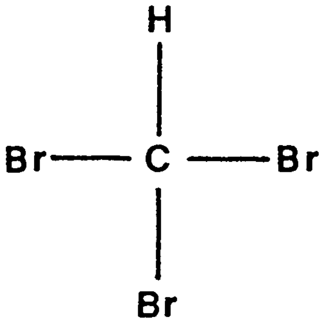
[1] *Precursors, THM (pre-CURSE-ors). Natural organic compounds found in all surface and groundwaters. These compounds MAY react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-anes) (THMs) they MUST be present in order for THMs to form.*



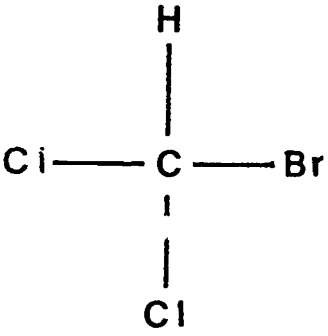
Methane, CH_4



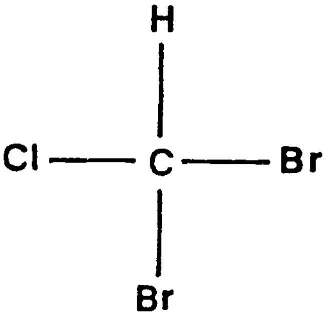
Chloroform, $CHCl_3$



Bromoform, $CHBr_3$



Bromodichloromethane, $CHBrCl_2$



Dibromochloromethane, $CHBr_2Cl$

Fig. 15.1 Methane and THMs

APPLIES TO: All community water systems that add a disinfectant to their water supply which serve a population greater than 10,000 persons.

MONITORING REQUIREMENTS: Monitoring compliance based on an annual running TTHM (total trihalomethane) average of four quarters of data. Schedule, locations, and numbers of samples depends on system size and to be worked out with State or EPA.

ENSURING MICROBIOLOGICAL QUALITY: State or EPA must be notified of significant modifications to treatment processes to remove TTHMs in order to ensure microbiological quality of the treated water.

The MCL for TTHMs was not established on the basis of the health effects data, but was set as a feasible level for compliance. The supporting material for the regulation states very clearly that the MCL may be lowered in the future to 0.025 mg/*L* or perhaps as low as 0.010 mg/*L*

The rest of this chapter is devoted to a discussion of how to collect samples for THM analysis and how a utility can evaluate the many alternatives available to control THMs in its system. This discussion is presented in outline form. A much more detailed treatment of control techniques for THMs is presented in an EPA publication entitled *TREATMENT TECHNIQUES FOR CONTROLLING TRIHALOMETHANES IN DRINKING WATER*, by J.M. Symons, et al., September 1981.[2] A large part of this chapter is a summary of material from that source.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.0A What are THM precursors?

15.0B Why is free chlorine added to drinking water?

15.0C What is one source for bromide in drinking water?

15.0D How are trihalomethanes formed?

15.1 FEASIBILITY ANALYSIS PROCESS

In any problem solving process, it is useful to follow a series of prescribed steps that will lead you to the most cost-effective solution. Table 15.1 lists the stages of a feasibility analysis process that has been used to solve a water utility's THM problem. However, the process outlined in Table 15.1 is very general and can also be applied to solving other treatment or operational problems.

TABLE 15.1 FEASIBILITY ANALYSIS PROCESS

1 Determine extent of THM problem
    a Monitor THM levels
    b THM chemistry (time of formation)
2. Evaluate control strategies
    a Change sources of supply
    b Treatment options
        (1) Remove THMs
        (2) Remove precursors
        (3) Adjust or modify the chlorine application points
        (4) Use alternate disinfectants
3 Evaluate existing treatment processes
4. Examine studies of proposed treatment processes (Bench-, pilot- and full-scale)
5 Select a cost-effective option
6 Implement the chosen option

15.2 PROBLEM DEFINITION

In order to determine the extent of a THM problem in a system, a reliable analytical technique must be used THM analytical services may be developed by the utility or may be purchased from a contract laboratory. A discussion of the THM analytical methods will not be made here; rather, the reader is referred to the *FEDERAL REGISTER* publication of the regulation or to the EPA document prepared by J.M. Symons which was previously discussed

15.20 Sampling

To determine the extent of the THM problem, collect *REPRESENTATIVE SAMPLES*[3] from the distribution system of the water utility and analyze them according to an approved method to determine if the utility is in compliance with the THM regulation. Of course, four quarters of data are needed to make a definite judgment on the MCL. However, even one quarter of data can show how close the system will be to complying with the MCL. See Section 15.21, "THM Calculations," Examples 1 and 2 for procedures on how to calculate quarterly average TTHM levels and annual TTHM running averages.

To collect samples to determine THM levels, use the following procedures:

1 A minimum of four samples per quarter (every three months) must be taken on the same day for each treatment plant in the distribution system.
2. Twenty-five percent of these samples must be collected from the extremities of the distribution system (the points farthest from each treatment plant), and
3 Seventy-five percent of the five samples must be representative of the population served by the distribution system.

---

[2] *Available from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Catalog Number 20221. Price to members, $16.00; nonmembers, $20.00.*

[3] *Representative Sample A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.*

Do not collect samples from swivel faucets, faucets with aerators, or faucets with hoses because of the possibility of contaminating the sample or loss of THMs

To collect samples for THM analysis, use a narrow-mouth screw-cap glass sample bottle that can hold at least 25 mL of water Use a polytetrafluorethylene (PTFE)-faced silicon-septia bottle-cap liner to provide an airtight seal over the sample bottle. The bottle cap must screw tightly on the sample bottles

Some sample bottles will contain a small amount of a chemical reducing agent (usually sodium thiosulfate or sodium sulfite). The reducing agent will stop the chemical reaction that occurs between chlorine and the THM precursors (humic and fluvic acids). By stopping this chemical reaction, THMs will not continue to form in the sample after it has been collected from the distribution system. When using sample bottles that contain a reducing agent, do not rinse out the reducing agent before collecting the sample.

Some sample bottles will not contain a reducing agent. Water samples from these bottles will be tested for the maximum concentration of TTHMs that can form over an extended period of time. These tests cannot be performed if a reducing agent has been added to the sample. When using sample bottles that do not contain a reducing agent, do not add any chemicals to the bottles.

When collecting water samples for THM analysis, use the following procedures.

1. Turn on the sampling tap,
2. Allow sufficient time (about five minutes) for the water temperature to become constant.
3. Fill the sample bottle until it begins to overflow,
4. Set the bottle on a level surface and place the bottle-cap liner on top of the bottle,
5. Screw the bottle cap tightly on the bottle and turn the bottle upside down,
6. The sample is properly sealed if no air bubbles are present, and
7. If air bubbles are present, remove the bottle cap and bottle-cap liner, turn on the sampling tap and add a small amount of water to the sample in the bottle, and repeat steps 4 through 6.

A good practice is to collect two samples at each location. This procedure allows the laboratory to double check test results and if a sample bottle is broken, there will be another sample available for testing.

Each sample bottle must include a label on which important information is recorded. Be sure to write on the label the sample location, date, and name of person collecting the sample. Samples should be sent to the laboratory immediately after they are collected and should be analyzed within 14 days. When sending samples to the lab, be sure to include the complete name and address of the person to whom the test results are to be returned. Samples do not have to be refrigerated during storage. Do not use dry ice when shipping or storing samples because the water in the bottles may freeze and break the sample bottles.

15.21 THM Calculations

FORMULAS

In order to calculate the average of a group of measurements, sum up the measurements and divide the total by the number of measurements.

$$\text{Average} = \frac{\text{Sum of Measurements}}{\text{Number of Measurements}}$$

To calculate the running annual average, sum up the average measurements for each quarter and divide the total by the number of quarters.

$$\text{Running Average} = \frac{\text{Sum of Averages for Each Quarter}}{\text{Number of Quarters}}$$

Whenever data for a new quarter becomes available, the newest quarterly average replaces the oldest quarterly average and the running annual average is recalculated.

EXAMPLE 1

A water utility collected and analyzed eight samples from a water distribution system on the same day for TTHMs. The results are shown below.

Sample No.	1	2	3	4	5	6	7	8
TTHM, µg/L	80	50	70	110	90	120	80	90

What was the average TTHM for the day?

Known	Unknown
Results from analysis of 8 TTHM samples	Average TTHM level for the day.

Calculate the average TTHM level in micrograms per liter.

$$\text{Ave TTHM, } \mu g/L = \frac{\text{Sum of Measurements, } \mu g/L}{\text{Number of Measurements}}$$

$$= \frac{80\ \mu g/L + 50\ \mu g/L + 70\ \mu g/L + 110\ \mu g/L + 90\ \mu g/L + 120\ \mu g/L + 80\ \mu g/L + 90\ \mu g/L}{8\text{ measurements}}$$

$$= \frac{690\ \mu g/L}{8}$$

$$= 86\ \mu g/L$$

EXAMPLE 2

The results of the quarterly average TTHM measurements for two years are given below Calculate the running annual average of the four quarterly measurements in micrograms per liter.

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, µg/L	87	72	99	82	62	111	138	89

Known	Unknown
Results from analysis of 2 years of TTHM samples	Running annual average of quarterly TTHM measurements

Calculate the running annual average of the quarterly TTHM measurements.

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{\text{Sum of Ave TTHM for Four Quarters}}{\text{Number of Quarters}}$$

Quarters 1, 2, 3, and 4

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{87\ \mu g/L + 72\ \mu g/L + 99\ \mu g/L + 82\ \mu g/L}{4}$$

$$= \frac{340\ \mu g/L}{4}$$

$$= 85\ \mu g/L$$

Quarters 2, 3, 4, and 1

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{72\ \mu g/L + 99\ \mu g/L + 82\ \mu g/L + 62\ \mu g/L}{4}$$

$$= \frac{315\ \mu g/L}{4}$$

$$= 79\ \mu g/L$$

Quarters 3, 4, 1 and 2

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{99\ \mu g/L + 82\ \mu g/L + 62\ \mu g/L + 111\ \mu g/L}{4}$$

$$= \frac{354\ \mu g/L}{4}$$

$$= 89\ \mu g/L$$

Quarters 4, 1, 2 and 3

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{82\ \mu g/L + 62\ \mu g/L + 111\ \mu g/L + 138\ \mu g/L}{4}$$

$$= \frac{393\ \mu g/L}{4}$$

$$= 98\ \mu g/L$$

Quarters 1, 2, 3, and 4

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{62\ \mu g/L + 111\ \mu g/L + 138\ \mu g/L + 89\ \mu g/L}{4}$$

$$= \frac{400\ \mu g/L}{4}$$

$$= 100\ \mu g/L$$

SUMMARY OF RESULTS

Quarter	1	2	3	4	1	2	3	4
Ave. Quarterly TTHM, $\mu g/L$	87	72	99	82	62	111	138	89
Annual Running TTHM Ave., $\mu g/L$				85	79	89	98	100

15.22 Chemistry of THM Formation

An understanding of the chemistry of THM formation is crucial if a water utility is to solve a THM problem. Equation 1 shown in Section 15.0, "The Trihalomethane (THM) Problem," describes the overall mechanism. Very little is known about the specific reactions that free chlorine and natural organics (precursors) undergo. In general, the effects of time, temperature, pH and concentrations of the chemicals on the production of THMs have been studied by various investigators and are fairly well understood.

Depending on the type of natural organics present in the water, the time it takes for 0.10 mg/*L* (100 $\mu g/L$) of THMs to form may range from minutes to days. Set up a THM monitoring program on the source water(s) of the utility to measure the production of THMs over an appropriate time period (time from when chlorine is first added to water until water is consumed). A plot of the THMs produced against time will give you an idea of the TTHM (Total TriHaloMethanes) formation potential (TTHMFP) of each source water. For many systems, a large part of the production of THMs will take place after the water leaves the treatment plant.

The higher the temperature, the faster the THMs will be produced. As might be expected, a dependence on temperature will probably show up as a seasonal effect — higher THM levels in the summer than in the winter. Temperature may not be the only controlling factor, however; higher levels may show up in the winter, as they have in California.

The higher the pH of the water, the faster the production of THMs. For most water utilities this will not be a concern; however, utilities raising the pH of treated water by caustic soda or by lime for corrosion control (Langelier Index) or using lime softening should be aware that free chlorine in contact with natural organics at a pH of 10.5 or higher will produce THMs much faster than if the pH were near 7.0.

The higher the concentrations of free chlorine and natural organics in the water, the more THMs will be produced. In the past, the amount of free chlorine that utilities used was only limited by economics and possible taste and odor complaints from consumers. Careful use of chlorine may help a utility to lower the THMs in its system. However, because of the danger of using too little chlorine (inadequate disinfection) in a system, the THM regulation specifically requires State or EPA approval of major treatment changes to meet the regulation.

The concentration of precursors in water is as important as the type of precursors that are found in water. Some naturally occurring organic compounds can produce 10 or 100 times the THMs on an equivalent basis as organics from another source. Also, some types of precursors will produce THMs faster than others. For this reason it is important to evaluate the TTHMFP of each source of supply as a possible THM control measure.

The effect of higher bromide concentrations on THM production is not as clear as the effects of temperature and pH. The more bromide present, the more bromide-containing THMs will be formed. Free chlorine selectively attacks the bromide ion and changes it to bromine, which reacts quickly with precursors to form bromoform, dibromochloromethane, and bromodichloromethane. The usual result of high bromide levels is higher THM levels because the higher molecular weights of these compounds mean more molecules are available for these chemical reactions.

Now that some of the basics of THM chemistry are understood and a THM problem can be properly defined, it is time to look at some of the possible control strategies.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.1A List the major steps that a water utility could take to solve a THM problem.

15.1B List the possible control strategies that could be evaluated to control a THM problem.

15.2A What important factors influence the production of trihalomethanes?

15.2B How does lime used for softening influence the production of THMs?

15.3 CONTROL STRATEGIES

Assuming that a utility discovers a THM problem in its system, there are two ways to control it: change the source of supply or provide some type of treatment. Changing the source of supply can consist of an entire range of alternatives such as shifting between wells of different quality, drawing water from different levels in a reservoir, or abandoning a surface supply altogether during part of the year. Since most utilities do not have the flexibility to abandon a source of supply, this alternative will have limited application.

The three treatment options available to control THMs are as follows:

1. Remove THMs after they are formed,
2. Remove THM precursors before chlorine is added, and
3. Use a disinfectant other than free chlorine.

A later section will examine each of these options and the processes associated with them. At this point it is useful to discuss overall treatment strategies. The general equation for forming THMs illustrates how each of the three options can work.

EQUATION 1

$$\begin{array}{c}\text{Free}\\\text{Chlorine}\end{array} + \begin{array}{c}\text{Natural}\\\text{Organics}\\\text{(precursor)}\end{array} + \text{Bromide} \rightarrow \text{THMs} + \begin{array}{c}\text{Other}\\\text{Products}\end{array}$$

Removing THMs after they are formed is generally not the strategy of choice unless there is a particular circumstance at the utility that warrants its evaluation. Since precursors are not necessarily removed when THMs are removed, there is the problem of continued THM formation, especially in the distribution system.

Removing precursors before free chlorine is added has some major advantages, particularly if the precursors can be removed by a fairly inexpensive process. Also, removing precursors allows the continued use of free chlorine as a disinfectant, which has been proven to be an effective barrier against disease for many decades. As the above equation shows, fewer precursors also means the formation of fewer "other products." These other products consist of high-molecular-weight organic compounds that contain chlorine and bromine. The health significance of these other products is not known, but concern has been raised by regulatory agencies.

Using a disinfectant other than free chlorine has a number of advantages and disadvantages that must be evaluated on a case-by-case basis. Abandoning free chlorine is a serious move in view of its superior performance as a disinfectant. However, if the alternate disinfectants are the lowest cost alternative, they must be given careful consideration.

15.4 EXISTING TREATMENT PROCESSES

Before beginning a complex, expensive research program, it is valuable to examine how well existing treatment processes can control the formation of THMs. The following sections cover the potential of individual processes for THM control; however, some generalizations can be made with regard to existing unit processes. Aeration-unit processes are sometimes available in water treatment plants to control tastes and odors. The same process may show measurable removals of THMs after they are formed. Oxidation of tastes and odors with chlorine dioxide (ClO_2) and potassium permanganate are common unit processes available in water treatment plants. Chlorine dioxide does not form THMs. Permanganate sometimes can be used to oxidize THM precursors if they are affected by this kind of treatment.

Coagulation/sedimentation/filtration and softening processes can remove THM precursors depending on the types that are present in the water supply. Studies at many water treatment plants have revealed that a significant reduction of total organic carbon (TOC) in source water by chemical coagulation often shows very little effect on total trihalomethane (TTHM) formation (which is a disappointment). Powdered activated carbon and granular activated carbon used for taste and odor control can have a limited impact on the removal of both THMs and THM precursors.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.3A If a utility discovers a THM problem, what are two ways to control the problem?

15.3B Why is abandoning the use of free chlorine considered a serious move?

15.4A List the water treatment processes that can be used to control THMs.

15.5 TREATMENT PROCESS RESEARCH STUDY RESULTS

15.50 Consider Options

There is a long list of treatment options that can be investigated for the control of THMs. Since a large number of them have already been studied and reported on, it is not necessary for every utility to repeat this work. A careful evaluation of the results published by the U.S. EPA will help a utility focus on the treatment processes that should be looked at on a bench-, pilot-, or full-scale basis.

Most feasible treatment options include the removal of precursor materials prior to the formation of a THM; the avoidance of generation of a THM by use of an alternate disinfectant; or the actual removal of a THM via aeration or carbon adsorption. Also the geographic and climatological conditions can have a very important influence on the choice of the most desirable process. For example, aeration is not a desirable method of treatment where severe cold weather is common.

15.51 Remove THMs After They Are Formed

There are three treatment processes available to remove THMs after they have been formed:

1. Oxidation
   a. Ozone
   b. Chlorine dioxide
   c Ozone/ultraviolet light
2. Aeration
   a. Open storage
   b. Diffused air
   c. Towers

3. Adsorption
   a. Powdered activated carbon
   b. Synthetic resins

OXIDATION. Oxidation of THMs using any one of the three oxidants listed above has not been very successful. The combination of ozone/ultraviolet light showed some promise, however, the cost-effectiveness of the process has yet to be demonstrated.

AERATION. In contrast, aeration is an effective process for removing THMs from water, although the individual THMs are removed at different efficiencies. THM removal efficiencies by aeration, ranging from the easiest to most difficult, are from chloroform to bromodichloromethane to dibromochloromethane and to bromoform. Allowing water containing THMs to stand uncovered will ultimately result in the THMs leaving the water, since they are *VOLATILE*[4] compounds that are poorly soluble in water. In other words, THMs have a natural tendency to migrate from water into the atmosphere if given the chance. Because of this tendency, THM reductions may be noticeable in effluents from open, finished water reservoirs after a significant detention time (days).

More efficient removal of THMs can be accomplished if energy is put into the aeration process. A convenient way to put energy into aeration is by bubbling air into water. Many water treatment plants currently have an aeration process of some kind to help control tastes and odors in the source water The efficiencies of these existing processes would not be expected to be very great for THM removal.

Operators should realize that aeration of treated water can cause a significant amount of contamination. Air in many areas may contain large amounts of dust, dirt, bacteria and other contaminants which can contaminate treated water and also lead to operation and maintenance problems.

In the research results that are currently available, counter-current tower aeration (Figure 15.2) has produced the highest removals of THMs with air-to-water ratios (the ratio of the volume of air added to the volume of water treated) in the 20 to 1 to 50 to 1 range. Treatment efficiencies greater than 90 percent removal have been demonstrated with some aeration towers on some types of water. Counter-current aeration towers are designed so that the water and air pass over a packing material countercurrent to each other (in opposite directions). A significant amount of theoretical work has been done on the possible tower designs for any given set of treatment conditions. Pilot-scale testing is usually recommended before a full-scale plant is constructed. Aeration is most effective on the more volatile chemicals. Chloroform is the most volatile of the THMs and is generally the most easily removed by aeration. Bromoform, on the other hand, is the least volatile THM and consequently is the hardest to remove by aeration. If the TTHM content of the water contains significant amounts of bromoform, aeration may not be the most desirable technique to investigate.

ADSORPTION. THMs can be removed by a wide variety of activated carbons and synthetic resins. The adsorption process involves the individual THM compounds leaving the water and becoming attached to the surface of the carbon or resin. THMs are generally considered difficult to adsorb on any surface. The efficiency by adsorption from easiest to most difficult is bromoform, dibromochloromethane, bromodichloromethane, and chloroform.

Powdered activated carbon (PAC) is usually added as a treatment chemical in the rapid-mix process or in the sedimentation basin effluent. PAC is normally used in water treatment for taste and odor control at dosages of less than 20 mg/*L* Studies have shown that PAC dosages of 100 mg/*L* or more are necessary to get significant removals of THMs Chloroform is particularly difficult to remove with PAC.

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[4] *Volatile (VOL-uh-tull) A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.*

Synthetic resins such as XE-340 have been demonstrated to be effective in removing THMs from water, however, economics must be taken into consideration, since the cost of the resins is high in comparison with other alternatives Regeneration of the resins has not been worked out satisfactorily Pilot-scale studies show some promise, but full-scale applications are not available.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15 5A Which is the better process for removing THMs after they are formed, oxidation or aeration?

15 5B How does the storage of water in uncovered reservoirs affect THM levels?

15 5C How does the adsorption process work?

15.52 Remove THM Precursors

A variety of treatment processes have been investigated to remove THM precursors before they come in contact with chlorine. These include:

1. Aeration
2. Oxidation
   a Ozone
   b. Chlorine dioxide
   c. Permanganate
   d Ozone/ultraviolet light
   e Hydrogen peroxide
3. Clarification
   a Coagulation/sedimentation/filtration
   b. Softening
4. Adsorption
   a. Powdered activated carbon
   b. Granular activated carbon
   c. Synthetic resins
5. Ion Exchange

AERATION. Since THM precursors are not volatile compounds, it is not surprising that aeration is ineffective in removing them from water.

OXIDATION. All of the oxidants listed above have some effect on removing or modifying THM precursors. Since THM precursors vary so much between locations, it is difficult to generalize on the effectiveness of any of the oxidants. In fact, some studies have demonstrated that the formation potential for THMs can *INCREASE* with the application of certain dosages of ozone and potassium permanganate. In general, it is necessary for bench- and/or pilot-scale studies to be performed on the water in question before the usefulness of any of these oxidants can be considered. The U.S. EPA is also concerned with the production of potentially harmful byproducts that could result from the use of any of these oxidants. Once again, studies on the water to be treated are necessary to determine whether or not this is a problem.

In the Southeastern United States in the warmer and highly organic waters, controlled oxidation levels with small doses of ozone can actually coagulate organic material and make it more efficient for conventional sedimentation. Too much ozone can break the organics down to be more reactive with chlorine. However, small controlled doses of ozone may be an effective microflocculant and may be added to conventional water treatment plants to improve the physical removal of THM precursors to the point that prechlorination disinfection is possible.

CLARIFICATION The clarification process used in water treatment plants has the potential for removing significant amounts of THM precursors. Dozens of studies by the U S. EPA have demonstrated widely varying removal efficiencies (0 to 100 percent) because of the highly variable nature of THM precursors from place to place. The use of this process to remove THM precursors, which is available in most water treatment plants, holds great promise for an economical solution to any THM problem. Moving the addition of free chlorine to a point following the clarification process is the key to success for this approach. Many water utilities have adopted this approach to solve their problem.

ADSORPTION. The use of PAC and GAC are effective in removing THM precursors; however, the economics of these processes must be carefully evaluated. Dozens of studies have reported a wide variety of THM precursor removal efficiencies. Because of the high cost of PAC and GAC, their use as THM control methods will be restricted to those cases where no other alternatives are available. Synthetic resins showed limited removal potential for THM precursors. Effective regeneration of the resins for additional precursor removal has not been demonstrated.

ION EXCHANGE. Anion exchange resins can be effective for removing THM precursors which generally have a negative charge. Both strong-base and weak-base anion exchange resins have been investigated. As with the activated carbons discussed above, anion exchange resins will only find a role in controlling THMs if the economics of the treatment process for a particular site are favorable. Disposal of the spent regenerant liquid may be a problem.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.5D List the major treatment processes that have been investigated to remove THM precursors before they come in contact with chlorine.

15.5E What is the key to the success of using clarification to remove THM precursors from the water being treated?

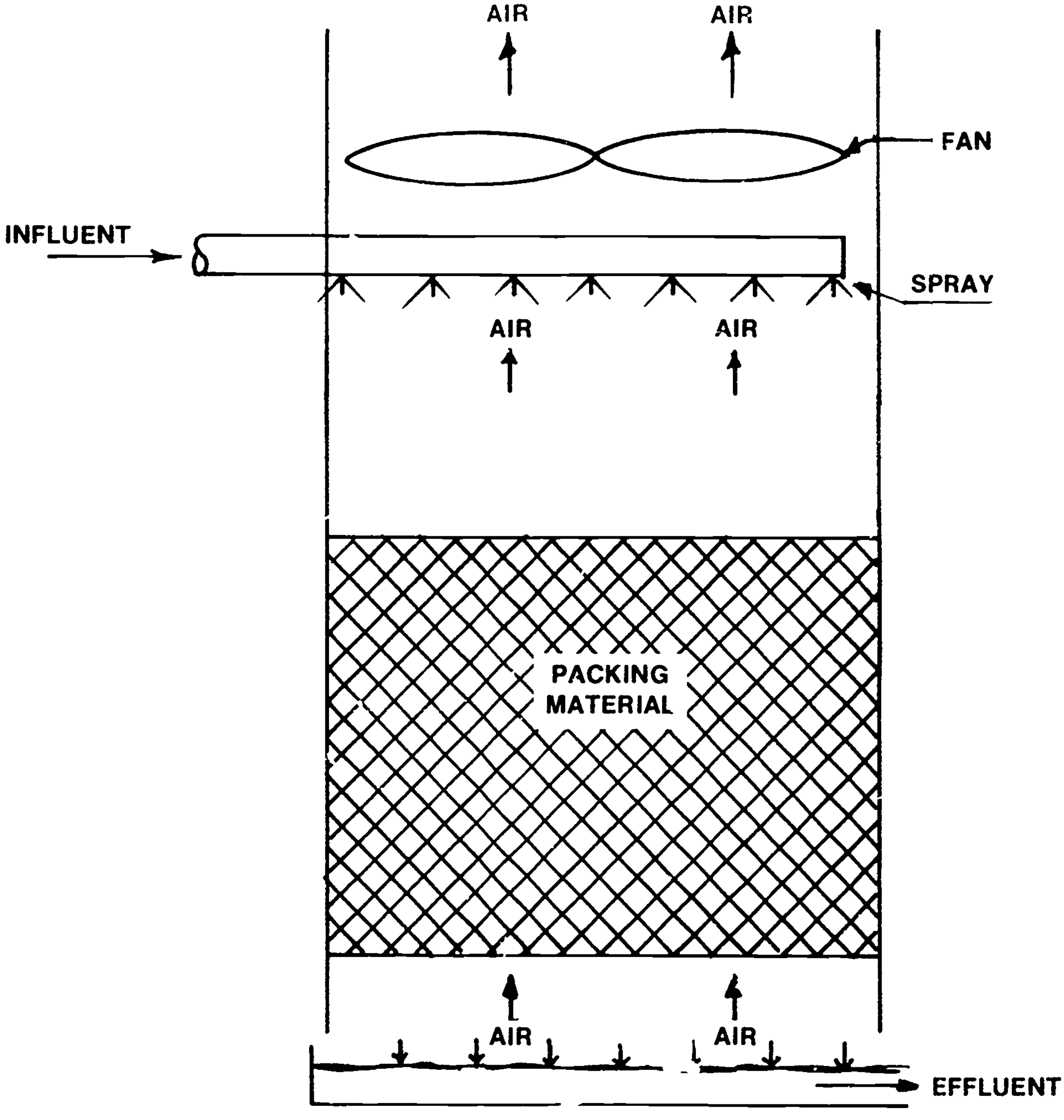


Fig. 15.2 Countercurrent aeration tower

15.53 Alternate Disinfectants

Removing free chlorine from the chlorine/bromide/precursor reaction will stop the formation of any significant amounts of THMs. However, free chlorine has been an effective barrier between people and disease-causing bacteria since the beginning of this century, and abandoning its use is a very serious step There are other disinfectants that can be used instead of free chlorine, but the advantages and disadvantages of each alternative must be carefully evaluated

The most commonly considered alternate disinfectants are ozone, chlorine dioxide, and chloramines. Ozone is a gas that is produced by passing oxygen through an electrical discharge While ozone is a highly effective disinfectant, it is very expensive, it must be generated on site, and it does not leave a residual in the treated water. Chlorine dioxide is a gas produced by the reaction of free chlorine and sodium chlorite. Chlorine dioxide is a very effective disinfectant which does leave a residual in the treated water; however, there are some concerns regarding the health implications of the inorganic breakdown products, chlorite and chlorate. The THM regulation recommended a 0.5 mg/*L* limit for the total concentration of chlorine dioxide, chlorite, and chlorate in water after chlorine-dioxide treatment

Chloramines are produced in water by the reaction between free chlorine and ammonia. Chloramines are weaker disinfectants than free chlorine, ozone, or chlorine dioxide, bu the residuals remain much longer than free chlorine and they have been used successfully by dozens of water utilities for many years. The effectiveness of monochloramines as a disinfectant depends on water temperature, pH, and biological quality, as well as the proper ratio of ammonia to chlorine. For example, the City of Denver has used chloramines for many years. The use of chloramines can also cause problems in a utility's system unless proper precautions are taken. Chloramines must be removed from the water before it is used in kidney dialysis machines. Chloramines in water can pass through kidney dialysis machines and into a patient's blood where the ammonia will decrease the oxygen carrying capacity of the blood. In addition, chloramines are toxic to fish in home aquariums, and they must be removed from water before it comes in contact with them. Dechlorination of water with activated carbon, ascorbic acid, or sodium thiosulfate will prevent any of these problems if the removal of chloramines is properly controlled. Any oxidants that are present in drinking water can cause problems with kidney dialysis machines and fish in home aquariums. However, chloramines are somewhat more difficult to remove than the other alternate disinfectants.

Before an alternate disinfectant is applied to any system, the source of the water supply, water quality and treatment effectiveness for bacteriological control must be evaluated. For example, the use of a weaker disinfectant such as chloramines may not be appropriate for a surface water supply that is highly contaminated with discharges from municipal and industrial wastewater treatment plants unless an extra high dosage and a long contact time are provided. Also, many of the conventional water treatment processes are capable of removing bacteria, viruses and protozoa from the water (for example, softening and coagulation/sedimentation/filtration). These conventional processes may help to provide the required disinfection barrier between a contaminated supply and the population served, which could allow the use of a less potent disinfectant in the distribution system.

Upgraded monitoring of the distribution system before and after a disinfectant change must be provided by the utility The THM regulation specifies guidelines that the states must use in establishing such a monitoring program. Guidelines describing coliforms, standard plate count, turbidity, and nutrients are included in the suggested monitoring list With "before and after" monitoring by the water utility, it will be possible to determine if there is any significant degradation of the bacteriological quality in the distribution system Control of THMs must not be accomplished at the expense of a higher risk of bacterial and viral diseases among the population that is being served. Therefore, a decision to use a disinfectant other than free chlorine must be based on a carefully considered plan A utility that rushes into the use of an alternate disinfectant without the required studies is likely to experience many problems that are easily avoided with proper planning

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.5F What items must be considered before an alternate disinfectant is applied to any system?

15 5G What type of distribution system monitoring must be provided by a utility before and after a disinfectant change?

15 5H What water quality indicators should be monitored before and after a disinfectant change?

15.6 SELECTION AND IMPLEMENTATION OF A COST-EFFECTIVE ALTERNATIVE

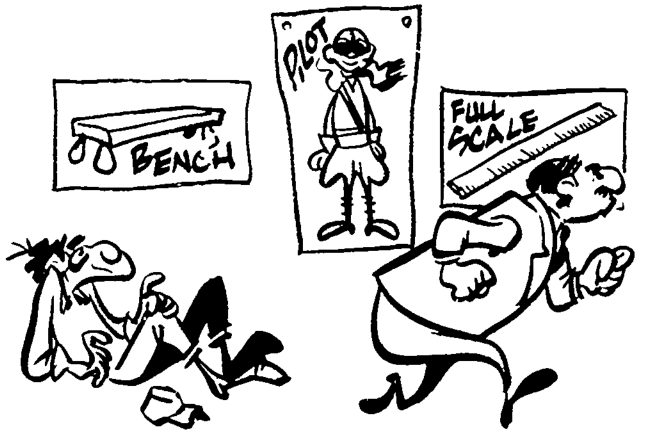
A detailed evaluation of the comparative economics of the many treatment processes described above is outside the scope of this chapter In many cases, a utility will commission a special cost-effectiveness study that will be accomplished in house or by an outside consultant. The U.S. EPA THM treatment manual presents a detailed look at cost estimates for various alternatives with equivalent THM control levels However, this data is not current and should be updated to reflect current economic conditions whenever cost studies are conducted.

If existing processes are not capable of solving a utility's THM problem, the least-cost solution will probably be an alternate disinfectant. While no statistics are currently available, evidence from discussions with consultants and utility managers suggests that alternate disinfectants, especially chloramines, are the overwhelming least-cost solution for water utilities with a THM problem. However, the use of chloramines may cause problems for persons using kidney dialysis machines.

Implementation of a THM control strategy requires a number of well defined steps·

1. Full-scale design,
2 Construction,
3 Startup, and
4 Operation.

The length of time required to complete these steps will depend on the complexity of the control strategy chosen and the availability of engineering services to complete the assigned tasks. Throughout the implementation phase, it is important that the bench-, pilot-, and full-scale tests initiated in the feasibility-analysis phase be continued so that the chosen strategy can be refined and optimized. For example, a pilot plant can be used to train treatment plant operators to use the new technology that will soon be on-line.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.6A If existing water treatment processes are not capable of solving a THM problem, what is the most likely least-cost solution?

15.6B What appears to be the most popular alternate disinfectant?

15.7 REGULATORY UPDATE

On February 28, 1983, the U.S. EPA published in the *FEDERAL REGISTER* (page 8406) an amendment to the THM regulation originally published on November 29, 1979. The amendment specifies the treatment alternatives that a utility must consider or investigate in detail before it can apply for and receive a variance from meeting the MCL as defined under the regulation. The U.S. Environmental Protection Agency or the state may require a community water system to use a "generally available" technology before granting a variance. "Generally available" or Group 1 treatment techniques are:

1. Use of chloramines or chlorine dioxide as an alternative or supplement to chlorine for oxidation and disinfection,
2. Use of chloramines, chlorine dioxide, or potassium permanganate as an alternative to chlorine for preoxidation,
3. Moving the point of chlorination in order to reduce THM formation,
4. Improvement of existing clarification, and
5. Use of powdered activated carbon (PAC), intermittently as necessary, to reduce TTHM or THM precursors. The dosage of PAC is not to exceed an annual average of 10 mg/*L*.

Any of these technologies may be required in the variance unless the regulatory agency, USEPA or the state, determine that "such treatment method . . . is not available and effective for TTHM control for the system." The rule allows exemption from the use of a technique if the method would not be technically appropriate and technically feasible for the system or if the method would result in only a marginal reduction in TTHM.

The rule also allows the regulator to require the study of Group 2 technologies by water systems where Group 1 technologies are not appropriate or sufficient in meeting the MCL. If a Group 2 technology indicates that it would be technically feasible and economically reasonable and result in significant TTHM reductions in line with the cost of treatment, then the regulator can require the use of a Group 2 technology

The listed Group 2 technologies are introduction of off-line water storage, aeration, introduction of clarification, alternative sources of raw water, and the use of ozone as an alternative or supplement to chlorine for disinfection or oxidation.

The February 28, 1983, amendment to the THM regulations does not mention granular activated carbon (GAC) or biological activated carbon (BAC) as treatment alternatives that must be considered. These two treatment methods were judged to be too expensive and to not have sufficient US experience to warrant their evaluation for THM control. In general, the amendment is designed to reduce the economic impact of the THM regulation on those utilities that have THM problems and limited resources to drastically modify their treatment procedures.

Utilities that may be affected by THM regulations are advised to follow future developments in the *FEDERAL REGISTER*.

15.8 SUMMARY AND CONCLUSIONS

1. Trihalomethanes are produced when free chlorine, which is added as a disinfectant, reacts with naturally occurring bromide and organic compounds.
2. A trihalomethane regulation is now in effect which has established a 0.10 mg/*L* maximum contaminant level and monitoring requirements.
3. A feasibility-analysis process is a series of logical steps to arrive at a cost-effective solution to a THM problem:
    1. Determine the extent of THM problem
        a. Monitor
        b. THM chemistry
    2. Evaluate control strategies
        a. Change sources of supply
        b. Treatment options
            (1) Remove THMs
            (2) Remove precursors
            (3) Use alternate disinfectants

   3. Evaluate existing treatment processes
   4. Research studies of treatment processes
      a. Bench-, pilot-, and full-scale
   5. Select a cost-effective option
   6. Implement chosen option

4. There are three treatment options available to control THMs:
   1. Remove THMs after they are formed,
   2. Remove THM precursors before chlorine is added, and
   3. Use a disinfectant other than free chlorine.
5. A water utility must not create a possible health problem by ignoring bacteriological safeguards in an attempt to solve a THM problem
6. An amendment to the THM regulation specifies treatment techniques that must be evaluated before a utility may receive a variance Since this amendment affects a utility's feasibility analysis procedure, the steps outlined in the amendment should be followed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 131.

15.7A What treatment processes must utilities evaluate before applying for and receiving a variance?

15.7B If treatment processes are not technically feasible nor economically reasonable, then what should utilities consider?

15.9 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A 33, "Trihalomethanes" Work all of the problems on your pocket calculator. You should be able to get the same answers.

15.10 ADDITIONAL READING

1. *TREATMENT TECHNIQUES FOR CONTROLLING TRIHALOMETHANES IN DRINKING WATER* by James. M. Symons, Alan S. Stevens, Robert M. Clark, Edwin E. Geldreich, O. Thomas Love, Jr., and Jack DeMarco. Drinking Water Research Division, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. EPA-600/2-81-156, September 1981. Available from Data Processing Department, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Catalog Number 20221. Price to members, $16.00; nonmembers, $20.00
2. *CHLORAMINATION FOR THM CONTROL: PRINCIPLES AND PRACTICES.* AWWA Computer Services, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 20181. Price, members, $12.50; nonmembers, $15.50.
3. *STRATEGIES FOR THE CONTROL OF TRIHALOMETHANES.* AWWA Computer Services, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 20174. Price, members, $12.50; nonmembers, $15.50.

DISCUSSION AND REVIEW QUESTIONS

Chapter 15. TRIHALOMETHANES

Work these discussion and review questions before continuing with the Objective Test on page 132 The purpose of these questions is to indicate to you how well you understand the material in this chapter. Write the answers to these questions in your notebook.

1. How are trihalomethanes formed in drinking water?
2. On what basis was the Maximum Contaminant Level (MCL) for total trihalomethanes (TTHMs) established?
3. What is the influence of higher temperatures and pH on the production of trihalomethanes (THMs)?
4. What are some of the options if a water utility decides to investigate changing the source of the water supply?
5. What are the advantages of removing precursors before free chlorine is added?
6. Why might ozone be used prior to clarification and filtration?
7. List the three alternative disinfectants to free chlorine and the advantages and limitations to each one.
8. What items must be considered before an alternate disinfectant is applied to any system?
9. What are the advantages of using a pilot plant in the implementation of a THM control strategy?

SUGGESTED ANSWERS

Chapter 15. TRIHALOMETHANES

Answers to questions on page 121.

15.0A THM precursors are defined as natural organic compounds found in all surface and groundwaters The THM precursors react with halogens (such as chlorine) to form trihalomethanes (THMs); they must be present in order for THMs to form.

15.0B Free chlorine is added to drinking water as a disinfectant.

15.0C One source of bromide is sea water.

15.0D Trihalomethanes are formed by the reactions of natural organic compounds with halogens (such as chlorine).

Answers to questions on page 123.

15.1A The major steps that a water utility could take to solve a THM problem include

1. Determine extent of THM problem.
2. Evaluate control strategies,
3. Evaluate existing treatment processes,
4. Examine research studies of treatment processes,
5. Select most cost-effective option, and
6. Implement selected option.

15 1B Control strategies that could be evaluated to control a THM problem include:

1. Change sources of supply, and
2. Treatment options
   (a) Remove THMs,
   (b) Remove precursors, and
   (c) Use alternate disinfectants

15 2A Important factors that influence the production of trihalomethanes include the effects of time, temperature, pH and the types and concentrations of chemicals.

15.2B Those utilities that use lime softening should be aware that free chlorine in contact with natural organics at a pH of 10.5 or higher will produce THMs faster than if the pH were near 7.0.

Answers to questions on page 124.

15.3A The two types of controlling a THM problem are (1) change the source of supply or (2) provide some type of treatment.

15.3B Abandoning the use of free chlorine is a serious move in view of its superior performance as a disinfectant.

15.4A Water treatment processes that can be used to control THMs include:

1. Aeration,
2. Oxidation with potassium permanganate,
3. Coagulation, flocculation and filtration,
4. Softening processes, and
5. Powdered activated carbon applications.

Answers to questions on page 126.

15.5A Aeration is a much more effective process than oxidation for removing THMs after they have been formed.

15.5B THM concentrations should be reduced in waters which have been stored in uncovered reservoirs because of loss to the atmosphere.

15 5C The adsorption process involves the individual THM compounds leaving the water and becoming attached to the surface of the carbon or resin.

Answers to questions on page 126.

15 5D The major treatment processes that have been investigated to remove THM precursors before they come in contact with chlorine include:

1. Aeration,
2 Oxidation (including ozone oxidation prior to coagulation and clarification).
3. Clarification,
4 Adsorption, and
5. Ion exchange.

15.5E Moving the addition of free chlorine to a point following the clarification process is the key to success when using clarification to remove THM precursors.

Answers to questions on page 128.

15.5F Before an alternate disinfectant is applied to any system, the source of the water supply, water quality and treatment effectiveness for bacteriological control must be evaluated.

15.5G Upgraded monitoring (more samples and tests) of the distribution system before and after a disinfectant change must be provided by a utility.

15.5H Before and after a disinfectant change, the distribution system monitoring program should include coliforms, standard plate count, turbidity and nutrients.

Answers to questions on page 129.

15 6A If existing water treatment processes are not capable of solving a THM problem, the least cost solution will probably be an alternate disinfectant.

15 6B Apparently the most popular alternate disinfectant is chloramines.

Answers to questions on page 130.

15.7A Treatment processes which utilities must evaluate before applying for and receiving a variance include:

1. Use of chloramines or chlorine dioxide as an alternative or supplement to chlorine for oxidation and disinfection,
2. Use of chloramines, chlorine dioxide, or potassium permanganate as an alternative to chlorine for preoxidation,
3. Moving the point of chlorination in order to reduce THM formation,
4. Improvement of existing clarification, and
5. Use of powdered activated carbon (PAC), intermittently as necessary to reduce TTHM or THM precursors. The dosage of PAC is not to exceed an annual average of 10 mg/*L*.

15 7B If treatment processes are not technically feasible nor economically reasonable, then utilities must consider:

1. Off-line storage for precursor reduction,
2. Aeration where appropriate,
3. Introduction of clarification where not practiced,
4. Alternative sources of raw water, and
5. Use of ozone as an alternative or supplement to chlorine for disinfection or oxidation

OBJECTIVE TEST

Chapter 15. TRIHALOMETHANES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Trihalomethanes are formed in drinking water when free chlorine comes in contact with naturally occurring organic compounds.
   1. True
   2. False
2. The trihalomethane regulations apply to all community water systems that add a disinfectant to their water supply.
   1. True
   2. False
3. The Maximum Contaminant Level (MCL) for total trihalomethanes (TTHMs) was established solely on the basis of health-effects data
   1. True
   2. False
4. Depending on the type of natural organics present in the water, the time it takes for 0.10 mg/*L* of THMs to form may range from minutes to days.
   1. True
   2. False
5. Most THM precursors enter source waters from industrial organic chemicals.
   1. True
   2. False
6. The concentration of precursors in water is as important as the types of precursors that are found in water for the production of THMs.
   1. True
   2. False
7. All types of precursors will produce THMs at the same rate.
   1. True
   2. False
8. Removal of THMs after they are formed using oxidants has been very successful.
   1. True
   2. False
9. Aeration is an effective process for removing THMs from water.
   1. True
   2. False
10. Aeration is an effective means for removing THM precursors
    1. True
    2. False
11. THM precursors vary considerably between locations.
    1. True
    2. False
12. Removing free chlorine from the chlorine/bromide/precursor reaction will stop the formation of any significant amounts of THMs
    1. True
    2. False
13. A chemical reducing agent is added to THM sample bottles to stop the chemical reaction between chlorine and the THM precursors.
    1. True
    2. False
14. Trihalomethanes are produced when free chlorine reacts with naturally occurring bromide and organic compounds.
    1. True
    2. False
15. A water utility may apply for a variance from the THM regulations.
    1. True
    2. False

MULTIPLE CHOICE

16 Examples of organic compounds include

1. Calcium.
2 Carbohydrates.
3. Fats.
4. Trihalomethanes
5. Vitamins

17. Naturally occurring organics get into water when the water partially dissolves organic materials from

1. Algae.
2. Leaves
3. Rocks.
4. Salts.
5. Soils.

18. The total trihalomethanes in water are the sum of the concentrations of

1. Bromodichloromethane.
2. Bromoform
3 Chloroform.
4. Dibromochloromethane.
5. Methane.

19. The Maximum Contaminant Level (MCL) for total trihalomethanes (TTHMs) is

1. 0.01 mg/*L*.
2. 0 03 mg/*L*
3 0.05 mg/*L*.
4. 0.10 mg/*L*
5. 0.20 mg/*L*.

20. Important factors that influence the production of trihalomethanes include

1. Concentration of chemicals.
2. Location of chlorine application.
3. pH.
4. Temperature.
5. Time.

21. Treatment techniques available to control THMs include

1 Drawing water from different levels in a reservoir.
2. Removing THM precursors before chlorine is added
3. Removing THMs after they are formed.
4. Shifting to a different source.
5. Using a disinfectant other than free chlorine.

22 Which of the following treatment processes are effective in removing THM precursors?

1. Aeration
2. Coagulation, flocculation and filtration
3. Open storage
4. Potassium permanganate
5. Softening processes

23 Which of the following treatment processes are effective in removing THMs after they have been formed?

1. Adsorption
2. Aeration
3. Coagulation, flocculation and filtration
4. Oxidation
5. Softening processes

24 Oxidation treatment processes include

1 Chlorine dioxide.
2. Granular activated carbon
3. Ozone.
4 Powdered activated carbon
5 Synthetic resins

25. The most commonly considered alternate disinfectants to free chlorine are

1. Chloramines
2. Chlorine dioxide.
3. Hydrochloric acid
4 Hypochlorite.
5 Ozone

26. Dechlorination of water containing chloramines can be accomplished by the use of

1. Activated carbon.
2. Ammonia.
3 Ascorbic acid.
4. Hypochlorite.
5 Sodium thiosulfate.

27. Water quality indicators which should be monitored in the distribution system before and after a disinfectant change include

1. Chloride.
2. Coliforms.
3. Nutrients.
4. Standard plate count
5 Turbidity.

28 The results of the quarterly average TTHM measurements for one year are given below. Calculate the running annual average for the fourth quarter.

Quarter	1	2	3	4
Ave Quarterly TTHM, $\mu g/L$	63	89	121	72

1 43 $\mu g/L$
2 68 $\mu g/L$
3. 86 $\mu g/L$
4 93 $\mu g/L$
5 95 $\mu g/L$

CHAPTER 16

DEMINERALIZATION

by

Dave Argo

TABLE OF CONTENTS

Chapter 16 Demineralization

(Removal of Dissolved Minerals by Membrane Processes)

LESSON 3

OBJECTIVES

Chapter 16. DEMINERALIZATION

Following completion of Chapter 16, you should be able to

1. Describe the various demineralizing processes,
2. Explain how the reverse osmosis process works,
3. Operate and maintain a reverse osmosis demineralization plant,
4. Explain the principles of electrodialysis,
5. Identify and describe the parts of an electrodialysis plant,
6. Operate and maintain an electrodialysis plant, and
7. Safely perform your duties around reverse osmosis and electrodialysis plants.

GLOSSARY

Chapter 16. DEMINERALIZATION

ANGSTROM (ANG-strem) ANGSTROM

A unit of length equal to one tenth of a nanometer or one ten-billionth of a meter (1 Angstrom = 0.000 000 000 1 meter). One Angstrom is the approximate diameter of an atom.

CHELATION (key-LAY-shun) CHELATION

A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of metals (copper). Also see SEQUESTRATION.

COLLOIDS (CALL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier and settling out.

CONCENTRATION POLARIZATION CONCENTRATION POLARIZATION

The ratio of the salt concentration in the membrane boundary layer to the salt concentration in the water being treated. The most common and serious problem resulting from concentration polarization is the increasing tendency for precipitation of sparingly soluble salts and the deposition of particulate matter on the membrane surface.

DEMINERALIZATION (DEE-MIN-er-al-uh-ZAY-shun) DEMINERALIZATION

A treatment process which removes dissolved minerals (salts) from water.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

ESTER (ESS-ter) ESTER

A compound formed by the reaction between an acid and an alcohol with the elimination of a molecule of water.

FEEDWATER FEEDWATER

The water that is fed to a treatment process; the water that is going to be treated.

FLUX FLUX

A flowing or flow.

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

Chemical reaction in which a compound is converted into another compound by taking up water.

OSMOSIS (oz-MOE-sis) OSMOSIS

The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane. The membrane allows the passage of the water (solvent) but not the dissolved solids (solutes). This process tends to equalize the conditions on either side of the membrane.

PERMEATE (PURR-me-ate) PERMEATE

The demineralized water.

REVERSE OSMOSIS (oz-MOE-sis) REVERSE OSMOSIS

The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the water (solvent) but not the disolved solids (solutes). The liquid produced is a demineralized water. Also see OSMOSIS.

SALINITY SALINITY

(1) The relative concentration of dissolved salts, usually sodium chloride, in a given water.

(2) A measure of the concentration of dissolved mineral substances in water.

SEQUESTRATION (SEE-kwes-TRAY-shun) SEQUESTRATION

A chemical complexing (forming or joining together) of metallic cations (such as iron) with certain inorganic compounds, such as phosphate. Sequestration prevents the precipitation of the metals (iron). Also see CHELATION.

SPECIFIC CONDUCTANCE SPECIFIC CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called CONDUCTANCE.

TOTAL DISSOLVED SOLIDS (TDS) TOTAL DISSOLVED SOLIDS (TDS)

All of the dissolved solids in a water. TDS is measured on a sample of water that has passed through a very fine mesh filter to remove suspended solids. The water passing through the filter is evaporated and the residue represents the dissolved solids. Also see SPECIFIC CONDUCTANCE.

Chapter 16. DEMINERALIZATION

(Removal of Dissolved Minerals by Membrane Processes)

(Lesson 1 of 3 Lessons)

16.0 SOURCES OF MINERALIZED WATERS

As our country's population continues to grow, so does our demand for more water resources. Traditionally, water supplies have been obtained from "fresh water" sources. This constantly increasing need for water has started to deplete the available fresh water supplies in some areas of the country.

Faced with potential shortages, water planners must now consider new treatment technologies which until recently were not considered to be economically feasible. Since most of the earth's water supplies are saline (the ocean is high in dissolved minerals) rather than fresh, these impurities must be removed. One process receiving considerable attention is demineralization. Demineralization is the process which removes dissolved minerals (salts) from water.

All available water supplies can be classified according to their mineral quality. All waters contain various amounts of *TOTAL DISSOLVED SOLIDS (TDS)*[1], including fresh water. A majority of the dissolved materials are inorganic minerals (salts) Minerals are compounds commonly found in nature which consist of positive metallic ions (such as calcium, sodium) bonded to negative ions (such as chloride, sulfate, carbonate) Many of these compounds are soluble in water and come from the weathering and erosion of the earth's surface.

Fresh water supplies, which have been the major sources of water developed in the past, usually contain less than 1000 mg/*L* of total dissolved solids. Secondary drinking water standards recommend 500 mg/*L* TDS as the limit Waters containing slightly higher concentrations can be used without adverse effects.

Brackish water contains from 1000 to 10,000 mg/*L* TDS (sea water has 35,000 mg/*L* TDS). Most brackish water is found in groundwater. Figure 16.1 shows that over one half of the United States overlays groundwater containing TDS levels ranging from 1000 to 3000 mg/*L*. To date, brackish water has not been widely used for municipal drinking water supplies because of its highly mineralized taste and associated problems such as scaling in pipes. With the advent of new treatment technologies, however, demineralization of brackish waters (including reuse of wastewater) has great potential for further development.

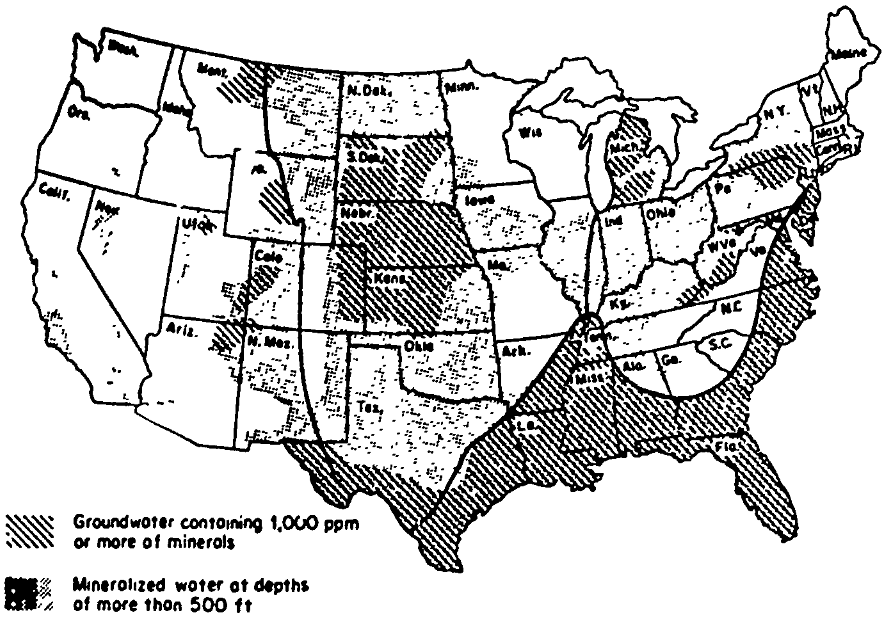


Fig. 16.1 Map of the conterminous United States showing depth to and quality of shallowest groundwater containing more than 1,000 mg/L dissolved solids

(from paper by Bill Katz. "Treating Brackish Water for Community Supplies," published in Proceedings in "Role of Desalting Technology," a series of Technology Transfer Workshops presented by the Office of Water Research and Technology)

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[1] *Total Dissolved Solids (TDS) All of the dissolved solids in a water. TDS is measured on a sample of water that has passed through a very fine mesh filter to remove suspended solids. The water passing through the filter is evaporated and the residue represents the dissolved solids. Also see SPECIFIC CONDUCTANCE.*

The largest available source of water in terms of quality is classified as sea water, which usually contains more than 35,000 mg/L TDS. While sea water may be an important future water resource because of its seemingly unlimited availability in coastal areas, it is more expensive to treat than brackish water because of its greater TDS concentration.

The purpose of this chapter is to introduce and familiarize the water treatment plant operator with the newer treatment processes which have been developed to remove the dissolved minerals (TDS) from water. The development of the membrane demineralization processes have significantly reduced the cost of demineralization. This savings, combined with diminished fresh water supplies, will increase the use of demineralization treatment processes. The large quantities of mineralized groundwater and the increased *SALINITY*[2] of many rivers and lakes due to waste discharges, agricultural runoff and other uses will increase the need for demineralization.

Some areas of the United States, such as the Florida Gulf Coast, are already turning to demineralization. A report by the Office of Water Research and Technology indicates the worldwide capacity of brackish water demineralization plants has increased from zero in 1962 to over 100 MGD (380 MLD or megaliters per day) by 1977. Thus, it is important that the water treatment plant operator become more knowledgeable concerning the methods used to demineralize water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 174.

16.0A What is demineralization?

16.0B Why is sea water more expensive to treat than brackish water?

16.1 DEMINERALIZING PROCESSES

Methods of removing minerals from water can be divided into two classes: (1) those that use a phase change such as freezing or distillation, and (2) non-phase change methods such as reverse osmosis, electrodialysis and ion exchange.

Demineralizing processes have primarily been used to remove dissolved inorganic material (TDS) from industrial water and wastewater, municipal water and wastewater, and sea water. However, some processes will also remove suspended material, organic material, bacteria and viruses. Application of the various demineralizing processes is partially dependent upon the total dissolved solids (TDS) concentration of the water to be treated. Figure 16.2 illustrates the approximate TDS range for use of two phase change processes (distillation and freezing) and three non-phase change processes (reverse osmosis, electrodialysis and ion exchange).

The selection of a demineralizing process for a particular application depends upon several factors including:

1. Mineral concentration in *FEEDWATER*[3] (brackish water supply),
2. Product water quality required,
3. Brine disposal facilities,
4. Pretreatment required,
5. Need to remove other material such as bacteria and virus, and
6. Availability of energy and chemicals required for the process.

The basic system is similar for all demineralizing processes and includes the processes shown in Figure 16.3.

Since freezing and distillation apply primarily to sea water demineralizing and their widespread use seems unlikely, these processes will not be discussed. Neither will ion exchange because of its limited use for brackish water (1000 to 3000 mg/L TDS). Currently, activity within the water industry is focused primarily on the membrane demineralizing processes, known as reverse osmosis and electrodialysis.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 174.

16.1A List the two classes of methods of removing minerals from water.

16.1B List the common membrane demineralizing processes.

16.2 REVERSE OSMOSIS

16.20 What is Reverse Osmosis?

Osmosis can be defined as the passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane. The membrane allows the passage of the water (solvent) but not the dissolved solids (solutes).

Osmosis plays a vital role in many biological processes. Nutrient and waste minerals are transported by osmosis through the cells of animal tissues, which show varying degrees of permeability to different dissolved solids. A striking example of a natural osmotic process is the behavior of blood cells placed in pure water. Water passes through the cell walls to dilute the solution inside the cell. The cell swells and eventually bursts, releasing its red pigment. If the blood cells are placed in a concentrated sugar solution, the reverse process occurs; the cells shrink and shrivel up as water moves out into the sugar solution.

The bottom half of Figure 16.4 illustrates osmosis. The transfer of the water (solvent) from the fresh side of the membrane continues until the level (shown in shaded area) rises, and the head or pressure is large enough to prevent

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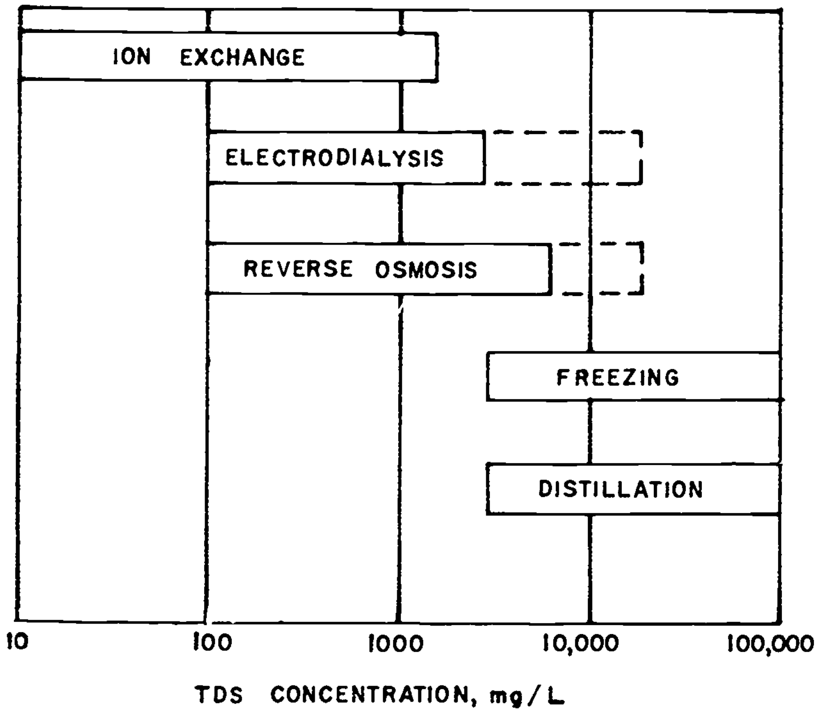
[2] *Salinity (1) The relative concentration of dissolved salts, usually sodium chloride, in a given water. (2) A measure of the concentration of dissolved mineral substances in water.*

[3] *Feedwater. The water that is fed to a treatment process; the water that is going to be treated.*



NOTE: The dashed lines indicate a feasible range of operation, but not typical range.

Fig. 16.2 Demineralization processes versus feedwater TDS concentrations

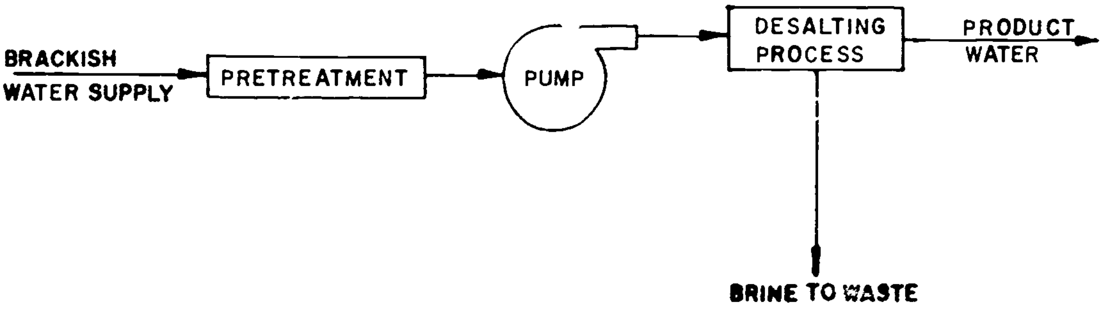
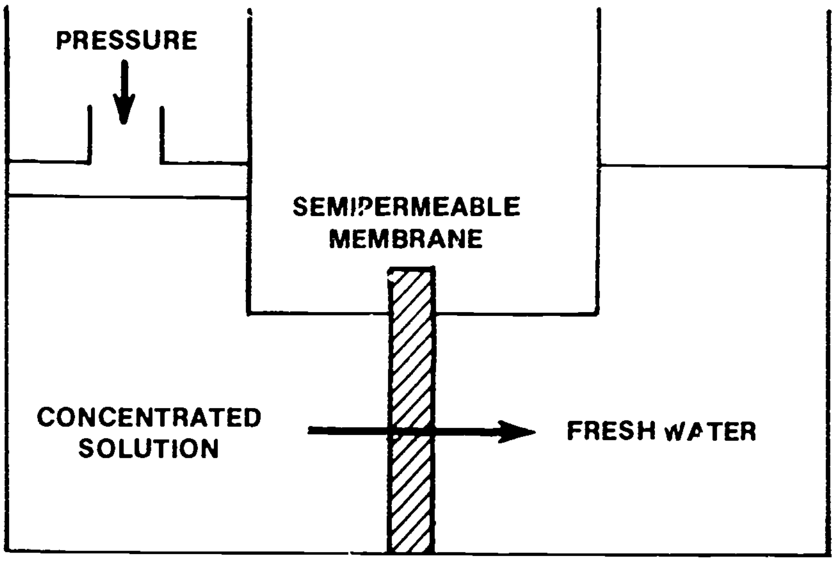


Fig. 16.3 Basic system for demineralizing processes

REVERSE OSMOSIS-FLOW REVERSED BY APPLICATION OF PRESSURE TO HIGH CONCENTRATION SOLUTION



OSMOSIS-NORMAL FLOW FROM LOW TO HIGH CONCENTRATION

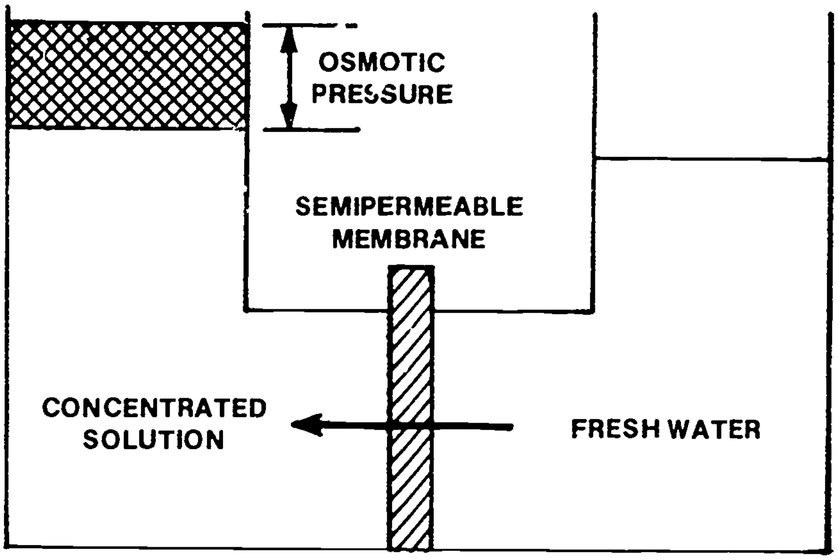


Fig. 16.4 Flows through a semipermeable membrane

any net transfer of the solvent (water) to the more concentrated solution. At equilibrium, the quantity of water passing in either direction is equal, the difference in water level between the two sides of the membrane is defined as the osmotic pressure of the solution.

If a piston is placed on the more-concentrated solution side of the semipermeable membrane (Figure 16.4) and a pressure, P, is applied which is greater than the osmotic pressure, water flows from the more concentrated solution to the "fresh" water side of the membrane. This condition illustrates the process of reverse osmosis.

16.21 Reverse Osmosis Membrane Structure and Composition

Many materials have been studied and characterized for possible value as membranes for water purification The best general-purpose membrane developed to date is simply described as a modified cellulose acetate film. The techniques for preparing these membranes were discovered by Loeb and Sourirajan at UCLA. Table 16.1 lists the important characteristics of the common types of membranes.

The modified cellulose acetate membrane in general use today is approximately 100 μ thick (that is, 100 microns or 0.004 in.). The membrane is asymmetric (one side different from the other), having on one surface a relatively dense layer approximately 2000 Å (1 cm = 1×10^8 Å or 100 million Angstroms) or 0.2 micron thick which serves as the rejecting surface. The remainder of the film is a relatively spongy porous mass, the membrane currently in use contains approximately two-thirds water by weight, and generally must be maintained wet at all times.

In recent years, progress in developing new polymeric materials superior to cellulose acetate membrane have produced a family of new materials consisting of aromatic polyamids and polyimides. Although not widely available on a commercial scale yet, these thin-film composite membranes appear to have several advantages over the old cellulose type and are considered to be the membrane of the future

TABLE 16.1 CHARACTERISTICS OF MEMBRANE TYPES

A. *CELLULOSE ACETATE CLASS*
(cellulose diacetate, cellulose triacetate and blended cellulose diacetate/triacetate)

1. Membrane must be wetted in storage.
2. Membrane is susceptible to hydrolysis at high and low pH.
3. Membrane is susceptible to deterioration in the presence of microorganisms capable of cellulose enzyme production.
4. Membrane is subject to compaction and loss of productivity with time.
5. Membrane can withstand prolonged maximum oxidant concentration of one milligram per liter.

B. *POLYAMIDE MEMBRANE*

1. Membrane is not subject to biological degradation.
2. Membrane is extremely sensitive to oxidants.
3. Membrane can operate in a pH range of 4 to 11 without hydrolysis.
4. Membrane can operate at higher temperatures without degradation.

C *THIN FILM COMPOSITE*

1. Membrane is wet-dry stable.
2. Membrane has a thin semipermeable barrier which results in a high flux.
3. Membrane has a high selectivity.
4. Membrane has an improved resistance to compaction and bacterial attack.
5. Membrane has improved stability at high temperatures.
6. Membrane is stable in acidic (pH 2) and caustic feed (pH 12).
7. Membrane is sensitive to oxidants.

16.22 Membrane Performance and Properties

The basic behavior of semipermeable cellulose acetate reverse osmosis membranes can be described by two equations. The product water flow through a semipermeable membrane can be expressed as shown in Equation 1.

EQUATION 1

$$F_w = A(\Delta P - \Delta \pi)$$

Where

F_w = Water *FLUX*[4] (gm/sq cm – sec),

A = Water permeability constant (gm/sq cm – sec atm[5]),

ΔP = Pressure differential applied across the membrane (atm),

$\Delta \pi$ = Osmotic pressure differential across the membrane (atm)

Note that the water flux is the flow of water in grams per second through a membrane area of one square centimeter. Think of this as similar to the flow through a rapid sand filter in gallons per minute through a filter area of one square foot (GPM/sq ft).

The mineral (salt) flux (mineral passage) through the membrane can be expressed as shown in Equation 2.

EQUATION 2

$$F_S = B(C_1 - C_2)$$

Where

F_S = Mineral flux (gm/sq cm – sec),

B = Mineral permeability constant (cm/sec),

$C_1 - C_2$ = Concentration gradient across the membrane (gm/cu cm).

The water permeability (A) and mineral permeability (B) constants are characteristics of the particular membrane which is used and the processing which it has received.

---

[4] *Flux. A flowing or flow.*

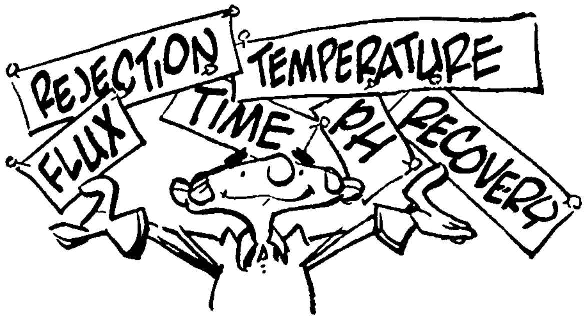
[5] *atm. The abbreviation for atmosphere. One atmosphere is equal to a pressure of 14.7 psi or 101 kPa*

An examination of Equations (1) and (2) shows that the water flux (the rate of water flow through the membrane) is dependent upon the applied pressure, *WHILE THE MINERAL FLUX IS NOT DEPENDENT ON PRESSURE.* As the pressure of the feedwater is increased, the flow of water through the membrane increases while the flow of minerals remains essentially constant. Therefore, both the quantity and the quality of the purified product should increase with increased pressure. This occurs because there is more water to dilute the same amount of mineral.

The water flux *DECREASES* (F_w) as the mineral content of the feed increases because the osmotic pressure contribution increases ($\Delta\pi$) with increasing mineral content. In other words, since $\Delta\pi$ increases, the term ($\Delta P - \Delta\pi$) decreases which results in a decrease in F_w, the water flux. Further, as more and more feed water passes through the membrane, the mineral content of the feedwater becomes higher and higher (more concentrated). The osmotic pressure contribution ($\Delta\pi$) of the concentrate increases, resulting in a lower water flux.

Finally, since the membrane rejects a constant percentage of mineral, product water quality decreases with increased feedwater concentration. Also note that Equation 2 reveals that the greater the concentration gradient ($C_1 - C_2$) across the membrane, the greater the mineral flux (mineral flow). Therefore, the greater the feed concentration, the greater the mineral flux and also mineral concentration in the product water.

Water treatment plant operators must have a basic understanding of these mathematical relationships which describe RO (reverse osmosis) membrane performance. To help develop a better understanding of the interrelationships of flux, rejection, time, temperature, pH, and recovery, further explanation of these variables continues in the next section.



EXAMPLE 1

Convert a water flux of 5 × 10^{-4} gm/sq cm − sec to gallons per day per square foot.

	Known	Unknown
Water Flux, gm/sq cm-sec	= 5 × 10^{-4} gm/cm-sec[6]	Flow, GPD/sq ft

Convert the water flux from gm/sq cm − sec to flow in GPD/sq ft.

$$\text{Flow, GPD/sq ft} = \frac{\overset{\text{Water Flux,}}{(\text{gm/sq cm-sec})}(1\ \text{liter})(1\ \text{Gal})(100\ \text{cm})^2(3600\ \text{sec})(24\ \text{hr})}{(1000\ \text{gm})(3.785\ L)(3.28\ \text{ft})^2(1\ \text{hr})(1\ \text{day})}$$

$$= \frac{(0.0005\ \text{gm/sq cm-sec})(1\ \text{Liter})(1\ \text{Gal})(100\ \text{cm})^2(3600\ \text{sec})(24\ \text{hr})}{(1000\ \text{gm})(3.785\ L)(3.28\ \text{ft})^2(1\ \text{hr})(1\ \text{day})}$$

$$= 10.6\ \text{GPD/sq ft}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 174.

16.2A What is the osmotic pressure of a solution?

16.2B What type of semipermeable membrane is commonly used today?

16.2C What is the meaning of water flux and of mineral flux? What units are used to express measurement of these quantities?

16.2D When additional pressure is applied to the side of a membrane with a concentrated solution, what happens?

16.2E When higher mineral concentrations occur in the feedwater, what happens to the product water?

16.23 Definition of Flux

The term flux is the expression used to describe the rate of water flow through the semipermeable membrane. Flux is usually expressed in gallons per day per square foot of membrane surface or in grams per second per square centimeter.

Even under ideal conditions (pure feedwater and no fouling of the membrane surface), there is a decline in water flux with time. This decrease in flux is due to membrane compaction. This phenomenon is considered comparable to "creep" observed in other plastics or even metals when subjected to compressing stresses (pressure).

The term "flux decline" is used to describe the loss of water flow through the membrane due to compaction plus fouling. In the real world, feedwaters are never "pure" and contain suspended solids, dissolved organics and inorganics, bacteria, and other potential foulants. These impurities can be deposited or grow on the membrane surface, thus hindering the flow of water through the membrane.

16.24 Mineral Rejection

The purpose of demineralization is to separate minerals from water and the ability of the membrane to reject minerals is called the mineral rejection. Mineral rejection is defined as:

EQUATION 3

$$\text{Rejection, \%} = \left(1 - \frac{\text{Product Concentration}}{\text{Feedwater Concentration}}\right) \times 100\%$$

---

[6] *5 × 10^{-4} is the same as 0.0005.*

Mineral rejections can be determined by measuring the TDS and using the above equation. Rejections also may be calculated for individual constituents in the solution by using their concentrations.

The basic equations which describe the performance of a reverse osmosis membrane indicate that rejection decreases as feedwater mineral concentration increases. Remember, this is because the higher mineral concentration increases the osmotic pressure. Figure 16.5 illustrates the rejection performance for a typical RO (reverse osmosis) membrane operating on three different feedwater solutions This figure shows that as feed mineral concentration increases (TDS in mg/*L*), rejection decreases at a given feed pressure. Notice also that rejection improves as feed pressure increases.

Typical rejection for most commonly encountered dissolved inorganics is usually between 92 to 95 percent. Divalent ions like calcium and sulfate are better rejected than monovalent ions such as sodium or chloride. Table 16.2 lists the typical rejection of an RO membrane operating on a brackish feedwater.

TABLE 16.2 TYPICAL REVERSE OSMOSIS REJECTIONS OF COMMON CONSTITUENTS FOUND IN BRACKISH WATER

Contamination	Units	Feedwater Concentration	Percent Removal
EC[a]	µmhos	1400	92
TDS[a]	mg/*L*	900	92
Calcium	mg/*L*	100	99
Chloride	mg/*L*	120	92
Sulfate	mg/*L*	338	99
Sodium	mg/*L*	158	92
Ammonia	mg/*L*	22.5	94
Nitrate	mg/*L*	2.9	55
COD[a]	mg/*L*	12.5	95
TOC[a]	mg/*L*	6.0	88
Silver	µg/*L*	1.2	88
Arsenic	µg/*L*	<5.0	—
Aluminum	µg/*L*	71.0	93
Barium	µg/*L*	24.0	96
Beryllium	µg/*L*	<1.0	—
Cadmium	µg/*L*	3.4	98
Cobalt	µg/*L*	4.6	>90
Chromium	µg/*L*	3.6	80
Copper	µg/*L*	12.7	63
Iron	µg/*L*	24.0	91
Mercury	µg/*L*	0.8	41
Manganese	µg/*L*	1.0	85
Nickel	µg/*L*	2.5	88
Lead	µg/*L*	<1.0	—
Selenium	µg/*L*	<5.0	—
Zinc	µg/*L*	<100.0	—

[a] EC, Electrical Conductivity; TDS, Total Dissolved Solids, COD, Chemical Oxygen Demand, and TOC, Total Organic Carbon

EXAMPLE 2

Estimate the ability of a reverse osmosis plant to reject minerals by calculating the mineral rejection as a percent. The feedwater contains 1500 mg/*L* TDS and the product water TDS is 150 mg/*L*.

Known		Unknown
Feedwater TDS, mg/*L*	= 1500 mg/*L*	Mineral Rejection, %
Product Water TDS, mg/*L*	= 150 mg/*L*	

Calculate the mineral rejection as a percent.

$$\text{Mineral Rejection, \%} = \left(1 - \frac{\text{Product TDS, mg}/L}{\text{Feed TDS, mg}/L}\right)(100\%)$$

$$= \left(1 - \frac{150 \text{ mg}/L}{1500 \text{ mg}/L}\right)(100\%)$$

$$= (1 - 0.1)(100\%)$$

$$= 90\%$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 174.

16.2F Water flux is usually expressed in what units?

16.2G What is "flux decline"?

16.2H How is mineral rejection measured?

16.25 Effects of Feedwater Temperature and pH on Membrane Performance

In reverse osmosis operation, feedwater temperature has a significant effect on membrane performance and must therefore be taken into account in system design and operation. Essentially, the value of the water permeation constant is only constant for a given temperature. As the temperature of the feedwater increases, flux increases. Usually, flux is reported at some standard temperature reference condition, such as 25°C. Figure 16.6 illustrates the increase in flux for a standard RO module over a range of operating temperatures when 400 psi (2758 kPa or 28 kg/sq cm) net operating pressure is applied.

You must remember that the membrane is an *ESTER*[7] and therefore subject to long-term *HYDROLYSIS*[8]. Hydrolysis results in a lessening of mineral rejection capability. The rate of hydrolysis is accelerated by increased temperature, and is also a function of feed pH (Figure 16.7). Slightly acidic pH values (5 to 6) insure a lower hydrolysis rate, as do cooler temperatures. Therefore, to insure the longest possible lifetime of the membrane and to slow hydrolysis, acid is added as a pretreatment step before demineralization. Table 16.3 indicates the relative time for mineral passage to increase 200 percent at different feedwater pH levels.

TABLE 16.3 TIME REQUIRED TO ACHIEVE A 200 PERCENT INCREASE IN MINERAL PASSAGE AT 23°C AT VARIOUS pH LEVELS

pH 5.0	6 years
6.0	3.8 years
7.0	1 year
8.0	0.14 year = 51 days
9.0	0.01 year = 3.6 days

---

[7] *Ester (ESS-ter). A compound formed by the reaction between an acid and an alcohol with the elimination of a molecule of water*

[8] *Hydrolysis (hi-DROLL-uh-sis). Chemical reaction in which a compound is converted into another compound by taking up water*

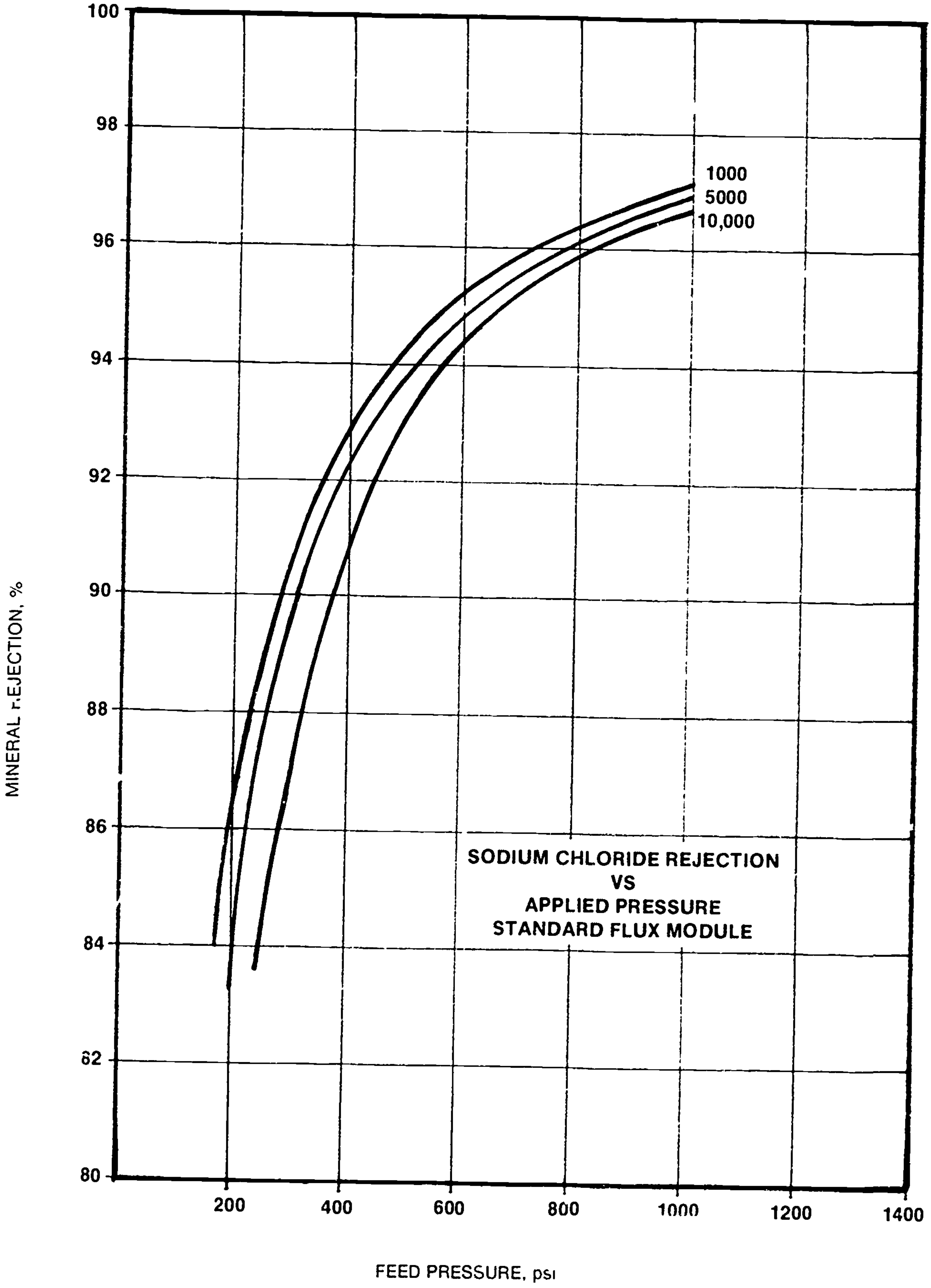


Fig. 16.5 Typical RO rejection for three different feedwater concentrations of TDS in mg/L

(Source REVERSE OSMOSIS PRINCIPLES AND APPLICATIONS by Fluids Systems. Division of UOP. October 1970)

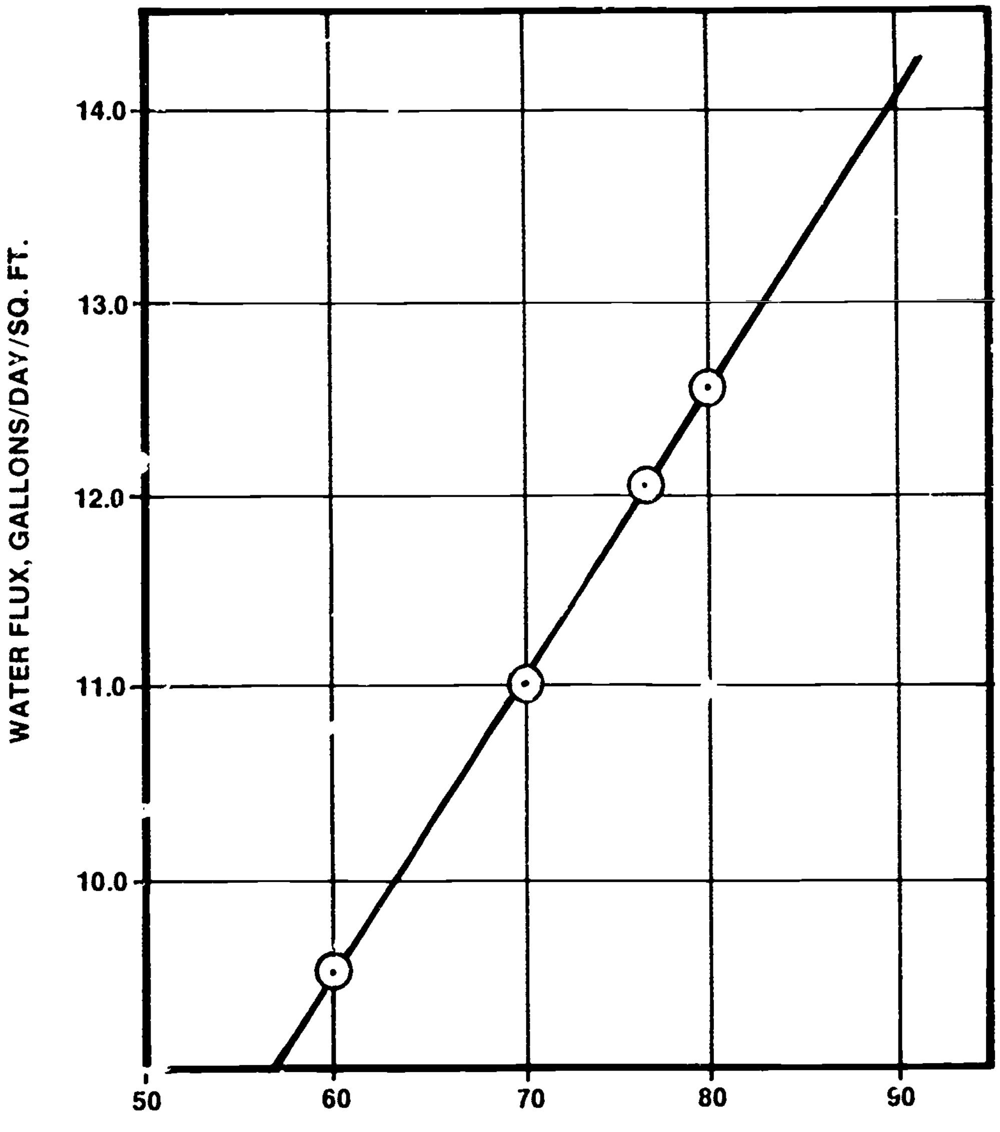


Fig. 16.6 Effect of temperature on water flux rate, cellulose acetate membrane operating pressure at 400 psi (2758 kPa or 28 kg/sq cm) net

(Source *REVERSE OSMOSIS PRINCIPLES AND APPLICATIONS* by Fluids Systems, Division of UOP, October 1970

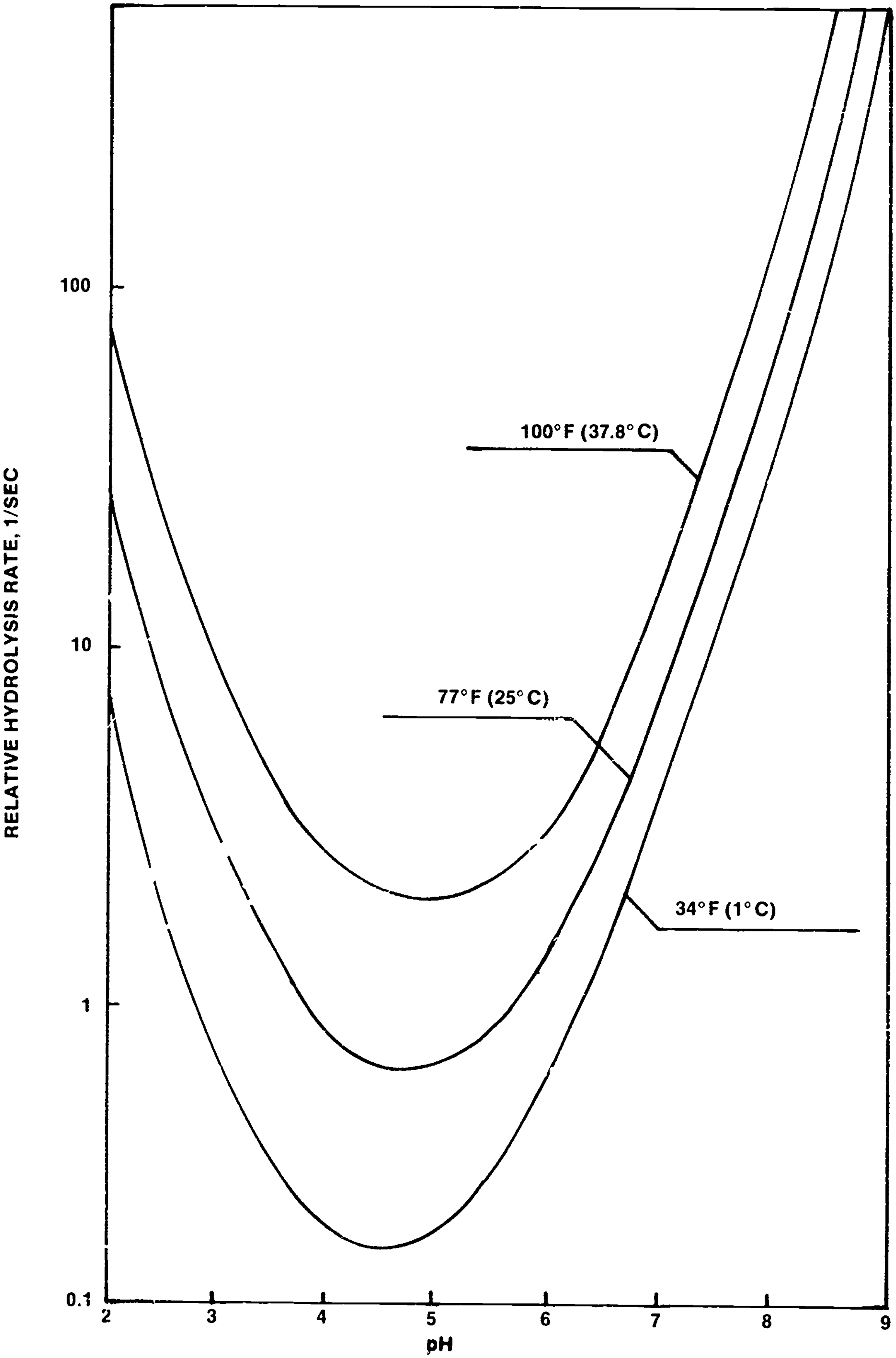


Fig. 16.7 Effect of temperature and pH on hydrolysis rate

16.26 Recovery

Recovery is defined as the percentage of feed flow which is recovered as product water. Expressed mathematically, recovery can be determined by Equation 4

EQUATION 4

$$\text{Recovery, \%,} = \frac{\text{Product Flow}}{\text{Feed Flow}} (100\%)$$

The recovery rate is usually determined or limited by two considerations. The first is the desired product water quality. Since the amount of mineral passing through the membrane is influenced by the concentration differential between the brine and product, there is a possibility of exceeding product quality criteria with excessive recovery. The second consideration concerns the solubility limits of minerals in the brine. One should not concentrate the brine to a degree that would precipitate minerals on the membrane. This effect is commonly referred to as concentration polarization.

THE MOST COMMON AND SERIOUS PROBLEM RESULTING FROM CONCENTRATION POLARIZATION IS THE INCREASING TENDENCY FOR PRECIPITATION OF SPARINGLY SOLUBLE SALTS AND THE DEPOSITION OF PARTICULATE MATTER ON THE MEMBRANE SURFACE.

In any flowing hydraulic system, the fluid near a solid surface travels more slowly than the main stream of the fluid. In other words, there is a liquid boundary layer at the solid surface. This is also true at the surface of the membrane in a spiral wound element or in any other membrane packaging configuration. Since water is transmitted through the membrane at a much more rapid rate than minerals, the concentration of the minerals builds up in the boundary layer and it is necessary for the minerals to diffuse back into the flowing stream. The ratio of the mineral concentration in the boundary layer (layer of water next to membrane) to the mineral concentration in the flowing water is defined as concentration polarization. Polarization will reduce both the flux and rejection of a reverse osmosis system. Since it is impractical to totally eliminate the polarization effect, it is necessary to minimize it by good design and operation.

The boundary layer effect can be minimized by increased water flow velocity and by promoting turbulence within the RO elements. Brine flow rates can be kept high as product water is removed by staging (reducing) the module pressure vessels. This is popularly referred to as a "Christmas Tree" arrangement. Typical flow arrangements such as 4 units - 2 units - 1 unit (85 percent recovery) or 2 units - 1 unit (75 percent recovery) are used most often (Figure 16.8).

These configurations consist of feeding water to a series of pressure vessels in parallel where about 50 percent of the water is separated by the membrane as product water and 50 percent of the water is rejected The reject is then fed to half as many vessels in parallel where again about 50 percent is product water and 50 percent rejected. This reject becomes the feed for the next set of vessels. By arranging the pressure vessels in the 4-2-1 arrangement, it is possible to recover over 85 percent of the feedwater as product water and to maintain adequate flow rates across the membrane surface to minimize polarization. For example, a system consisting of a total of 35 vessels would have a configuration of 20-10-5 pressure vessel arrangement for an 85 percent recovery.

EXAMPLE 3

Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 5.88 MGD and the product flow is 5.0 MGD.

Known		Unknown
Product Flow, MGD	= 5.0 MGD	Recovery, %
Feed Flow, MGD	= 5.88 MGD	

Calculate the recovery as a percent

$$\text{Recovery, \%} = \frac{(\text{Product Flow, MGD})(100\%)}{(\text{Feed Flow, MGD})}$$

$$= \frac{(5.0\text{ MGD})(100\%)}{(5.88\text{ MGD})}$$

$$= 85\%$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 174

16.2I How will an increase in feedwater temperature influence the water flux?

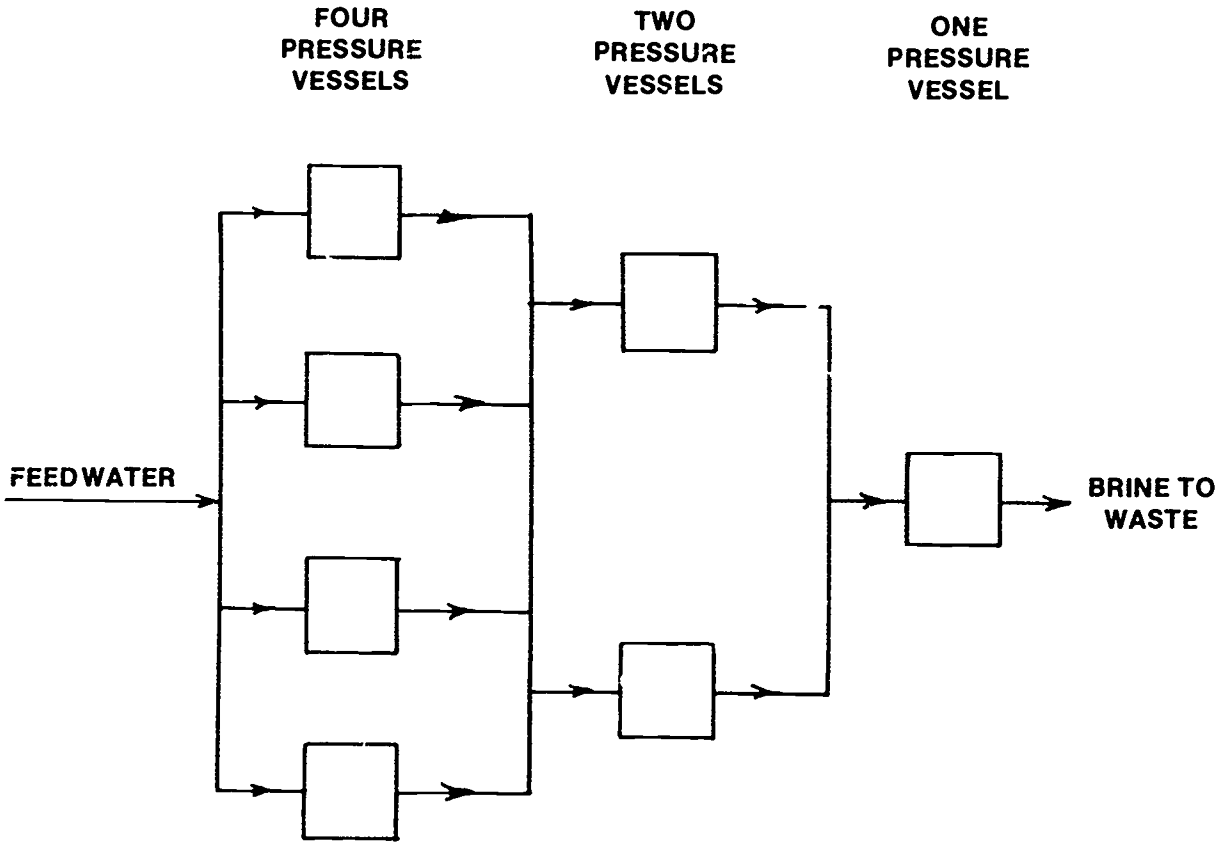
16.2J How does hydrolysis influence the mineral rejection capability of a membrane?

16.2K How is recovery defined?

16.2L Recovery rate is usually limited by what two considerations?

16.2M Define concentration polarization.

End of Lesson 1 of 3 Lessons
on
DEMINERALIZATION



NOTES:
1. BRINE FLOWS OUT OF PRESSURE VESSELS TO NEXT VESSEL.
2. PRODUCT WATER IS NOT SHOWN. PRODUCT WATER FLOWS OUT OF EACH VESSEL INTO A COMMON HEADER.

Fig. 16.8 Typical 4-2-1 "Christmas Tree" arrangement

DISCUSSION AND REVIEW QUESTIONS

Chapter 16. DEMINERALIZATION

(Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. Why has brackish water not been widely used for municipal drinking water supplies?
2. What is reverse osmosis?
3. Indicate what will happen to both the water flux and mineral flux when:
   1. Pressure differential applied across the membrane (ΔP) increases,
   2. Osmotic pressure differential across the membrane ($\Delta\pi$) increases, and
   3. Concentration gradient across the membrane ($C_1 - C_2$) increases.
4. What usually happens to water flux with time and why?
5. How does fouling develop on membranes?
6. What factors influence the rate of hydrolysis of a membrane and how?
7. What is the most common and serious problem resulting from concentration polarization?
8. Why do demineralization plants use a pressure vessel Christmas tree configuration?

CHAPTER 16. DEMINERALIZATION

(Lesson 2 of 3 Lessons)

16.3 DIFFERENT TYPES OF REVERSE OSMOSIS PLANTS

Operating plants use the RO principle in several different process designs and membrane configurations. There are three types of commercially available membrane systems which have been used in operating plants:

1. Spiral wound,
2. Hollow fine fiber, and
3. Tubular.

The spiral-wound RO module was developed by Gulf Environmental Systems Company (now Fluid Systems Division, UOP) under contract to the U.S. Office of Saline Water. This RO unit was conceived as a method of obtaining a relatively high ratio of membrane area to pressure vessel volume. The membrane is supported on both sides of a backing material and sealed with glue on 3 of the 4 edges of the laminate. The laminate is also sealed to a central tube which has been drilled to allow the demineralized water to enter. The membrane surfaces are separated by a screen material which acts as a brine spacer. The entire package is then rolled into a spiral configuration and wrapped in a cylindrical form. The membrane modules are loaded, end to end, into a pressure vessel as shown in Figure 16.9. Feed flow is parallel to the central tube while *PERMEATE*[9] flows through the membrane toward the central tube. Plants using this type of system include the brackish water demineralizing plants at Key Largo, Florida and Kashima, Japan; the wastewater demineralizing plants in California; and the sea water demineralizing plant at Jeddah in Saudi Arabia.

The hollow fiber type of membrane was developed by DuPont and Dow Chemical. The membranes manufactured by DuPont are made of aromatic polyamide fibers about the size of a human hair with an inside diameter of about 0.0016 inch (0.04 mm). In these very small diameters, fibers can withstand high pressures. In an operating process the fibers are placed in a pressure vessel; one end of each fiber is sealed and the other end protrudes outside the vessel. The brackish water is under pressure on the outside of the fibers and product water flows inside of the fiber to the open end. A DuPont module is illustrated in Figure 16.10. For operating plants, the membrane modules are assembled in a configuration similar to the spiral wound unit. Municipal demineralizing plants (manufactured by DuPont) in Greenfield, Iowa and in Florida and sea water demineralizing plants in the Middle East use this type of membrane.

Tubular membrane processes operate on much the same principle as the hollow fine fiber except that the tubes are much larger in diameter, on the order of 0.5 inch (12 mm). Use of this type of membrane system is usually limited to special situations such as for wastewater with high suspended solids concentration. The tubular membrane process is not economically competitive with other available systems for treatment of most waters.

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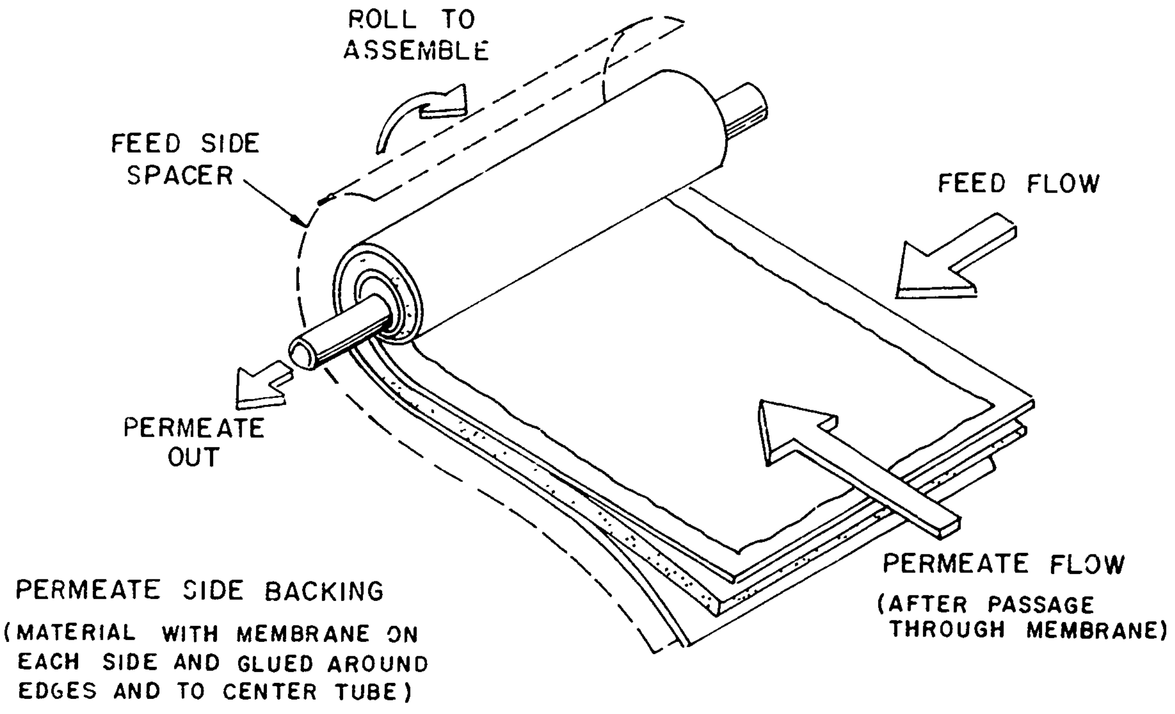
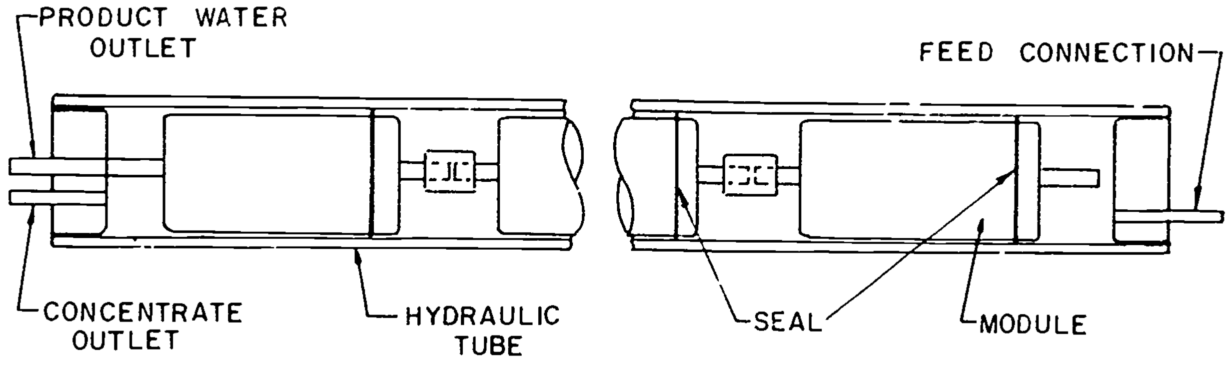
[9] *Permeate (PURR-me-ate). The desalted water. This is the water that has passed through the membrane.*



SPIRAL-WOUND REVERSE OSMOSIS MODULE



PRESSURE VESSEL ASSEMBLY

Fig. 16.9 Spiral-wound reverse osmosis module (as manufactured by UOP)

(From paper by Mack Wesner, "Desalting Process and Pretreatment," published in Proceedings on "Role of Desalting Technology," a series of Technology Transfer Workshops presented by the Office of Water Research and Technology)

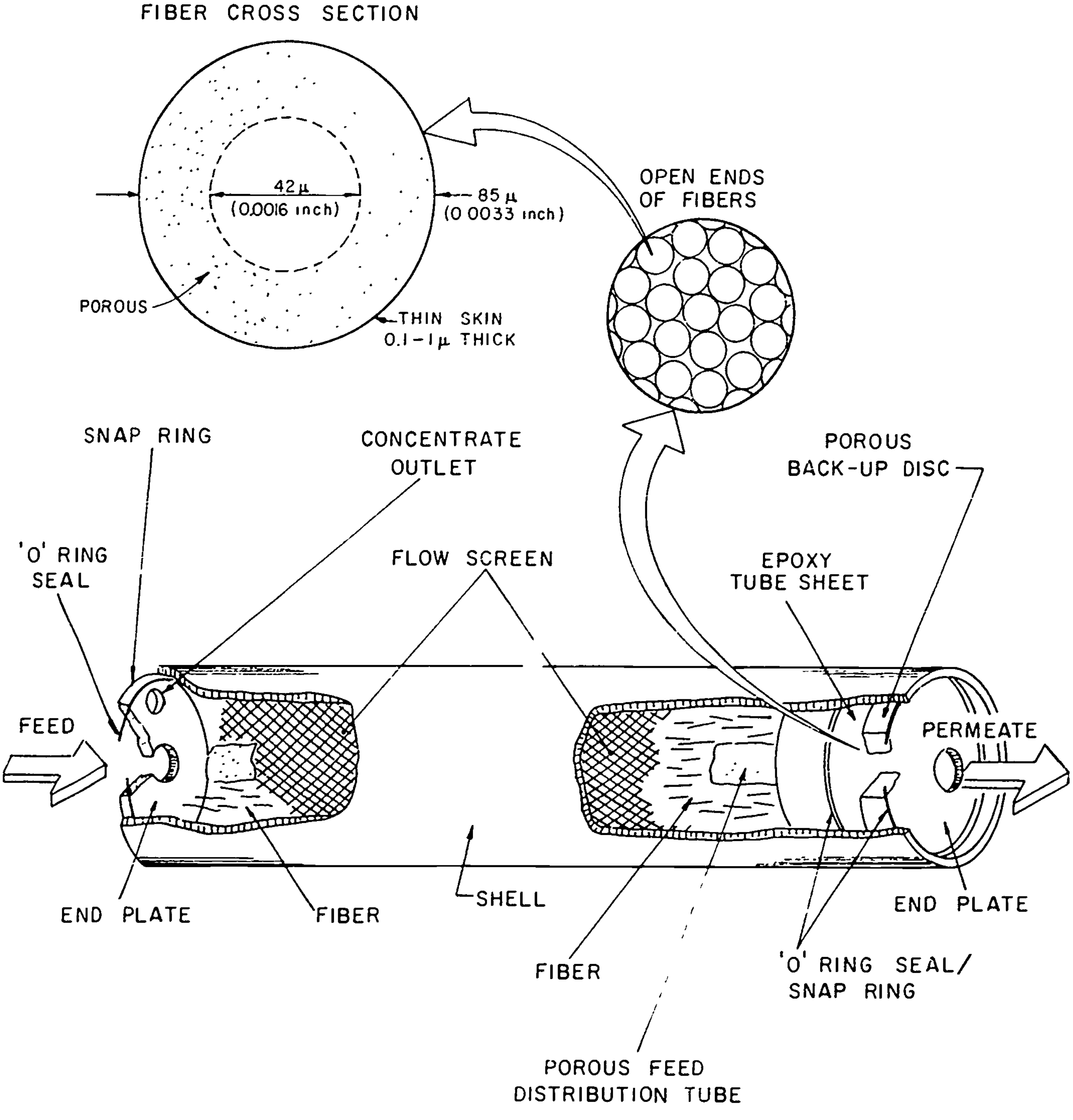


Fig. 16.10 Hollow fiber reverse osmosis module (as manufactured by DuPont)

(From paper by Mack Wesner, "Desalting Process and Pretreatment," published in Proceedings on "Role of Desalting Technology," a series of Techr ›logy Transfer Workshops presented by the Off.ce of Water Research and Technology)

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.3A List the three types of commercially available membrane systems which have been used in operating plants.

16.3B What type of membrane process is used to treat wastewater with a high suspended solids concentration?

16.4 OPERATION

16.40 Pretreatment

Water to be demineralized always contains impurities which should be removed by pretreatment to protect the membrane and to assure maximum efficiency of the reverse osmosis process. Depending on the water to be demineralized, it is usually necessary to treat the feedwater to remove materials and conditions potentially harmful to the RO process such as:

1. Remove turbidity/suspended solids,
2. Adjust pH and temperatures,
3. Remove materials to prevent scaling or fouling, and
4. Disinfect to prevent biological growth.

16.41 Removal of Turbidity and Suspended Solids

In general, the feedwater should be filtered to protect the reverse osmosis system and its accessory equipment. When the water source is a groundwater or previously treated municipal or industrial supply, this may be accomplished by a simple screening procedure. However, such a procedure may not be adequate when the source is an untreated surface water. The amount of suspended matter in surface waters may vary by several orders of magnitude and may change radically in character and composition in a very short time. In such cases, in addition to the mechanical action of the filter, the operator may have to introduce chemicals for coagulation and flocculation and use filtration equipment in which the media can be washed or renewed at low cost. Pressure and gravity sand filters and diatomaceous earth filters may be required, particularly for large installations. Where the particulates approach or are *COLLOIDAL*,[10] chemical treatment and filtration are almost essential.

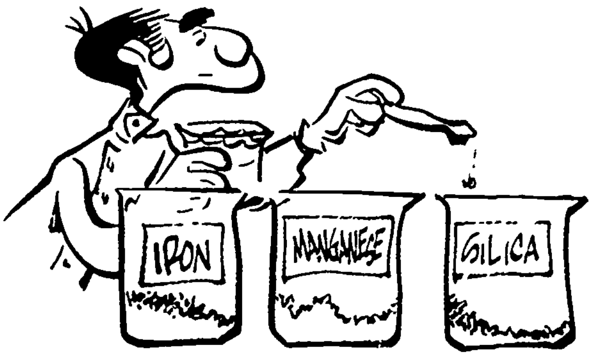
Cartridge filters function as a particle safeguard and not as a primary particle removal device. In general, the influent turbidity to a cartridge filter should be less than one TU. Typical cartridge filter sizes range from 5 to 20 microns and loading rates vary from 2 to 4 GPM sq ft (1.4 to 2.8 mm/sec).

16.42 pH and Temperature Control

As previously discussed, an important limiting factor in the life of cellulose acetate membranes in reverse osmosis is the rate of membrane hydrolysis. Cellulose acetate will break down (hydrolyze) to cellulose and acetic acid. The rate at which this hydrolysis occurs is a function of feedwater or source water pH and temperature. As the membrane hydrolyzes, both the amount of water and the amount of solute which permeate the membrane increase and the quality of the product water deteriorates. The rate of hydrolysis is at a minimum at a pH of about 4.7, and it increases with both increasing and decreasing pH. Thus it is standard practice to inject acid, usually sulfuric acid, to adjust feedwater pH to 5.5 Not only does pH adjustment minimize the effect of hydrolysis, but it is also essential in controlling precipitation of scale-forming or membrane-fouling minerals.

Calcium carbonate and calcium sulfate are probably the most common scaling salts encountered in natural waters and are certainly the most common cause of scale in reverse osmosis systems. The addition of a small amount of acid can reduce the pH to a point where the alkalinity is reduced; this shifts the equilibrium to the point where calcium bicarbonate, which is much more soluble, is present at all points within the reverse osmosis loop. Neutralization of 75 percent of the total alkalinity usually provides sufficient pH adjustment to achieve calcium carbonate scale control and bring the membrane into a reasonable part of the hydrolysis curve. The pH reached by 75 percent neutralization is about 5.7. Calcium carbonate precipitation is also inhibited by the control procedure used for calcium sulfate.

Calcium sulfate is relatively soluble in water in comparison to calcium carbonate. Again, however, as "pure" or product water is removed from a feed solution containing calcium and sulfate, these chemicals become further concentrated in the feed water. When the limits of saturation are eventually exceeded, precipitation of calcium sulfate will occur. Since calcium sulfate solubility occurs over a wide pH range, the scale control method used to inhibit calcium sulfate precipitation is a threshold treatment[11] with sodium hexametaphosphate (SHMP). This precipitation inhibitor represses both calcium carbonate and calcium sulfate by interfering with the crystal formation process. Other polyphosphates may also be used but are not as effective as the hexametaphosphate. Generally 2 to 5 mg/*L* of SHMP are added to the feedwater to decrease precipitation of calcium sulfate.



16.43 Other Potential Scalants

The oxides or hydroxides most commonly found in water are those of iron, manganese, and silica. The oxidized and precipitated forms of iron, manganese and silica can be a serious problem to any demineralization scheme because they can coat the reverse osmosis membrane with a tenacious (difficult to remove) film which will affect performance. The scale inhibitor most frequently used is sodium hexametaphosphate.

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[10] *Colloids (CALL-loids). Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.*

[11] *Threshold treatment refers to the practice of using the least amount of chemical to produce the desired effect.*

16.44 Microbiological Organisms

Reverse osmosis modules provide a large surface area for the attachment and growth of bacterial slimes and molds. These organisms may cause membrane fouling or even module pluging. There is also some evidence that occasionally the enzyme systems of some organisms will attack the cellulose acetate membrane. The continuous application of chlorine to produce a 1 to 2 mg/*L* chlorine residual will help inhibit or retard the growth of most of the organisms encountered. However, caution must be exercised since continuous exposure of the membrane to higher chlorine residuals will impair membrane efficiency. Shock concentrations of up to 10 mg/*L* of chlorine are applied from time to time. When an oxidant intolerant polyamide type membrane is used, cholorination must be followed with dechlorination. One of the dechlorination agents, sodium bisulfite is also known to be a disinfectant. Another disinfection option is the use of ultraviolet disinfection which leaves no oxidant residual in the water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.4A How are turbidity and suspended solids removed from feedwater to the reverse osmosis system?

16.4B How are colloidal particulates removed from feedwater to the reverse osmosis system?

16.4C What happens to the product water as an acetate membrane hydrolyzes?

16.4D How is the precipitation of calcium sulfate prevented?

16.4E How is biological fouling on membranes controlled?

16.45 RO Plant Operation

Following proper pretreatment, the water to be demineralized is pressurized by high pressure feed pumps and delivered to the RO pressure vessel membrane assemblies. An example of a typical RO plant layout is given in Figure 16.11. The membrane assemblies consist of a series of pressure vessels (usually fiberglass-reinforced plastic) arranged in the "Christmas Tree layout" depending on the desired recovery. Typical operating pressure for brackish water demineralizing varies from 400 to 500 psi (2760 to 3450 kPa or 28 to 35 kg/sq cm). A control valve on the influent manifold regulates the operating pressure. The volumes of feed flow and of product water are also monitored. The demineralized water is usually called permeate, and the reject, brine. The recovery rate is controlled by increasing feed flow (increase operating pressure) and controlling the brine or reject with a preset brine control valve. The operator must properly maintain and control all flows and recovery rates to avoid possible damage to the membranes from scaling.

You must remember that the

BRINE FLOW VALVES ARE NEVER TO BE FULLY CLOSED.

Should they be accidentally closed during operation, 100 percent recovery will result in almost certain damage to the membranes due to precipitation of inorganic salts ($CaSO_4$). Product or permeate flow is not regulated and varies as feedwater pressure and temperature change as previously discussed.

Most RO systems are designed to operate automatically and require a minimum of operator attention. However, the continuous monitoring of system performance is an important aspect of operation. An example of a typical operation log for monitoring the Orange County Water District's 5 MGD (19 MLD) RO plant is given in Table 16.4.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.4F How is the operating pressure on a reverse osmosis unit regulated?

16.4G The demineralized water is usually called ______, the reject ________.

16.4H How does the product or permeate flow vary or change?

16.46 Typical RO Plant Operations Checklist

1. Check cartridge filters. Properly installed filters insure additional removal of suspended solids that could damage either the high pressure feed pumps or foul the membrane elements. Cartridge filters should be replaced whenever head loss exceeds manufacturer's recommendations or effluent turbidity exceeds one TU.
2. Start up and check scale inhibitor feeding equipment and adjust feed rate to desired dose (2 to 5 mg/*L*). Most RO systems should not be operated without the addition of a scale inhibitor to protect membranes from precipitation of calcium sulfate or other inorganics. The scale inhibitor most frequently used is sodium hexametaphosphate.
3. If chlorine is used to prevent biological fouling, start chlorine feed and adjust dose to produce a chlorine residual of between 1 and 2 mg/*L*.
4. Start up and adjust acid feed system to correct feedwater pH to a level between 5.0 and 6.0 to protect membranes from possible damage due to hydrolysis. Note, feedwater should always be bypassed until the pH is properly adjusted.
5. Most RO systems are designed with automatic controls and various shutdown alarms. These alarms prevent startup or running of the unit until proper operating conditions are reached. After satisfying these conditions, high pressure feed pumps can be started and water delivered to the RO units. A control valve is used to regulate feedwater pressure. Typical operating pressures vary from 350 to 500 psi (2400 to 3400 kPa or 25 to 35 kg/sq cm).

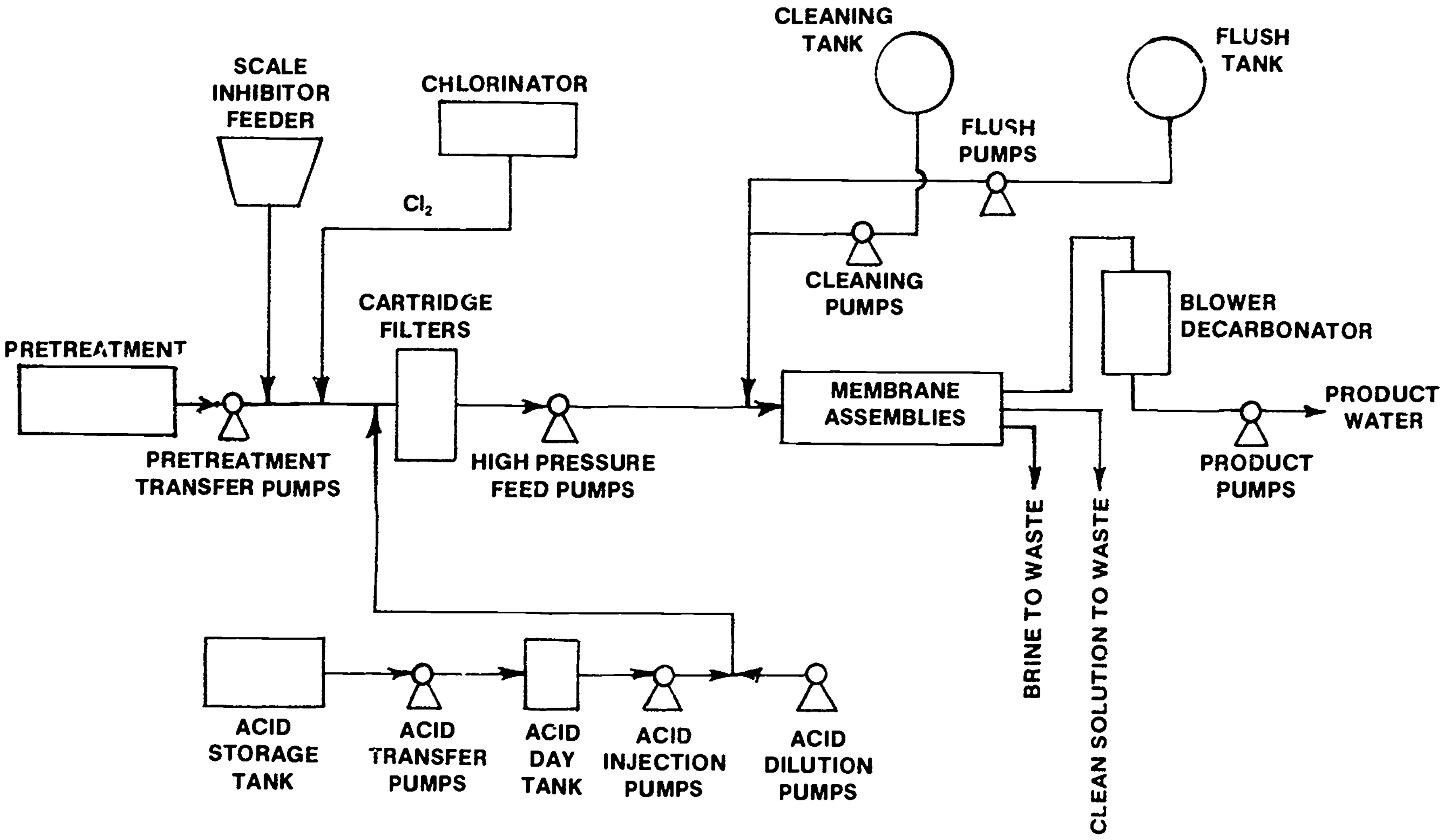

Fig. 16.11 RO flow diagram

TABLE 16.4 DATA SHEET ORANGE COUNTY WATER DISTRICT 5.0 MGD (19 MLD) REVERSE OSMOSIS SYSTEM

TIME	Pretreatment															
	Cl mg/l	Cartridge Filters								Turb NTU	Temp °F	Feed Cond µmhos/cm	pH	Pump 2 Disch		
		#1 psig		#2 psig		#3 psig		#4 psig						A psig	B psig	C psig
0400																
1200																
2000																

TIME	RO Unit 1			RO Unit 2			Total Brine				Total Product		
	Feed psig	Feed Flow MGD	Product Cond (µ)	Feed psig	Feed Flow MGD	Product Cond. (µ)	Flow MGD	pH	Conductivity µmhos/cm	KWH Ton	pH	Conductivity µmhos/cm	Flow MGD
0400													
1200													
2000													

TIME	RO Unit 1																	
	Section 1A-Product EC						Section 1B-Product EC						Section 1C-Product EC					
	Feed psig	Δ P			Product gpm	Brine MGD	Feed psig	Δ P			Product gpm	Brine MGD	Feed psig	Δ P			Product gpm	Brine MGD
		1st	2nd	3rd				1st	2nd	3rd				1st	2nd	3rd		
0400																		
1200																		
2000																		

TIME	RO Unit 2																	
	Section 2A-Product EC						Section 2B-Product EC						Section 2C-Product EC					
	Feed psig	Δ P			Product gpm	Brine MGD	Feed psig	Δ P			Product gpm	Brine MGD	Feed psig	Δ P			Product gpm	Brine MGD
		1st	2nd	3rd				1st	2nd	3rd				1st	2nd	3rd		
0400																		
1200																		
2000																		

TABLE 16.4 (Continued) DATA SHEET ORANGE COUNTY WATER DISTRICT 5.0 MGD (19 MLD) REVERSE OSMOSIS SYSTEM

Shift	Operator

Date

24 Hour Totalizer				
TIME	Feed Flow MGD	Bypass Flow MGD	Total Product MGD	Total Brine MGD
(A)2400$^{(II)}$				
(B)2400$^{(I)}$				

Cl$_2$	SHMP	ACID	ELAPSED TIME		POWER
2400$^{(11)}$			RO #1	RO #2	2400$^{(11)}$
2400$^{(1)}$	lbs	gal			2400$^{(1)}$

REMARKS:

6. Adjust feed and brine flow to establish the desired recovery rate
7. Once flow has been established, check the differential pressure (ΔP) across the RO unit which is usually indicated by a meter and recorded. The importance of ΔP relates to cleaning. When the elements become fouled, ΔP usually increases, thus indicating the need for cleaning. The ΔP should not exceed 70 to 100 psi (483 to 690 kPa or 5 to 7 kg/sq cm) because of possible damage to the RO modules.
8. With the system on-line, monitor the performance. Rely on flow measurements, product water quality, and various pressure indications. A sample of a typical log sheet is shown in Table 16.4.

16.47 Membrane Cleaning

Periodically the performance of the RO system will decline. This is usually observed when either the product water flow rate (flux) decreases, or salt removal (rejection) decreases. Table 16.5 summarizes common causes of membrane damage or loss of performance. Note that in Cases III and IV the corrective action requires cleaning of the element. Provisions for the periodic cleaning of the reverse osmosis elements are usually included in the system design. This makes it possible to clean impurites off the membrane surface and restore normal flow rates without removing the elements from the pressure vessels. Element cleaning should be performed at regular intervals to assure as low an operating pressure as practical. The elements should be cleaned when the pressure required to maintain the rated capacity has either been increased by 15 percent (or a 15 percent decrease in product water flow has occurred at constant pressure), or a rise of 15 percent in the system differential pressure has been observed.

Most RO systems are provided with in-place cleaning systems. This includes tanks, pumps, valves and piping for mixing and pumping cleaning solutions through the membrane elements. For cleaning, the unit is shut down and cleaning solutions are pumped through the vessels in a manner similar to feedwater Typically, cleaning solutions are passed through the pressure vessels at low pressure and at flow rates where the ΔP does not exceed 60 psi (414 kPa or 4.2 kg/sq cm) to avoid damaging the elements. The cleaning solutions are returned to clean tanks at the end of a cleaning cycle which usually lasts about one hour. Different cleaning solutions are available for use depending upon the type of fouling. Membranes are typically cleaned for approximately 45 minutes after which the cleaning solution is spent.

To remove inorganic precipitates, use an acid flush of citric acid. For biological or organic fouling, various solutions of detergents, sequestrants, chelating agents, bactericides, and enzymes are available. Examples include sodium tripolyphosphate, B13, Triton X-100, and EDTA.

To improve the long-term performance of an RO system, the membranes should be flushed with flush water during periods of shutdown to remove raw feed water and concentrate. If raw water is allowed to remain in the unit, precipitation may occur. Flushing is also done after cleaning to remove the cleaning solution prior to system startup. In some cases, where the system is shutdown for long periods of time, formaldehyde may be added to the flush water to inhibit biological growth.

TABLE 16.5 SUMMARY OF COMMON CAUSES OF MEMBRANE DAMAGE

	Symptoms	Cause	Restoration Procedures
Case I	1. Lower product water flow rate 2. Higher salt rejection	Membrane compaction[a] accelerated by operating pressure greater than 500 psi (3450 kPa or 35 kg/sq cm).	None. Requires element replacement when product water flow rate reaches an unacceptable level.
Case II	1. Higher product level flow rate 2. Lower salt rejection	Membrane hydrolysis 1. pH outside operating limits 2. Bacteria degradation 3. Temperature outside operating limits.	Injection of colloid 189 (size) or element replacement.
Case III	1. Lower product water flow rate 2. Lower salt rejection	Membrane fouling.	Element cleaning.
Case IV	1. Lower product water flow rate 2. High ΔP 3. High operating pressure	Membrane fouling.	Element cleaning.

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[a] Membrane Compaction. Product water flow rate declines with operational time in addition to fouling of the membrane surface due to other factors. Water flow rate plotted versus time on log-log paper will yield a straight line (flow rate decline).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.4I Why is chlorine added to the feedwater to a reverse osmosis unit?

16.4J Why must the operator check the differential pressure (ΔP) across the RO unit?

16.4K When should the reverse osmosis elements be cleaned?

16.48 Safety

16.480 Use Proper Procedures

As in any water treatment plant, there are forces and chemicals used in a reverse osmosis plant which must be handled properly to insure the safety and protection of personnel. Safety needs for demineralization plants can be divided into three general groups consisting of chemicals, electrical, and hydraulics.

16.481 Chemicals

Operation of an RO plant requires the use of a wide variety of chemicals. Whenever you must handle chemicals, follow the proper procedures for each chemical. Manufacturer's recommendations for use of each chemical must be observed. A list of the commonly used chemicals requiring special handling found in an RO plant operation include:

1. Acid,
2. Chlorine,
3. Sodium hexametaphosphate,
4. Formaldehyde,
5. Citric acid, and
6. Numerous cleaning agents.

See Chapter 20, "Safety," for more detailed procedures on the safe use of hazardous chemicals.

16.482 Hydraulic Safety

For the reverse osmosis process to function properly, hydraulic pressure in excess of the solution's average osmotic pressure (π) is required. Within the plant, therefore, most of the pipes, tubing, vessels, and their associated equipment, along with the substances inside these items operate under varying levels of hydraulic pressure (200 to 500 psi, 1380 to 3450 kPa, or 14 to 35 kg/sq cm). Therefore, prior to *ANY* repairs, modifications, or work of any kind, *NO MATTER HOW MINOR*, know the substances contained, isolate the piece of equipment and equalize pressure levels to atmospheric pressure.

After being repaired, any piece of equipment should be purged of *ALL* foreign substances *BEFORE* being restarted. When bringing a piece(s) of equipment on-line, increase the hydraulic pressures slowly. Keep all personnel in a safe area to maximize their personal safety.

16.483 Electrical Safety

An RO plant consists of a series of electrically powered pumps and mechanical equipment. Electric shocks due to the use of electrical equipment occur without warning and are usually serious. The average individual thinks of the hazards of electric shock in terms of high voltage and does not always realize that it is primarily the current that kills, not the voltage. Consequently, persons who work around low-voltage equipment do not always have the same healthy respect for current as they do for high voltage. Whenever working around electrically operated equipment, strictly observe all applicable rules of the National Electrical Safety Code.[12]

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.4L List the three general groups of safety needs for a demineralization plant.

16.4M What type of electrical equipment is used around reverse osmosis plants?

End of Lesson 2 of 3 Lessons
on
DEMINERALIZATION

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[12] *NATIONAL ELECTRICAL SAFETY CODE. Available from Institute of Electrical and Electronic Engineers, Inc., IEEE Service Center, PO Box 1331, 445 Hoes Lane, Piscataway, NJ 08855-1331.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 16. DEMINERALIZATION

(Lesson 2 of 3 Lessons)

Write the answers to these questions in your notebook before continuing The problem numbering continues from Lesson 1

9. Why does water to be demineralized require pretreatment?
10. What problems are created for demineralization processes by the oxidized and precipitated forms of iron, manganese and silica?
11. How does the operator of a reverse osmosis plant avoid possible damage to the membrane from scaling?
12. What will happen in a reverse osmosis plant if the brine flow valves are accidentally closed during operation?
13. What is the purpose of cartridge filters and when should they be replaced?
14. How can the operator determine if the performance of the RO system is declining?
15. What does hydraulic safety consist of around a reverse osmosis process?

CHAPTER 16. DEMINERALIZATION

(Lesson 3 of 3 Lessons)

16.5 ELECTRODIALYSIS

Electrodialysis (ED) is a well developed process with a history of many years of operation on brackish well water supplies. A 650,000 GPD (2.5 MLD) ED plant, manufactured by Ionics, Inc., Watertown, Massachusetts, began operation on well water at Buckeye, Arizona in September 1972 and has been in continuous operation to date. ED plants are also in operation demineralizing municipal water supplies in Siesta Key, Florida; Sanibel Island, Florida; Sorrento Shores, Florida and at the Foss Reservoir in Oklahoma. The process is also used for industrial water demineralizing.

Typical removals of inorganic salts from brackish water by ED range from 25 to 40 percent of dissolved solids per stage of treatment. Higher removals require treatment by multiple stages in series. Less than 20 percent of the organics remaining in activated carbon treated secondary effluent are removed by electrodialysis. Energy required for ED is about 0.2 to 0.4 kilowatt-hours per 1000 gallons (kWh/1000 gal) for each 100 mg/L dissolved solids removed, plus 2 to 3 kWh/1000 gal for pumping feedwater and brine. Advantages of the ED process include: (1) well developed technology, including equipment and membranes; (2) efficient removal of most inorganic constituents; and (3) waste brine contains only salts removed plus a small amount of acid used for pH control in some ED applications.

In the ED process brackish water flows between alternating cation-permeable and anion-permeable membranes as illustrated in Figure 16.12. A direct electric current provides the motive force to cause ions to migrate through the membranes. Many alternating cation and anion membranes, each separated by a plastic spacer, are assembled into membrane stacks. The spacers (about 0.04 inches or one mm thick) contain the water streams within the stack and direct the flow of water through a tortuous path across the exposed faces of the membranes. Membrane thicknesses generally range between 0.005 and 0.025 inches or 0.125 to 0.625 mm.

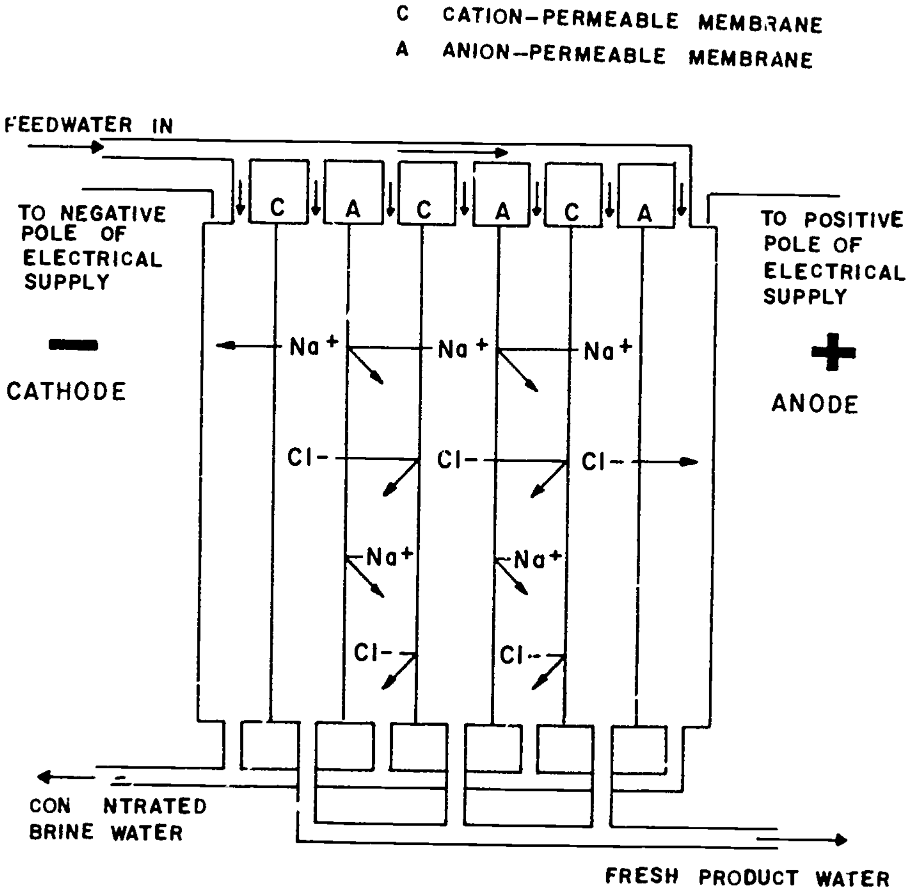


Fig. 16.12 Electrodialysis demineralization process
(From *STANDARD OPERATION INSTRUCTION PLAN FOR ELECTRODIALYSIS*, prepared by IONICS, Inc.)

Physically, the equipment takes the form of a plate-and-frame assembly similar to that of a filter press. The spacers determine the thickness of the solution compartments and also define the flow paths of the water over the membrane surface. Several hundred membranes and their separating spacers are usually assembled between a single set of electrodes to form a membrane stack. End plates and tie rods complete the assembly. When a membrane is placed between two salt solutions and subjected to the passage of a direct electric current, most of the current will be carried through the membrane by ions, hence the membrane is said to be ion selective. Typical selectivities are greater than 90 percent. When the passage of current is continued for a sufficient length of time, the solution on the side of the membrane that is furnishing the ions becomes partially desalted, and the solution adjacent to the other side of the membrane becomes more concentrated. These desalting and concentrating phenomena occur in thin layers of solution immediately adjacent to the membrane resulting in the desalting of the bulk of the solution.

Passage of water between the membranes of a single stack, or stage, usually requires 10 to 20 seconds, during which time the entering minerals in the feedwater are removed. The actual percentage removal that is achieved varies with water temperature, type and amounts of ions present, flow rate of the water and stack design. Typical removals per stage range from 25 to 40 percent and systems use one to six stages. An ED system will operate at temperatures up to 110 degrees Fahrenheit (110°F or 43°C) and the removal efficiency increases with increasing temperature. Ion-selective membranes in commercial electrodialysis equipment are commonly guaranteed for as long as 5 years and experience has demonstrated an effective life of over 10 years.

The most commonly encountered problem in ED operation is scaling (or fouling) of the membranes by both organic and inorganic materials. Alkaline scales are troublesome in the concentrating compartments when the diffusion of ions to the surface of the anion membrane in the diluting cell is insufficient to carry the current. Water is then electrolyzed and hydroxide ions pass through the membrane and raise the pH in the cell. This increase is often sufficient to cause precipitation of materials such as magnesium hydroxide or calcium carbonate. The accumulation of particulate matter increases the electrical resistance of the membrane; this may damage or destroy the membranes. This condition can be offset by feeding acid to the concentrate water stream to maintain a negative Langelier Index to assure scale-free operation.

Ionics, Inc., has developed a type of ED unit which does not require the addition of acid or other chemicals for scale control. This system reverses the DC current direction and the flow path of the dilution and concentrating streams every 15 minutes. The electrodes reverse by switching the polarity of the cathodes and anodes. The stream flow paths also exchange their source every 15 minutes. Motor-operated valves controlled by timers switch the streams so that the flow path that was previously the diluting stream becomes the concentrating stream and the flow path that was previously the concentrating stream becomes the diluting stream. This reversing polarity system is commonly referred to as electrodialysis polarity reversal (EDR).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.5A What are the typical removals of inorganic salts from brackish water by electrodialysis (ED) per stage of treatment?

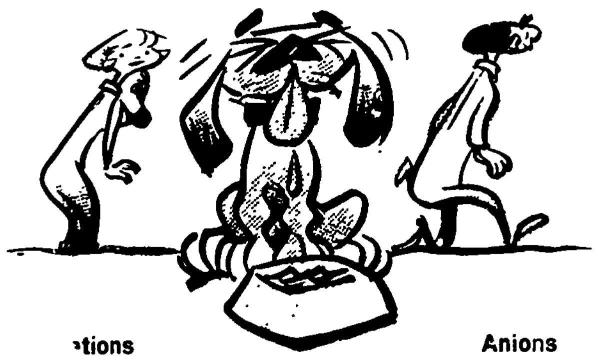
16.5B What is a membrane stack in an electrodialysis unit?

16.5C What is the most commonly encountered problem in ED operation?

16.6 PRINCIPLES OF ELECTRODIALYSIS

16.60 Anions and Cations in Water

When most common salts, minerals, acids, and alkalis are dissolved in water, each molecule splits into two oppositely charged particles called "ions." All positively charged ions are known as "cations" and all negatively charged ions, as "anions." For instance, when common table salt (sodium chloride or NaCl) is dissolved in water, it separates into positive sodium ions (Na^+) and negative chloride ions (Cl^-). The following ions are in sea water or brackish water in appreciable quantities.



Cations		Anions	
Sodium	Na^+	Chloride	Cl^-
Calcium	Ca^{2+}	Bicarbonate	HCO_3^-
Magnesium	Mg^{2+}	Sulfate	SO_4^{2-}

16.61 Effect of Direct Current (D.C.) Potential on Ions

If a D.C. potential is applied across a solution of salt in water by means of insertion of two electrodes in the solution, the cations will move towards a negative electrode, which is known as the "cathode," and the anions will move towards the positive electrode, which is known as the "anode." In Figure 16.13 (A) we have a solution of sodium chloride in water. The cations (Na^+) and anions (Cl^-) are moving about at random. In Figure 16.13 (B) a D.C. potential has been introduced in the solution and the anions move toward the positive electrode and the cations move toward the negative electrode.

16.62 Anion and Cation Membranes and Three-Cell Unit

Advantage could be taken of this movement of ions if proper barriers were available to isolate the purified zone in Figure 16.3 (B) so as to prevent remixing. There are two types of membranes which can be used as such barriers:

1. Cation Membranes — Permit only the passage of cations (positively charged ions); and
2. Anion Membranes — Permit only the passage of anions (negatively charged ions).

Introduction of a cation membrane and anion membrane into a salt solution to form three water-tight compartments (Figure 16.13 (C)) followed by a direct electric current into the water (Figure 16.13 (D)) will result in the demineralization of the central compartment.

In the three-cell unit shown in Figure 16.13 (C) and (D), "1" is the anode (positive electrode), "2" is the anion membrane, "3" is the cation membrane, and "4" is the cathode (negative electrode). In Figure 16.13 (C) there is no electric flow so the ions move at random in their respective compartments. In Figure 16.13 (D), the introduction of a D.C. potential gives these ions direction: the cations (Na^+) move toward the cathode and the anions (Cl^-) toward the anode. The following occurs:

1. Na^+ from compartment A cannot pass through anion membrane (2) into compartment B,
2. Cl^- from compartment A reacts at the anode (1) to give off chlorine gas,
3. Na^+ from compartment B passes through cation membrane (3) into compartment C,
4. Cl^- from compartment B passes through anion membrane (2) into compartment A,
5. Na^+ from compartment C reacts at the cathode to give off hydrogen gas and hydroxyl ions (OH^-), and
6. Cl^- from compartment C cannot pass through cation membrane (3) into compartment B.

This description indicates how the overall effect has produced a demineralization of the central compartment.

16.63 Multi-compartment Unit

Figure 16.14 presents a multi-compartment unit similar in principle to a stack. Letter "A" designates the anion membranes; letter "C" the cation membranes; the "+" sign the anode; the "−" sign the cathode. A salt solution of Na^+ and Cl^- ions flows between the membrane. On application of the D.C. potential, the overall effect will be as shown, a movement of ions from the compartments bounded by an anion membrane on the left and a cation membrane on the right into the adjacent compartments. The compartments losing salt are labeled "dilute" and those receiving the transferred salt, "brine." Two electrode compartments are also found in the drawing. Each is bordered by a cation membrane and the electrode. At the anode, a reaction takes place evolving chlorine and oxygen gases; at the cathode, hydrogen gas is produced and hydroxyl ions (OH^-) are left in the solution. Hydroxyl ions are alkaline.

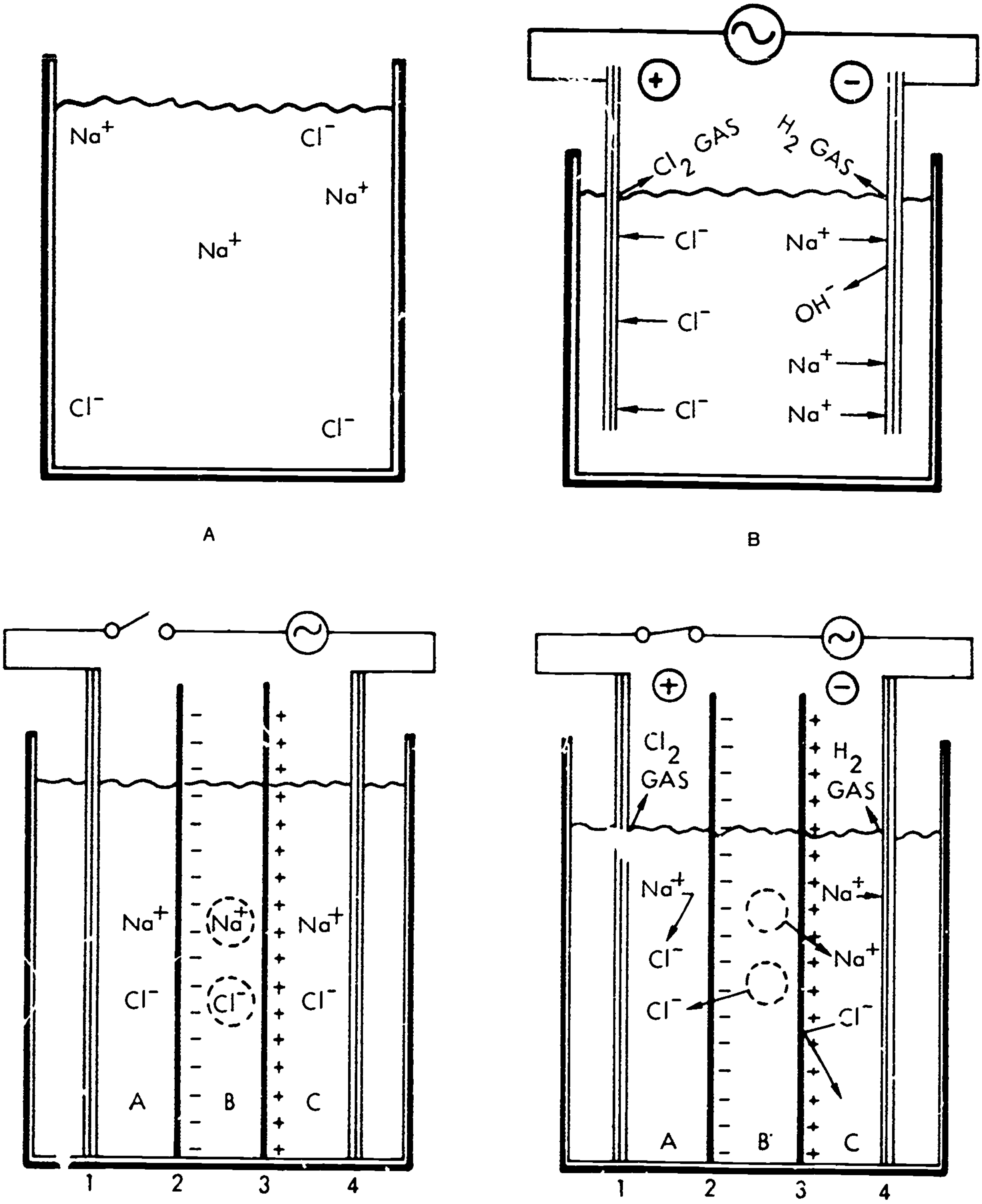
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.6A What happens if a D.C. potential is applied across a solution of salt in water by means of insertion of two electrodes in the solution?

16.6B What type of ions can pass through cation membranes?

16.6C In a multi-compartment ED unit, the compartments losing salt are labeled ______ and those receiving the transferred salt, ______.



C (NO CURRENT FLOW)

D (CURRENT FLOW)

Fig. 16 13 Influence of current flow

(From *STANDARD OPERATION INSTRUCTION PLAN FOR ELECTRODIALYSIS*, prepared by IONICS, Inc)

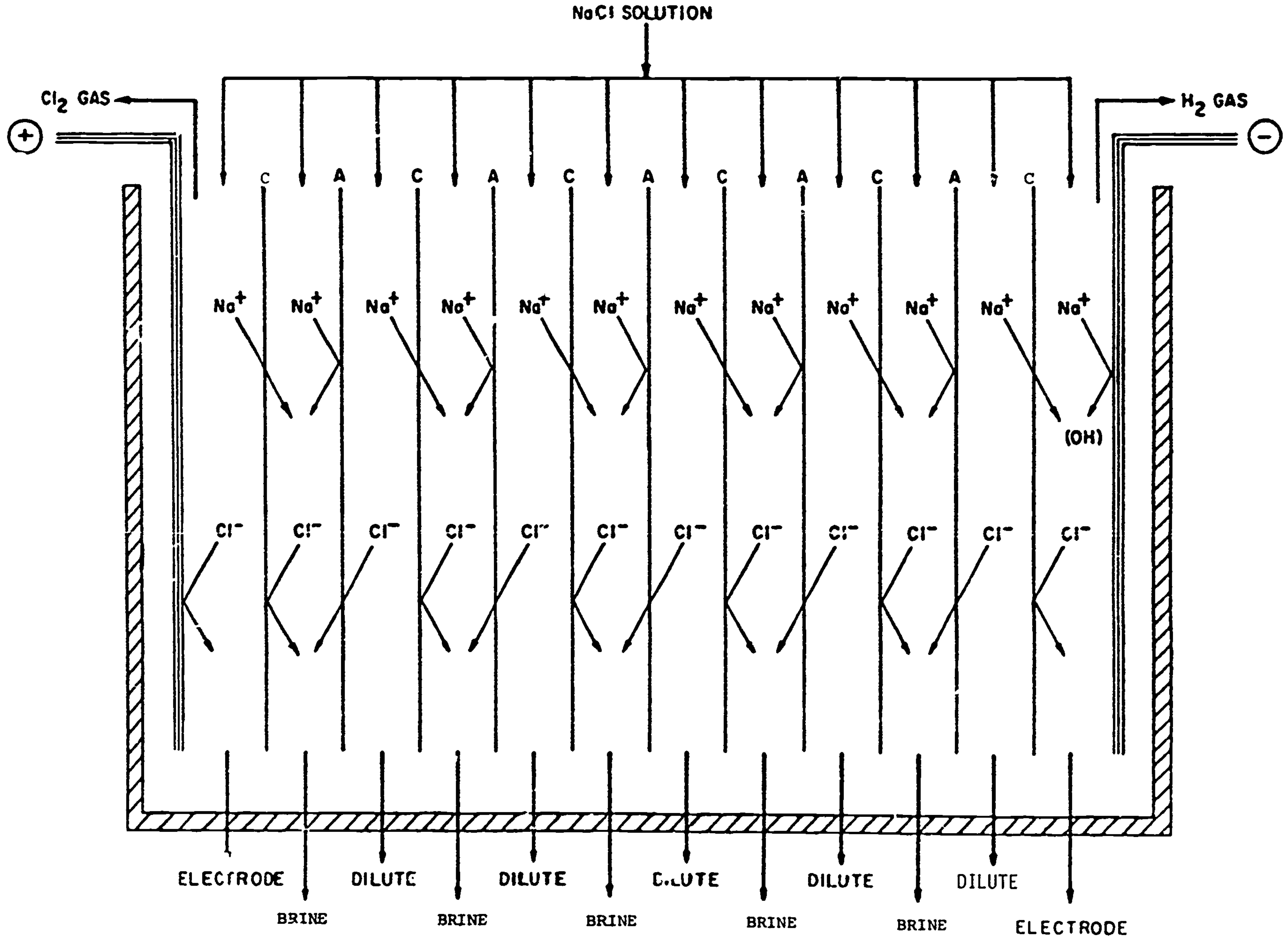


Fig. 16.14 Multi-compartment ED stack

(From *STANDARD INSTRUCTION PLAN FOR ELECTRODIALYSIS*, prepared by IONICS, Inc.)

16.7 PARTS OF AN ELECTRODIALYSIS UNIT

16.70 Flow Diagram

The basic electrodialysis unit consists of:

1. Pretreatment equipment,
2. Pumping equipment (feed, brine and recirculation)
3. D.C. power supply,
4. Membrane and electrodes, and
5. In-place cleaning system.

Figure 16.15 shows a typical flow diagram and Figure 16.16 a photo of an electrodialysis unit.

16.71 Pretreatment

A certain degree of pretreatment of the feedwater supply is necessary in order to prepare it for demineralization in the stacks. Pretreatment depends on the specific water being treated, but it usually includes the removal of suspended or dissolved solids which could adversely affect the surface of the membranes or mechanically block the narrow passageways in the individual cells. Cartridge filters are used as a particle safeguard before the ED unit. Before development of the electrodialysis polarity reversal (EDR) unit, acid addition to prevent carbonate scaling was always practiced. With the electrodialysis reversal process, the requirement for acid addition is reduced or eliminated. Removal of specific materials such as iron, manganese, or chlorine residual if required is included in pretreatment.

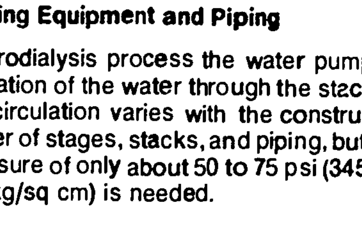
16.72 Pumping Equipment and Piping

In the electrodialysis process the water pump(s) is used only for circulation of the water through the stack. The head loss for this circulation varies with the construction of the stacks, number of stages, stacks, and piping, but generally a pumping pressure of only about 50 to 75 psi (345 to 517 kPa or 2.5 to 5.3 kg/sq cm) is needed.

Since only low operating pressures compared to RO are required. ED systems are constructed with common materials found in most water treatment applications. This has allowed the use of a great deal of standard plastic pipe and fittings. The use of plastic pipe produces benefits regarding lower cost (compared to stainless steel), high resistance to corrosion in a saline environment, and ease of construction.

16.73 D.C. Power Supply

The rectifier provides the D.C. power to the membrane stack assembly. The input (alternating current, A.C.) is converted by the rectifier to direct current which is applied to the electrodes on each side of the membrane stack to remove the ions from the feed stream. This equipment also includes a control module for periodic reversal of the current every 15 to 30 minutes on all new electrodialysis polarity reversal (EDR) models.



16.74 Membrane Stack

The membrane "stack" is so called because it is composed of a large number of stacked pieces, like a deck of cards. Half of these pieces are spacers and half are membranes which alternate from the bottom to the top of the stack. In other words, if one examines any portion of the stack, you will find a membrane above and below every spacer (except at the electrodes) and a spacer above and below every membrane. Two membranes or two spacers should never occur together.

Each membrane stack constitutes one stage of demineralization and is a separate hydraulic and electrical stage. The total number of stacks in the unit will be arranged in either one line or two lines running in parallel (each with an equal number of stacks). Since all the stacks in a line are connected in a series, the number of stacks per line will equal the number of stages of demineralization.

The membranes and spacers in the main section of the stack make up the number of cell pairs noted in the stack specifications. A cell pair consists of one anion membrane, one cation membrane and two inter-membrane spacers and is the basic demineralizing element. The metal electrodes located at the ends of the stack apply the D.C. electrical power required for demineralization.

16.75 Chemical Flush System

ED units are equipped with a Clean-In-Place (CIP) flush system to allow periodic flushing of the membrane stacks and associated piping with acid solutions down to pH 1 or with brine solutions up to 10 percent sodium chloride.

The two chemical solutions which are used most often for stack cleaning are a five percent solution of hydrochloric acid (for removal of scale and normal cleaning), and a five percent salt solution which has caustic soda added to adjust the pH to between 12 and 13 (for removal of organic fouling or slime).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

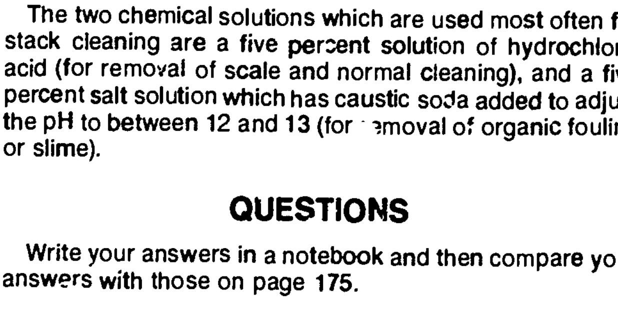
16.7A What must be removed by pretreatment of the feedwater supply to the electrodialysis unit?

16.7B What is the purpose of the rectifier in an electrodialysis unit?

16.8 ROUTINE OPERATING PROCEDURES

16.80 Design Specifications for Feedwater

The electrodialysis desalting unit will produce demineralized water at a rate dependent on water temperature and mineral composition of feedwater. The quality of the feedwater, and its ionic composition is extremely important and the design of the ED unit is based on these conditions.



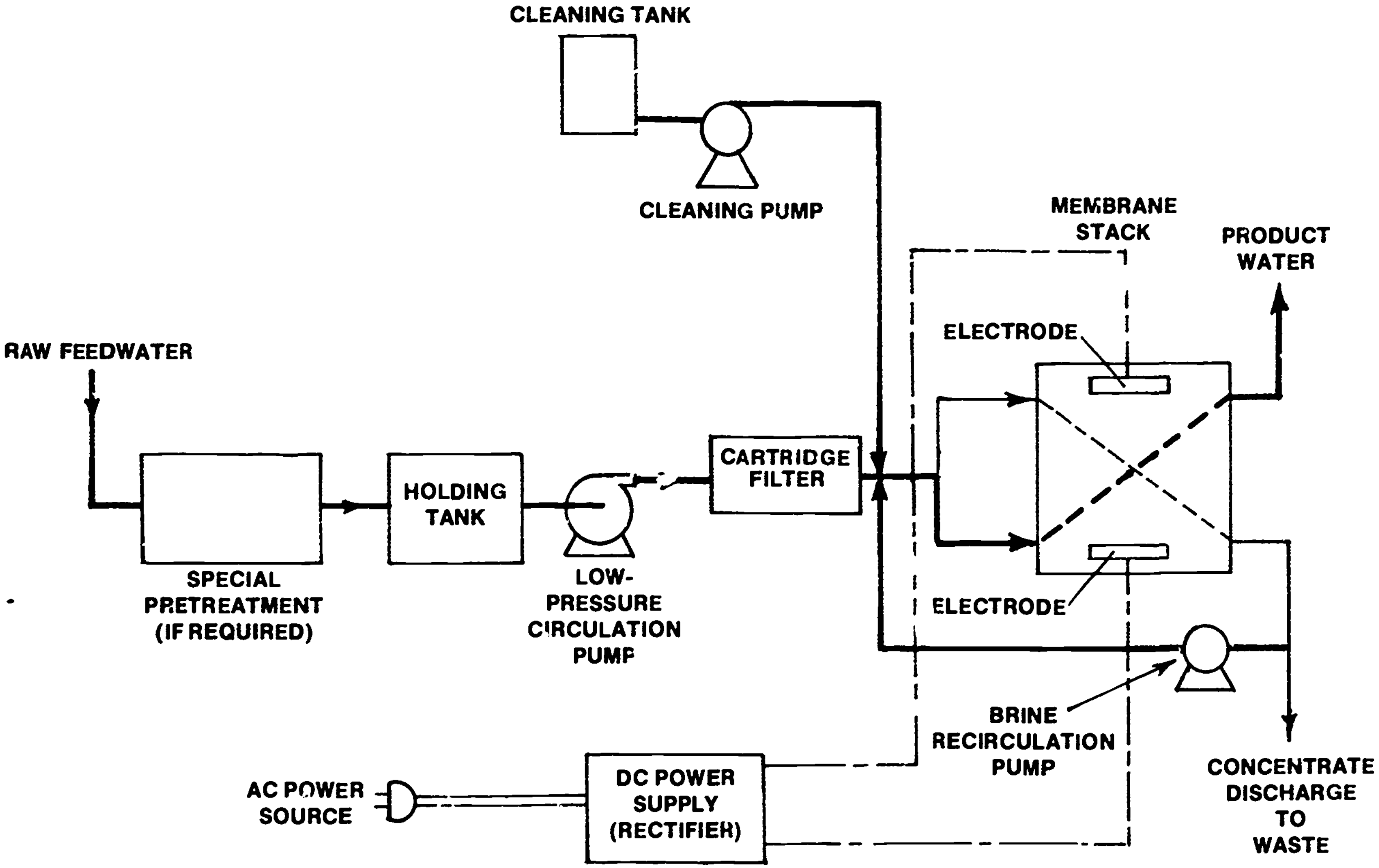


Fig. 16.15 Typical flow diagram

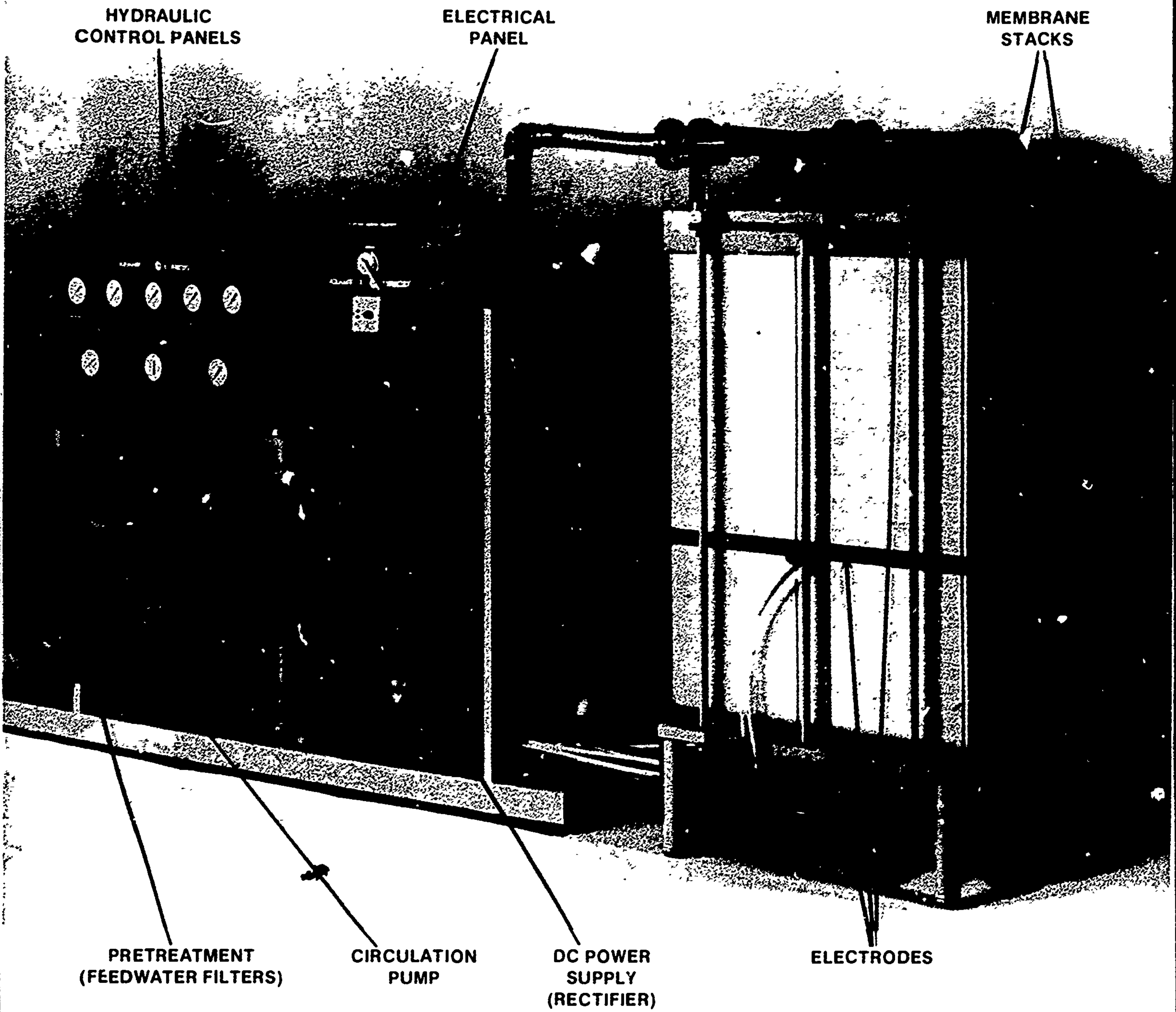


Fig. 16.16 Basic parts of an electrodialysis unit
(Courtesy of IONICS INCORPORATED)

The ions most often encountered in feedwater are:

Cations	Anions
1. Calcium	1. Bicarbonate
2. Iron	2. Chloride
3. Magnesium	3. Sulfate
4. Silica	
5. Sodium	

An excessive concentration of any of these constituents could lead to chemical fouling due to scaling. Iron in the feedwater will cause certain process problems; above 0.1 mg/*L* certain precautions have to be taken. One of the effects of excess iron in feedwater is the deposit of an orange film onto the membrane surface which increases the electrical resistance of the membrane stack. Concentrations of iron in excess of 0.3 mg/*L* should be removed by pretreatment.

There are other important considerations regarding feedwater quality. These include pH, biological, and bacteriological quality of the feed. To prevent biological fouling of the cation and anion membranes, the feedwater should be free of bacteria. Proper control of feedwater pH is also important, particularly in terms of corrosion control in piping and plumbing equipment. Because chlorine attacks the ED membrane, the feedwater cannot contain any chlorine residual. If prechlorination is practiced, the feedwater must be dechlorinated before entering the ED unit. Generally the unit should *NOT* be operated when the feedwater contains any of the following:

1. Chlorine residual of any concentration,
2. Hydrogen sulfide of any concentration,
3. Calgon or other hexametaphosphates in excess of 10 mg/*L*,
4. Manganese in excess of 0.1 mg/*L*, and
5. Iron in excess of 0.3 mg/*L*.

16.81 Detailed Operating Procedures

Detailed operating procedures vary from one system to the next. Most ED or EDR units come designed with fully automatic control systems. A typical operating log used to monitor an ED system is given in Table 16.6.

The detailed specifications for any plant will give the proper setting for the various controls on the unit. These control settings should be checked and recorded at least once every 24 hours using the sample log sheet given in Table 16.6. Any action needed to keep the plant running according to the specifications should be taken immediately.

In addition to checking the specifications, the routine maintenance schedule outlined below should be followed closely in order to reduce the risk of lengthy and expensive down times. Any process problems discovered must be acted upon immediately.

Daily

1. Fill out log sheet,
2. Verify that electrodes are bumping and flowing properly,
3. Inspect stacks for excess external leakage (greater than 10 gallons per hour or 38 liters per hour per stack), and
4. Check the pressure drop across the cartridge filter and change the cartridges whenever the pressure drop reaches 10 psi (69 kPa or 0.7 kg/sq cm).

Weekly

1. Voltage probe the membrane stacks,
2. Check the oil level on pumps fitted with automatic oilers,
3. Inspect all piping and skid components for leaks, and
4. Twice per week, measure all electrode waste flows.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 175.

16.8A List the ions most often encountered in the feedwater to an electrodialysis unit.

16.8B What items must be considered to prevent biological fouling of the cation and anion membranes?

16.8C Generally the electrodialysis unit should *NOT* be operated when the feed water contains (list the appropriate water quality constituents).

16.8D List the recommended daily activities for the operator of an electrodialysis unit.

16.9 SAFETY PRECAUTIONS

1. Grounding. The entire unit, including the stacks, must be connected to an electrical ground of each potential. *AT THE TIME OF INSTALLATION IT IS NECESSARY TO GROUND THE SKID OR THE CONTROL PANEL CABINET, EITHER BY A METAL CONDUIT OR A SEPARATE GROUNDING WIRE.*

   Each time the unit is moved or dismantled, check the ground connections before turning on the power. The skid, power supply cabinet, and stack(s) must always be firmly connected to the building ground or other suitable ground.

2. Check the *ELECTRODE TAB* connecting bolts and be sure these are tight and there is no corrosion. Loose connections at these points will cause overheating which could result in serious damage to the membrane stack.
3. Do not touch wet stack sides or electrode tabs when the D.C. power is on.
4. Always wear rubber gloves when voltage probing the membrane stack.
5. When washing down the area, never direct a hose on the membrane stack when the D.C. power is on.
6. Never operate a dry centrifugal pump, even when checking rotation.
7. Never apply D.C. voltage to the membrane stack without water flowing through the stack.
8. Expect the D.C. amperage to *DROP* when the feed water temperature *DROPS*. Never increase the D.C. stack voltage as the water temperature drops in an attempt to raise currents to those recorded at the higher temperatures unless you have received specific instructions to do so from the manufacturer.

TABLE 16.6 TYPICAL OPERATING LOG SHEET FOR ED UNIT

Date									
Polarity									
Feed Temp (°F)									
Feed TDS (mg/*L*)									
Product TDS (mg/*L*)									
Product Conductivity									
Dilute Flowrate (GPM)									
Brine Make-up (GPM)									
PRESSURES	Stack Inlet								
	Stack Outlet								
	Differential In								
	Differential Out								
	Before Filter								
	After Filter								
	Electrode Inlet								
Stage 1 Volts	Line 1								
	Line 2								
Stage 1 Amps	Line 1								
	Line 2								
Stage 2 Volts	Line 1								
	Line 2								
Stage 2 Amps	Line 1								
	Line 2								
Stage 3 Volts	Line 1								
	Line 2								
Stage 3 Amps	Line 1								
	Line 2								
Stage 4 Volts	Line 1								
	Line 2								
Stage 4 Amps	Line 1								
	Line 2								
Stage 5 Volts	Line 1								
	Line 2								
Stage 5 Amps	Line 1								
	Line 2								
Stage 6 Volts	Line 1								
	Line 2								
Stage 6 Amps	Line 1								
	Line 2								

9. Expect the D.C. amperage to *RISE* when the feedwater temperature *RISES*. As this happens, the D.C. stack voltages must be lowered until the D.C. amperage returns to the normal setting. This conserves power and prevents damage to the stack.

10. Never allow oil, organic solutions, solvents, detergents, wastewater, chlorine, nitric acid, strong bleach or other oxidizing agents to come in contact with the membranes and spacers unless directed to do so by the manufacturer. Membranes can be damaged by a feedwater containing even 0.1 mg/*L* free chlorine.

11. Always keep the membranes wet. Store in the membrane tube supplied or in the original plastic bags provided the seals are not broken.

12. Do not smoke or use exposed flames or sparks in the gas separator tank area due to the presence of potentially explosive gases.

13. Do not service the gas separator tank when the unit is in operation. Especially avoid the vent lines where toxic and explosive gases can be present. If it is necessary to service the tank, operate the unit for 30 minutes without D.C. power, then wait an additional hour before beginning work or ventilate with fans to ensure complete dispersion of dangerous gases.

14. If it is necessary to troubleshoot any of the electric panels, be extremely careful of the live panel voltages. This maintenance should be done only by someone familiar with the circuits and wiring. The unit should never be operated with the panel doors open, except for maintenance purposes, and only by experienced personnel.

15. Should shorting occur from a metal end plate across the plastic end block to the electrode, *IMMEDIATELY* turn off the rectifier. Try to eliminate the cause of the shorting by wiping excess moisture off the block. Also be sure to completely remove the black carbon that has formed at the point of shorting. If this is not effectively done, the shorting will recur when the rectifier is turned back on.

16. Feedwater containing Calgon or other hexametaphosphates will cause high membrane stack resistance. Avoid operation when these are present.

17. Red warning lamps are mounted on the wire way for the stack power connections. The lamps are lit when the D.C. power is applied to the stacks.

18. When the plant is on automatic, the plant is controlled by the product water tank's level switch. Therefore, when working on the equipment, the plant should be switched to manual operation and locked out, thus avoiding the possibility of an unexpected startup.

19. Use of the "STOP" switch or "STOP/START" switch activates an automatic flushing cycle and therefore does *NOT* immediately stop operation of all components of the unit. If the operation of the entire unit must be stopped immediately, the MAIN BREAKER should be switched off.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 176.

16.9A What problems can be created by loose connections at the electrode tab connecting bolts?

16.9B What happens to the D.C. amperage when the feed water temperature drops?

16.9C How can shorting be prevented from the metal end plate across the plastic end block to the electrode?

16.9D How can the operation of the entire electrodialysis unit be stopped immediately?

16.10 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual. Read and work the problems in Section A.34, "Demineralization." You should be able to get the same answers on your pocket calculator.

16.11 ADDITIONAL READING

1. *TEXAS MANUAL*, Chapter 11, "Special Water Treatment (Desalting)."

End of Lesson 3 of 3 Lessons on DEMINERALIZATION

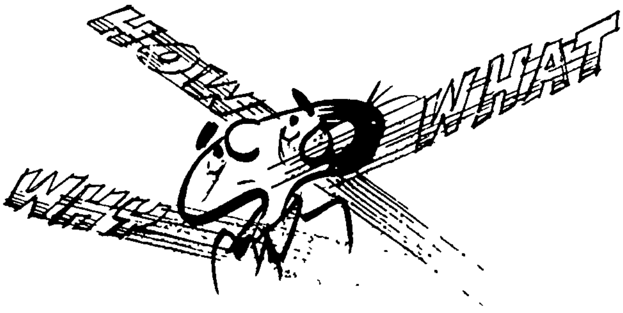
DISCUSSION AND REVIEW QUESTIONS

Chapter 16. DEMINERALIZATION

(Lesson 3 of 3 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 176. The problem numbering continues from Lesson 2.

16. How does an electrodialysis unit demineralize brackish water?
17. What are the basic parts of an electrodialysis unit?
18. What are the benefits of using plastic pipe in an electrodialysis plant?
19. What is the purpose of the chemical flush system in an electrodialysis unit?
20. An excessive concentration of any specific ion in the feedwater to an electrodialysis unit can cause what problem?
21. When should you check to be sure that an electrodialysis unit is properly grounded?



SUGGESTED ANSWERS

Chapter 16. DEMINERALIZATION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 142.

16.0A Demineralization is the process which removes dissolved minerals (salts) from water.

16.0B Sea water is more expensive to treat than brackish water becauses of its much higher TDS concentration.

Answers to questions on page 142.

16.1A Methods of removing minerals from water can be divided into two classes:

1. Those that use a phase change such as freezing and distillation, and
2. Non-phase change methods such as reverse osmosis, electrodialysis and ion exchange.

16.1B The common membrane demineralizing processes are reverse osmosis and electrodialysis.

Answers to questions on page 146.

16.2A The osmotic pressure of a solution is the difference in water level on both sides of a membrane.

16.2B The modified cellulose acetate membrane is commonly used today.

16.2C The water flux is the flow of water in grams per second through a membrane area of one square centimeter (or gallons per day per square foot) while the mineral flux is the flow of minerals in grams per second through a membrane area of one square centimeter.

16.2D When additional pressure is applied to the side of a membrane with a concentrated solution, the water flux (rate of water flow through the membrane) will increase, but the mineral flux (rate of flow of minerals) will remain constant.

16.2E When higher mineral concentrations occur in the feedwater, the mineral concentrations will increase in the product water.

Answers to questions on page 147.

16.2F Water flux is usually expressed in gallons per day per square foot (or grams per second per square centimeter) of membrane surface.

16.2G The term "flux decline" is used to describe the loss of water flow through the membrane due to compaction plus fouling.

16.2H Mineral rejection is defined as

$$\text{Rejection, \%} = \left(1 - \frac{\text{Product Concentration}}{\text{Feedwater Concentration}}\right)(100\%)$$

Mineral rejection can be determined by measuring the TDS and using the above equation. Rejections also may be calculated for individual constituents in the solution by using their concentrations.

Answers to questions on page 151.

16.2I An increase in feedwater temperature will increase the water flux.

16.2J Hydrolysis of a membrane results in a lessening of mineral rejection capability.

16.2K Recovery is defined as the percentage feed flow which is recovered as product water

$$\text{Recovery, \%} = \frac{(\text{Product Flow})\ (100\%)}{\text{Feed Flow}}$$

16.2L Recovery rate is usually limited by (1) desired product water quality and (2) the solubility limits of minerals in the brine.

16.2M Concentration polarization is the ratio of the mineral concentration in the membrane boundary layer to the mineral concentration in the flow stream.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 156.

16.3A The three types of commercially available membrane systems which have been used in operating plants are (1) spiral wound, (2) hollow fine fiber, and (3) tubular.

16.3B The tubular membrane process is used to treat wastewater with a high suspended solids concentration.

Answers to questions on page 157.

16.4A To protect the reverse osmosis system and its accessory equipment, the feedwater should be filtered. When the water source is a groundwater or a previously treated municipal or industrial supply, filtration may be accomplished by a simple screening procedure. An untreated surface water will probably require coagulation, flocculation, sedimentation and filtration.

16.4B Colloidal particulates are removed from feedwater by chemical treatment and filtration.

16.4C As an acetate membrane hydrolyzes, both the amount of water and the amount of solute which permeate the membrane increase and the quality of the product water deteriorates.

16.4D The scale control method which is used to inhibit calcium sulfate precipitation is a threshold treatment with 2 to 5 mg/*L* of sodium hexametaphosphate (SHMP).

16.4E A 1 to 2 mg/*L* chlorine residual is maintained to control biological fouling.

Answers to questions on page 157.

16.4F Operating pressure on a reverse osmosis unit is regulated by a control valve on the influent manifold.

16.4G The demineralized water is usually called *PERMEATE*, the reject *BRINE*.

16.4H Product or permeate flow is not regulated and varies as feedwater pressure and temperature change.

Answers to questions on page 162.

16.4I Chlorine is added to the feedwater to prevent biological fouling.

16.4J The operator must check the differential pressure across the RO unit to know when to clean the elements. When the elements become fouled, ΔP usually increases, thus indicating the need for cleaning.

16.4K The reverse osmosis elements should be cleaned when the operator observes (1) lower product water flow rate, (2) lower salt rejection, (3) higher differential pressure (ΔP), and (4) higher operating pressure.

Answers to questions on page 162.

16.4L Safety needs for demineralization plants can be divided into three general groups consisting of chemicals, electrical and hydraulics.

16.4M Electrical equipment used around reverse osmosis plants consists of a series of electrically powered pumps.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 165.

16.5A Typical removals of inorganic salts from brackish water by ED range from 25 to 40 percent of dissolved solids per stage of treatment.

16.5B A membrane stack in an electrodialysis unit consists of several hundred membranes and their separating spacers assembled between a single set of electrodes. End plates and tie rods complete the assembly.

16.5C The most commonly encountered problem in ED operation is sealing (or fouling) of the membranes by both organic and inorganic materials. Alkaline scales are troublesome in the concentrating compartments when the diffusion of ions to the surface of the anion membrane in the diluting cell is insufficient to carry the current.

Answers to questions on page 165.

16.6A If a D.C. potential is applied across a solution of salt in water by means of insertion of two electrodes in the solution, the cations will move towards a negative electrode, which is known as the "cathode", and the anions will move towards the positive electrode, which is known as the "anode."

16.6B Only cations (positively charged ions) can pass through cation membranes.

16.6C In a multi-compartment ED unit, the compartments losing salt are labeled "dilute" and those receiving the transferred salt, "brine."

Answers to questions on page 168.

16.7A Iron, manganese and chlorine residual must be removed from the feedwater supply to the electrodialysis unit.

16.7B The rectifier provides the D.C. power to the membrane stack assembly. The input (alternating current, A.C.) is converted by the rectifier to D.C. which is applied to the electrodes on each side of the membrane stack to remove the ions from the feed stream.

Answers to questions on page 171.

16.8A The ions most often encountered in the feedwater to an electrodialysis unit include:

Cations	Anions
1. Calcium	1. Bicarbonate
2. Iron	2. Chloride
3. Magnesium	3. Sulfate
4. Silica	
5. Sodium	

16.8B To prevent biological fouling of the cation and anion membranes, the operator must control feed, pH, biological and bacteriological quality.

16.8C Generally the electrodialysis unit should *NOT* be operated when the feedwater contains any of the following:

1. Chlorine residual in any concentration,
2. Hydrogen sulfide of any concentration,
3. Calgon or other hexametaphosphates in excess of 10 mg/*L*,
4. Manganese in excess of 0.1 mg/*L*, and
5. Iron in excess of 0.3 mg/*L*.

16.8D The recommended daily activities for the operator of an electrodialysis unit include:

1. Fill out log sheet,
2. Verify that electrodes are bumping and flowing properly,
3. Inspect stacks for excess external leakage, and
4. Check the pressure drop across the cartridge filter and change the cartridges whenever the pressure drop reaches 10 psi.

Answers to questions on page 173.

16.9A Loose connections at the electrode tab connecting bolts will cause overheating which could result in serious damage to the membrane stack.

16.9B Expect the D.C. amperage to *DROP* when the feedwater temperature *DROPS.*

16.9C Should shorting occur from a metal end plate across the plastic end block to the electrode, *IMMEDIATELY* turn off the rectifier. Try to eliminate the cause of the shorting by wiping excess moisture off the block. Also, be sure to completely remove the black carbon that has formed at the point of shorting.

16.9D If the operation of the entire unit must be stopped immediately, the MAIN BREAKER should be switched off.

OBJECTIVE TEST

Chapter 16. DEMINERALIZATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice answers.

TRUE-FALSE

1. Most of the earth's water supplies are fresh water
   1. True
   2. False
2. All fresh waters contain total dissolved solids (TDS).
   1. True
   2. False
3. The development of the membrane demineralizing processes has significantly increased the cost of demineralizing water.
   1. True
   2. False
4. Osmosis is the passage of a liquid from a concentrated to a dilute solution across a semipermeable membrane.
   1. True
   2. False
5. Semipermeable RO membranes generally must be maintained wet at all times.
   1. True
   2. False
6. When the pressure differential applied across the membrane increases, the salt flux will increase.
   1. True
   2. False
7. Water flux through a membrane over time tends to increase because of membrane erosion.
   1. True
   2. False
8. Mineral rejection by a reverse osmosis membrane increases as feedwater mineral concentration increases.
   1. True
   2. False
9. The value of the water permeation constant is only constant for a given temperature.
   1. True
   2. False
10. Minerals are transmitted through the membrane at a much more rapid rate than water.
    1. True
    2. False
11. Water to be demineralized always contains impurities which must be removed by pretreatment.
    1. True
    2. False
12. The rate of acetate membrane hydrolysis is at its minimum at about a pH of 4.7, and the rate increases with both increasing and decreasing pH.
    1. True
    2. False
13. Reverse osmosis modules provide a large surface area for the attachment and growth of bacterial slimes and molds.
    1. True
    2. False

14. The operator of a reverse osmosis plant must properly maintain and control all flows and recovery rates to avoid possible damage to the membranes from scaling.
    1. True
    2. False

15. The brine flow valves in a reverse osmosis plant must never be fully closed.
    1. True
    2. False

16. To properly operate a reverse osmosis plant, the product or permeate flow must be regulated.
    1. True
    2. False

17. Most RO systems should be operated with the addition of a scale inhibitor to protect membranes from precipitation of calcium sulfate or other inorganics.
    1. True
    2. False

18. When starting up a reverse osmosis unit, the feedwater should always be bypassed until the pH is properly adjusted.
    1. True
    2. False

19. To clean the elements of a reverse osmosis unit, the elements must be removed from the pressure vessel.
    1. True
    2. False

20. When working around electrical equipment, shut off and lock out electrical circuits if you are not a qualified electrician.
    1. True
    2. False

21. The removal efficiency of ED units increases with decreasing temperature.
    1. True
    2. False

22. If a D.C. potential is applied across a solution of salt water, the cations will move towards a negative electrode.
    1. True
    2. False

23. The negative electrode is known as the anode.
    1. True
    2. False

24. Electrodialysis requires much higher operating pressures than reverse osmosis.
    1. True
    2. False

25. The quality of the feedwater to an electrodialysis unit and its ionic composition are extremely important.
    1. True
    2. False

26. Always wear rubber gloves when voltage probing the membrane stack of an electrodialysis unit.
    1. True
    2. False

27. Always keep the electrodialysis membranes dry when not in use.
    1. True
    2. False

28. The gas separator tank on electrodialysis units should be serviced when the unit is in operation.
    1. True
    2. False

29. Feedwater containing Calgon or other hexametaphosphates will lower membrane stack resistance.
    1. True
    2. False

30. When an electrodialysis plant is operating on automatic controls, the plant is controlled by the product water tank's level switch.
    1. True
    2. False

MULTIPLE CHOICE

31. The need for demineralizing treatment processes is increasing due to
    1. Agricultural runoff into rivers.
    2. Increased demands for water.
    3. Increased mineral content of many rivers.
    4. Large quantities of mineralized groundwater.
    5. Weather modification programs.

32. Demineralizing processes include
    1. Distillation.
    2. Electrodialysis.
    3. Ion exchange.
    4. Mineralization.
    5. Reverse osmosis.

33. Materials that can be removed by some demineralizing processes include
    1. Bacteria.
    2. Organic material.
    3. pH.
    4. Suspended solids.
    5. Viruses.

34. The selection of a demineralization process for a particular application depends on
    1. Availability of energy and chemicals.
    2. Brine disposal facilities.
    3. Mineral concentration in feedwater.
    4. Pretreatment required.
    5. Product water quality required.

35. What happens when the osmotic pressure differential across a membrane decreases?
    1. Mineral flux does not change.
    2. Mineral flux will decrease.
    3. Water flux decreases.
    4. Water flux does not change.
    5. Water flux increases.

36. Fouling on RO membranes can be caused by
    1. Bacteria.
    2. Dissolved inorganics.
    3. Dissolved organics.
    4. Growths on membrane surfaces.
    5. Suspended solids.

37. To insure the longest possible lifetime of a membrane and to slow hydrolysis, ______ is added as a pretreatment step before demineralization.
    1. Acid
    2. Alkalinity
    3. Caustic
    4. Lime
    5. Polymer

38. Feedwater should be pretreated to remove materials and change conditions potentially harmful to the RO process such as
    1. Adjust pH.
    2. Adjust temperature.
    3. Disinfect to prevent biological growth
    4. Remove or prevent scaling or fouling.
    5. Remove turbidity/suspended solids.

39. Why is sulfuric acid usually added to the feedwater?
    1. To control precipitation of membrane fouling materials.
    2. To control precipitation of scale-forming minerals.
    3. To improve the alkalinity of the feedwater.
    4. To increase pH.
    5. To prevent corrosion.

40. What problems may be caused in the reverse osmosis process by microbiological organisms?
    1. Deterioration of cellulose acetate membrane
    2. Increase in coliforms in product water
    3. Membrane fouling
    4. Module plugging
    5. Reduction of organic matter

41. Typical operating pressures for brackish water demineralizing reverse osmosis processes vary from
    1. 20 to 40 psi.
    2. 70 to 100 psi.
    3. 150 to 350 psi.
    4. 400 to 500 psi.
    5. 1000 to 2000 psi.

42. Which of the following chemicals are used in the operation of a reverse osmosis unit?
    1. Caustic
    2. Chlorine
    3. Lime
    4. Sodium hexametaphosphate
    5. Sulfuric acid

43. The differential pressure (ΔP) across the RO unit should not exceed ______ because of possible damage to the RO modules.
    1. 20 to 40 psi
    2. 70 to 100 psi
    3. 100 to 250 psi
    4. 150 to 500 psi
    5. 1000 to 2000 psi

44. What types of cleaning solutions are used to remove biological or organic fouling from an RO membrane?
    1. Bactericides
    2. Chelating agents
    3. Citric acid
    4. Detergents
    5. Sequestrants

45. Advantages of the electrodialysis process include
    1. Efficient removal of most inorganic constituents.
    2. Low costs.
    3. Low energy requirements.
    4. Waste brine contains only salts removed from feedwater.
    5. Well developed technology.

46. The actual percentage removal of minerals by an ED unit varies with
    1. Flow rate of the water.
    2. pH.
    3. Stack design.
    4. Types and amounts of ions present.
    5. Water temperature.

47. Which of the following ions must be lowered or removed by pretreatment of the feedwater supply to the electrodialysis unit?
    1. Chlorine residual
    2. Hydrogen
    3. Hydroxyl
    4. Iron
    5. Manganese

48. Which of the following tasks should be performed daily by the operator on an electrodialysis unit?
    1. Check the oil level on pumps fitted with automatic oilers.
    2. Fill out log sheet.
    3. Inspect stacks for excess external leakage.
    4. Verify that electrodes are pumping and flowing properly.
    5. Voltage probe the membrane stacks.

49. Estimate the ability of a reverse osmosis plant to reject minerals by calculating the mineral rejection as a percent. The feedwater contains 1700 mg/*L* TDS and the product water is 140 mg/*L*.
    1. 85%
    2. 87%
    3. 90%
    4. 92%
    5. 95%

50. Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 4.5 MGD and the product flow is 3.9 MGD.
    1. 85%
    2. 87%
    3. 90%
    4. 92%
    5. 95%

End of Objective Test

CHAPTER 17

HANDLING AND DISPOSAL OF PROCESS WASTES

by

George Uyeno

TABLE OF CONTENTS

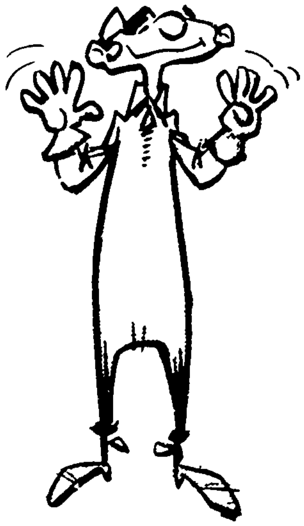
Chapter 17. Handling and Disposal of Process Wastes

OBJECTIVES

Chapter 17. HANDLING AND DISPOSAL OF PROCESS WASTES

Following completion of Chapter 17, you should be able to:

1. Outline the need for handling and disposal of process wastes,
2. Identify the sources of water treatment plant wastes,
3. Drain and clean sedimentation tanks,
4. Discharge process wastes to collection systems (sewers),
5. Operate and maintain backwash recovery ponds (lagoons) and sludge drying beds,
6. Dispose of process wastes,
7. Safely operate and maintain sludge handling and disposal equipment, and
8. Monitor and report on the disposal of process wastes.



GLOSSARY

Chapter 17. HANDLING AND DISPOSAL OF PROCESS WASTES

CENTRIFUGE
CENTRIFUGE

A mechanical device that uses centrifugal or rotational forces to separate solids from liquids.

CONDITIONING
CONDITIONING

Pretreatment of sludge to facilitate removal of water in subsequent treatment processes.

DECANT
DECANT

To draw off the upper layer of liquid (water) after the heavier material (a solid or another liquid) has settled.

DEWATER
DEWATER

To remove or separate a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of.

SLUDGE (sluj)
SLUDGE

The settleable solids separated from water during processing.

SUPERNATANT (sue-per-NAY-tent)
SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

THICKENING
THICKENING

Treatment to remove water from the sludge mass to reduce the volume that must be handled.

CHAPTER 17. HANDLING AND DISPOSAL OF PROCESS WASTES

17.0 NEED FOR HANDLING AND DISPOSAL OF PROCESS WASTES

The need for handling and disposal of potable water treatment plant wastes is a problem that must be faced by all plant operators. Many articles and books have been published on potable water treatment processes. Their emphasis is usually on producing wholesome and pure water for human consumption in compliance with EPA, state and local health department regulations, but very few mention sludge handling and disposal in any great detail. In response to a growing population and increasing concern about pollution of natural water sources, pollution control agencies, health departments, and fish and game departments established programs to enforce rules to prevent any waste discharge that would tend to discolor, pollute or generally be harmful to aquatic or plant life or the environment.

The law which restricts or prohibits the discharge of process wastes from water treatment plants is Public Law 92-500, the Water Pollution Control Act Amendments of 1972. This Act clearly includes treatment plant wastes such as sludge from a water treatment plant These wastes are considered an industrial waste which requires compliance with the provisions of the Act. Under the National Pollutant Discharge Elimination System (NPDES) provisions, a permit must be obtained in order to discharge wastes from a water treatment plant. Water treatment plants are classified into three categories.

Category 1 Plants that use one of the following three processes: (1) coagulation, (2) oxidative iron and manganese removal, or (3) direct filtration.

Category 2 Plants that use only chemical softening processes.

Category 3 Plants that use combinations of coagulation and chemical softening, or oxidative iron-manganese removal and chemical softening.

Enforcement of PL 92-500 is the responsibility of each state. Many NPDES permits have been issued by the states to water treatment plants using state standards applicable to the local conditions at the time the permits were issued. Water quality indicators for which waste discharge limitations have been issued include pH, total suspended solids, settleable solids, total iron and manganese, flow rate, total dissolved solids (TDS), BOD, turbidity, total residual chlorine, temperature, floating solids and visible forms of waste.

Water treatment plants can no longer simply discharge dirty backwash water or settled sludge into lakes, rivers, streams or tributaries as was done in the past. Current regulations require daily monitoring of any discharge and analysis of such water quality indicators as pH, turbidity, TDS, settleable solids or other harmful materials. The results of the analyses must be logged and reported frequently to the proper authorities and must conform to their rigid standards. For these reasons, it is absolutely necessary to make provisions for facilities to handle these wastes on a routine basis. While the most important part of an operator's job is still the end product, good potable water, an operator's duties are not complete until all by-products and wastes are disposed of in an acceptable and documented manner.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 203.

17.0A Why are strict laws needed regarding the disposal of process wastes?

17.0B If a discharge results from the disposal of process wastes, what water quality indicators may require monitoring?

17.1 SOURCES OF TREATMENT PROCESS WASTES

Although there are many types of water treatment plants and methods for treating water, most of them probably operate in the following general manner. Alum or polymers are applied to the water in a rapid mix chamber, agitated by mechanical means or through a cylinder designed for hydraulic flash mixing for coagulation. Following this, the water passes through mechanical flocculators or a series of baffles for flocculation. The water then moves into the sedimentation tank where the floc is allowed to settle out before the water moves to the filters. The sedimentation tanks may be of various shapes and depths; however, they are most commonly rectangular or circular. Many large plants are equipped with either mechanical rakes or scrapers which periodically remove sludge from a hopper or with a vacuum-type sludge removal device. The sludge is continuously scraped into the hopper. The hopper is emptied from one to three times per day for 20 to 30 minutes each time depending on the size of the hopper and the density of the sludge.

Sludge is then usually moved to drying beds. The smaller and older plants may not have these sludge handling facilities available. Many new water treatment plants are equipped with sludge collection headers with squeegees. This system does not need any sludge hoppers. The collection headers are supported by a travelling bridge or floats. The sludge is pumped out of the bottom of the basin and into a sludge channel on the walkway level. This system is described in Chapter 5, "Sedimentation."

Another type of plant similar to the one above contains an upflow solids-contact unit with clarifiers. The clarifiers are usually circular in shape and have sludge draw-off levels which must be monitored; the solids are then drawn off periodically as sludge.

For small plants and in areas where water must be pumped, pressure filters may be used and the coagulant is applied directly to the filter. Sedimentation tanks or clarifiers may occasionally accompany the use of pressure filters but this is not usually the case if the quality of the source water is good.

In another type of plant layout (not too commonly used), the sedimentation tank also functions as the backwash recovery area. In this case the backwash wastewater is pumped back to the head of the plant. Most of the solids will settle out when the water flows through the sedimentation basin. This method does eliminate the need for backwash recovery ponds or lagoons.

Diatomaceous earth filtration is different from all other types of filtration in its method of operation. There is usually no pretreatment of the water. Disposal of backwash wastes is still a problem. Table 17.1 summarizes the various sources of treatment process wastes and the methods of collecting, handling and disposal of these wastes.

TABLE 17.1 COLLECTON, HANDLING AND DISPOSAL OF PROCESS WASTES

SOURCES OF WASTES

1. Trash racks
2. Grit basins
3. Alum, ferric hydroxide or polymer sludges from sedimentation basins
4. Filter backwash
5. Lime-soda softening
6. Ion exchange brine

COLLECTION OF SLUDGES

1. Mechanical scrapers or vacuum devices
2. Manual (hoses and squeegees)
3. Pumps (into tank trucks or dewatering facilities)

DEWATERING OF SLUDGES

1. Solar drying lagoons
2. Sand drying beds
3. Centrifuges[a]
4. Belt presses
5. Filter presses
6. Vacuum filters

DISPOSAL OF SLUDGES AND BRINES

1. Wastewater collection systems (sewers)
2. Landfills (usually dewatered sludges)
3. Spread on land

---

[a] Mechanical devices that use centrifugal or rotational forces to separate solids from liquids (sludge from water).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 203.

17.1A How is sludge removed from sedimentation tanks?

17.1B How is sludge removed from an upflow solids-contact type of unit?

17.2 PROCESS SLUDGE VOLUMES

All of the different methods of sludge collection require some type of facilities for handling processed waste. The possibilities here include sedimentation tanks, backwash recovery ponds, drying beds, lagoons, ponds, holding tanks, adequate land, access to sewer systems or vacuum trucks or similar equipment for removal and disposal of the waste material.

The amount of sludge accumulation depends on the type and amount of suspended matter in the source water being treated as well as on the level of dosage and the type of coagulant used. As an example, let's examine sludge production at two 5 MGD (19 MLD) plants. The annual water production at each was 800 to 900 million gallons (3000 to 3400 megaliters). Plant One had no source water stabilizing reservoir and the raw water turbidity ranged from 3 units during the summer months to over 100 units during the winter, with an annual average alum dosage of 11 mg/*L*. Yearly sludge accumulation was approximately 500,000 gallons (1.9 megaliters). Plant Two with a 15 million gallon (56.8 megaliters) source water stabilizing reservoir treated raw water which never exceeded 20 turbidity units at the intake with an average alum dosage of 8 mg/*L*. The annual sludge accumulation was approximately 300,000 gallons (1.14 megaliters). In both cases, non-ionic polymer was used for filter aid at approximately 15 ppb. The source water stabilizing reservoir provided water to be treated with a reduced turbidity level with a more constant quality of water which required less alum and produced less sludge.

Organic polymers may be used instead of alum to reduce the quantity of sludge produced. Polymer sludges are relatively denser and easier to dewater for subsequent handling and disposal. Not all waters can be treated by polymers instead of using alum.

For plants without sludge collection devices, the volume of sludge produced and the frequency of cleaning the sedimentation tank is affected by several factors. Items to consider include:

1. Water demand,
2. Suspended solids loads and when peak demands occur,
3. Water temperature (as the temperature of the water increases, the settling rate of the solids will increase),
4. Detention time (as the detention time increases, the amount of solids that settle out will increase),
5. Volume of sludge deposited in basin (as the volume of sludge increases, the detention time decreases as well as the efficiency of the basin),
6. Volume of treated water storage for the system (the greater the volume of treated water storage, the more time is available for sludge removal),
7. Time required to clean and make any necessary repairs during the shutdown, and

8. Availability of adequate drying beds, lagoons, landfill, a vacuum tank truck, pumps or equipment, and adequate help with all necessary safety equipment and procedures.

Sedimentation tanks should be drained and cleaned at least twice a year and more often if the sludge buildup interferes with the treatment processes (filtration and disinfection). Alum or polymer sludge solids content is only 0.5 to 1 percent for continuous sludge removal and 2 to 4 percent when the sludge is allowed to accumulate and compact. Therefore, the sludge can flow readily in pipes or be pumped, especially with wastewater-type pumps.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 203.

17.2A How can a source water stabilizing reservoir reduce the volume of sludge handled?

17.2B If a plant does not have sludge drying beds or lagoons, how is the raw or wet sludge handled?

17.3 METHODS OF HANDLING AND DISPOSING OF PROCESS WASTES (Figure 17.1)

Various methods are used to handle and dispose of process wastes. The facilities at your plant will depend on when the plant was built, the region where the plant is located (topography and climate), the sources of sludge and the methods of ultimate disposal.

An effective method of handling sludge is to regularly during the day remove sludge from sedimentation tanks to a drying bed. When one drying bed is full of sludge, the sludge is allowed to dry while the other drying beds are being filled. A key to speedy drying is the regular removal of the water on top of the sludge.

Some plants require that portions of the facilities be shut down twice a year, the tanks drained and the sludge removed. This is an excellent time to inspect the tanks and equipment and perform any necessary maintenance and repairs.

Backwash recovery ponds or lagoons are used to separate the water from the solids after the filters have been backwashed. The water is usually returned or recycled to the plant headworks for treatment with the source water. These ponds also may be used to concentrate or thicken sludges from sedimentation tanks. Sludges from the lime-soda softening process are usually stored in lagoons. The drainage water is removed and the sludge may be covered or hauled off to a disposal site. Lime softening sludges may be applied to agricultural lands to achieve the best soil pH for optimum crop yields.

Larger plants or plants that produce large volumes of sludge may use *THICKENING*,[1] *CONDITIONING*[2] and *DEWATERING*[3] processes to reduce the volume of sludge that must be handled and ultimately disposed of. Sometimes polymers are added to sludges for conditioning prior to dewatering. Belt filter presses, centrifuges, solar lagoons and drying beds are some of the processes used to dewater sludges.

Ultimately process wastes such as trash, grit, sludge and brine must be disposed of in a manner that will not harm the environment. Trash and grit may be disposed of in landfills. Sometimes sludge and brine are discharged into wastewater collection systems (sewers); however, this procedure may cause operational problems for the wastewater treatment plant operator. To avoid upsetting wastewater treatment plants, discharges to sewers must be made very slowly to take advantage of the dilution provided by the wastewater. Sludges are commonly disposed of by spreading on land or dumping in landfills. The method used will depend on the volume of the sludge, sludge moisture content, land available, and distance from the plant to the ultimate disposal site.

The remainder of this chapter will discuss the detailed operational procedures that an operator must consider when handling and disposing of process wastes. Sections are also provided on equipment operation and maintenance as well as on monitoring and reporting.

QUESTIONS

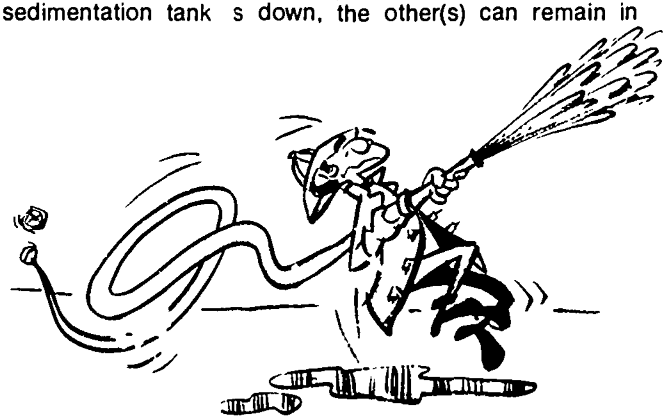
Write your answers in a notebook and then compare your answers with those on page 203.

17.3A List the methods that may be used to dewater sludge.

17.3B When should sedimentation tanks be inspected and repaired?

17.4 DRAINING AND CLEANING OF TANKS

Plants without mechanical sludge collectors will require the use of manual labor to remove the sludge once or twice a year. When two or more sedimentation tanks are designed into a plant, the job of cleaning is made easier. While one sedimentation tank is down, the other(s) can remain in



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[1] *Thickening. Treatment to remove water from the sludge mass to reduce the volume that must be handled.*

[2] *Conditioning. Pretreatment of sludge to facilitate removal of water in subsequent treatment processes.*

[3] *Dewatering. Treatment which removes or separates a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of.*

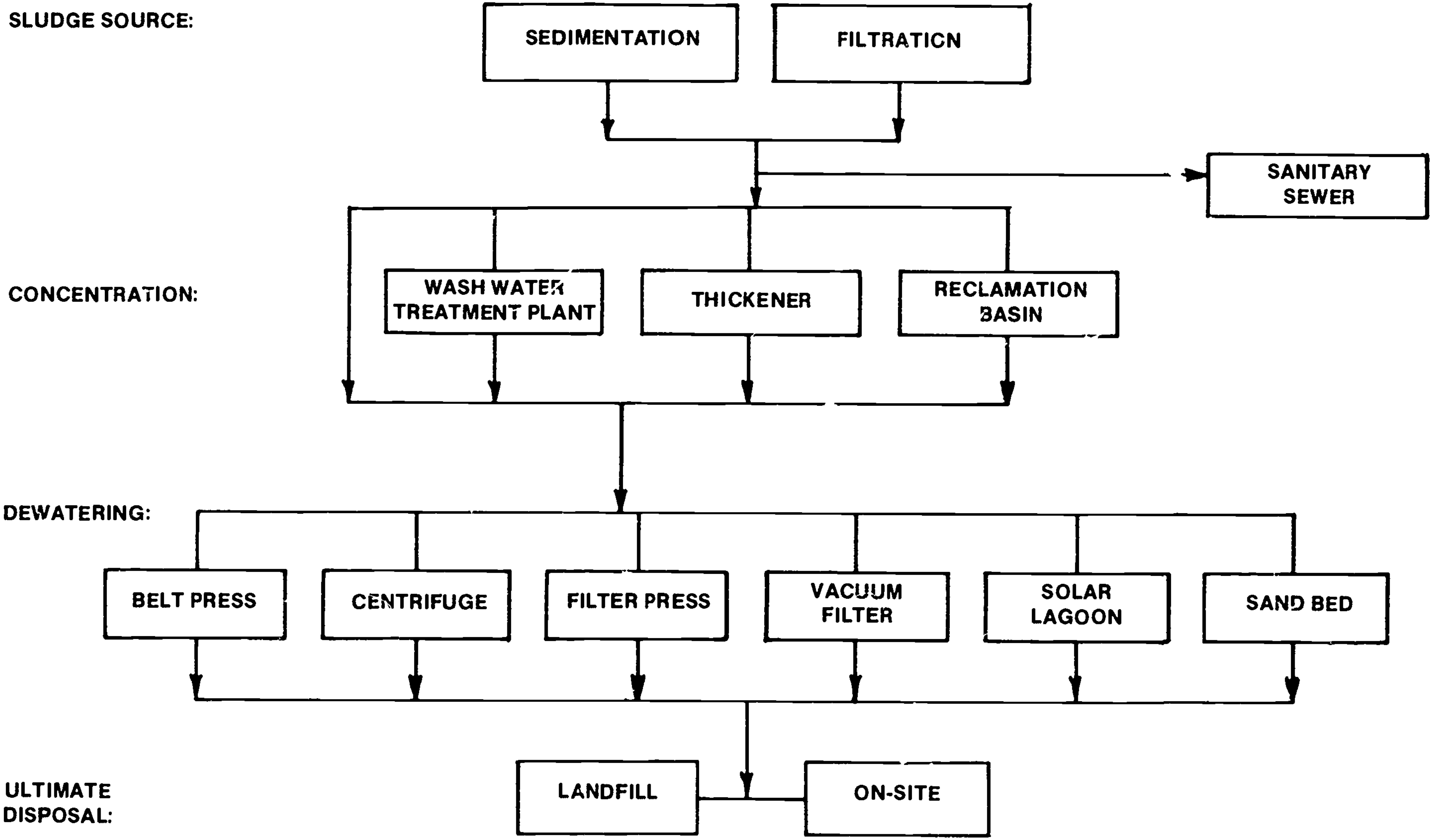

Fig. 17.1 Sludge processing alternatives

operation. The cleaning of sedimentation tanks should be done prior to and/or after peak demand months. Generally, early spring and the fall of the year are the better times to take some facilities out of service for cleaning.

Before draining any tank, always determine the level of the water table. If the water table is high, an empty tank could float like a cork on the water surface and cause considerable damage to the tank and piping. A properly designed tank will have provisions to drain high water tables or will contain other protective features (bottom pressure-relief discs to let groundwater into tank to prevent damage).

After any necessary intake valve(s) or gate(s) changes are made, drain the water down to the sludge blanket by partially opening the drain valve from the sedimentation tank into the lagoon or drying bed. After the first few minutes (if the valve is not wide open), the water will become clear. This portion of the water can be diverted from the lagoon or drying bed, if proper plumbing is available, and returned to the source to be reprocessed. Most drying beds will not handle this great a volume of water unless this draining process is extended over a period of a few days. Pump(s) can be used to transfer the settled water to another sedimentation tank that is still in operation.

As the water gets down to the sludge, fully open the drain valve into the drying bed(s). A large quantity of the sludge will drain by itself. As shown in Figure 17.2, the tank wall is 10 feet (3 m) high with the sludge level showing about five feet (1.5 m) from the top. When the level drops down to about two feet (0.6 m) of depth by the drain opening, the sludge will have to be assisted by an operator with a squeegee (Figure 17.3).

During the draining stages, the walls and all the equipment should be completely hosed down and inspected for damage. All necessary repairs should be made at this time. Once sludge dries on any coated surface, it is difficult to remove so it is important to hose everything down during the process of draining and while the sludge is still wet. All gears, sprockets, and moving parts should be lubricated immediately after hosing down to prevent "freeze up" resulting from exposure to the air during inspection and repair. By using drying beds and drying bed *DECANT*[4] pumps, ample amounts of water may be used for cleaning and assisting draining of the sludge. Under these conditions, two to three operators can clean out one sedimentation tank for a plant of 5 to 10 MGD (19 to 38 MLD) in one day. Additional time is required for initial draw down, gathering up of tools and equipment, final cleanup and any repairs that may be needed.

Sludge that settles out near the entrance to the sedimentation tank is more dense, especially when a polymer is used for flocculation aid. Therefore, the drain should be located in the headworks area. Once the sludge ceases to flow freely, even with the dilution water, then operators will have to push it towards the drain with squeegees (Figure 17.4).

The volume of sludge can vary with the size of the basin or clarifier, the quality of the source water being treated, the use of alum, polymer or combinations of both, and the frequency of cleaning. This volume may range from 100,000 to 200,000 gallons (0.38 to 0.76 ML), depending on the size of the basin and how long the sludge has accumulated in the basin.

Caution must be exercised whenever operators are in any closed tank (confined space):

1. Do not operate gasoline engines in the tank,
2. Provide adequate ventilation of clean air at all times,
3. Provide a source of water to clean off boots and tools where the operators come out of the tank, and
4. Use the buddy system. Someone must be outside the tank and watching anyone inside the tank.

Before filling the tank, thoroughly inspect and repair all equipment and valves. Wash everything down with clean water or a solution of 200 mg/*L* chlorine to disinfect the basin. If a chlorine wash solution is not used, fill the tank 10 percent full with a 50 mg/*L* chlorine solution and then finish filling it with clean water from the plant. The final free chlorine residual should not be so high that water with a free chlorine residual greater than 0.5 mg/*L* reaches the consumers.

Although manually draining and cleaning tanks requires more operator hours and plant down time than mechanical sludge removal, it does have its advantages. A more sanitary condition in the tank is obtained by cleaning up algae buildups or other deposits that are not picked up by mechanical collectors and regular inspection of equipment can eliminate many potential breakdown conditions. Even basins with continuous sludge collection systems should be drained once a year for inspection and maintenance.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 203.

17.4A How can sludge be removed from tanks without mechanical or vacuum-type sludge collectors?

17.4B When draining a sedimentation tank, what should be done with the settled water above the sludge?

17.4C What precautions must be exercised whenever an operator enters a closed tank (confined space)?

17.5 BACKWASH RECOVERY PONDS (SOLAR LAGOONS)

Because of water pollution control legislation enacted since the 1960s, many recently constructed water treatment plants now have backwash recovery ponds (Figure 17.5). In many instances these ponds can serve a dual purpose. In addition to their primary function as backwash recovery ponds, they can also be used to collect the sludge from sedimentation tanks and clarifiers with a few modifications. While these modified ponds are capable of performing both functions at the same time, it would be preferable to pay particular attention to timing these operations so that they do not overlap. Water for hosing down the sedimentation basin and assisting the flow of sludge should be used sparingly. Also, the backwash recovery pump suction pipe should be floated near the surface, by use of a flexible hose and tire tube or any similar float, so that any excess water can be recycled without also drawing out sludge. This will be very important if the filters must be backwashed at the same time sludge is being cleaned out of the backwash recovery ponds.

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[4] *Decant. To draw off the upper layer of liquid (water) after the heavier material (a solid or another liquid) has settled.*

Fig. 17.2 Sludge being drained from a clarifier

Fig. 17.3 Operator with a squeegee assisting sludge out of clarifier

Fig. 17.4 Operators pushing sludge towards drain with squeegees and vacuum truck removing sludge

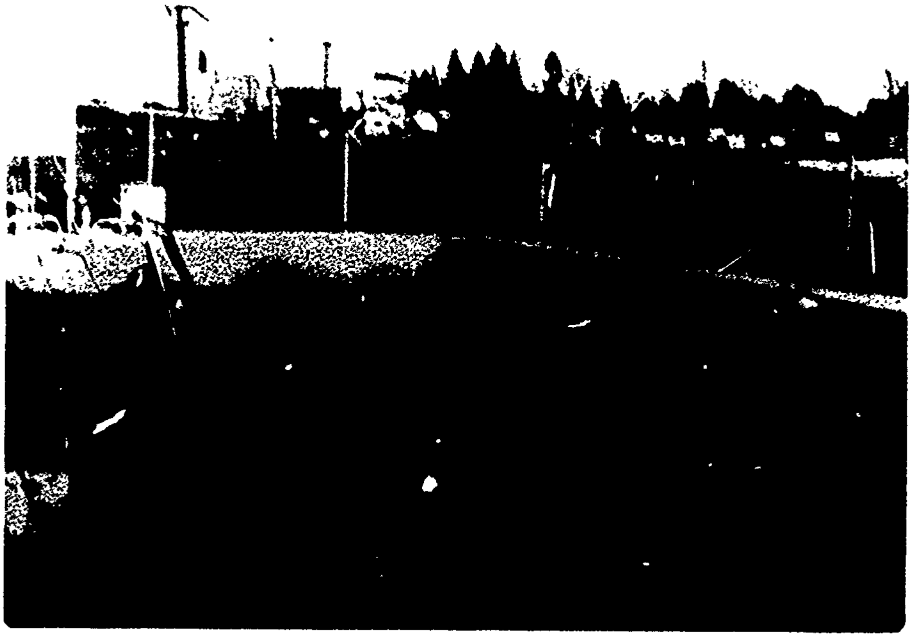
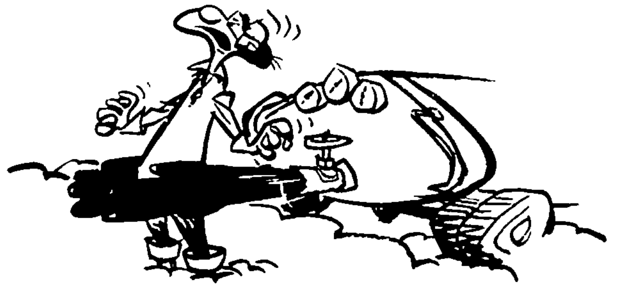


Fig. 17.5 Backwash recovery pond

A vacuum tank truck will be needed to move the wet sludge (a vacuum tank truck is shown in Figure 17.4). The capacity of the vacuum truck's tank in the picture is 5000 gallons (19 cu m) and it has a 6-inch (150 mm) suction hose. About 15 minutes are required to fill up the tank if sludge is fed to the suction end constantly without breaking the vacuum. A lift of 12 feet (3.6 m) can be obtained without too much difficulty.

Sludge is sometimes applied to land as a soil conditioner. Polymer sludges are suitable as a soil conditioner. Sludges produced by direct filtration, without coagulants, usually make excellent soil conditioners both with and without polymers. The sludge may be applied either wet or dry. Because commercial soil conditioner is becoming more expensive, sale of sludge as a soil conditioner can help to offset sludge handling and disposal costs.



Most plants that use the lime-soda ash softening process collect the sludge and dewater the sludge in a lagoon. A variable length riser or discharge pipe is used to draw off the water that is separated from the sludge. When the lagoon is full and the sludge is dried, the surface may be covered with soil as in a landfill operation. In some plants where space is scarce, the dried sludge is hauled off to a landfill and the lagoon refilled. Lime softening sludges also can be disposed of by application to agricultural soils to adjust the pH for optimum crop yields.

Discharge of lime-soda sludges to the waterwater collection system (sewers) is a poor practice because (1) the sewers could become plugged regularly, and (2) the operator at the wastewater treatment plant will have to handle and dispose of the sludge. However, the lime-soda sludge may help the wastewater treatment plant operator by (1) adjusting the pH, or (2) serving as a coagulant aid in treating the incoming wastewater.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 204.

17.5A Why is timing critical if backwash recovery ponds are used to handle sludge from sedimentation basins?

17.5B Why must the suction pipe for the backwash recovery pump be floated near the surface of the pond?

17.5C How can lime-soda softening sludge be disposed of ultimately?

17.6 SLUDGE DEWATERING PROCESSES[5]

17.60 Solar Drying Lagoons

Solar drying lagoons are shallow, small-volume storage ponds in which treatment process sludge (sometimes concentrated) is stored for extended time periods. Sludge solids settle to the bottom of the lagoon by plain sedimentation (gravity settling) and the clear *SUPERNATANT*[6] water is skimmed off the top with the aid of an outlet structure that drains the clear surface waters. Evaporation removes additional water and the solar drying process proceeds until the sludge reaches a concentration of from 30 to 50 percent solids. At this point, the sludge can be disposed of on-site or at a sanitary landfill. Obviously, the solar drying process is dependent on environmental conditions (weather) and may take many months to complete. For this reason, several lagoons should be provided (a minimum of three) so that sludge loading and drying can be rotated from one lagoon to another.

17.61 Sand Drying Beds

Sand drying beds have been used extensively in municipal wastewater treatment where high solids volumes are handled. Sand drying beds are similar in construction to a sand filter, and consist of a layer of sand, a support gravel layer, an underdrain system, and some means for manual or mechanical removal of the sludge (see Figures 17.6, 17.7 and 17.8). They are built with underdrains covered with gradations of aggregate and sand. The drains discharge into a sump where recovery pumps can return the water drained from the sludge back to the plant to be reprocessed. Frequently, three beds are used so one can be dried out while one is being filled from the draw-down of wet sludge from the sedimentation tanks. The third bed contains dried sludge which is being hauled out.

The efficiency of the sand drying bed dewatering process can be greatly improved by preconditioning the process sludge with chemical coagulants. The drying time can vary from days to weeks, depending on weather conditions and the degree of preconditioning of the sludge. The frequency of removal of dried sludge will vary with different plants depending on the volume of sludge produced, size of drying beds, and drying conditions (weather).

Sludge has a unique characteristic about it that once it has even partially dried, it will not expand, therefore, layer after layer of wet sludge can be added over a period of time. This

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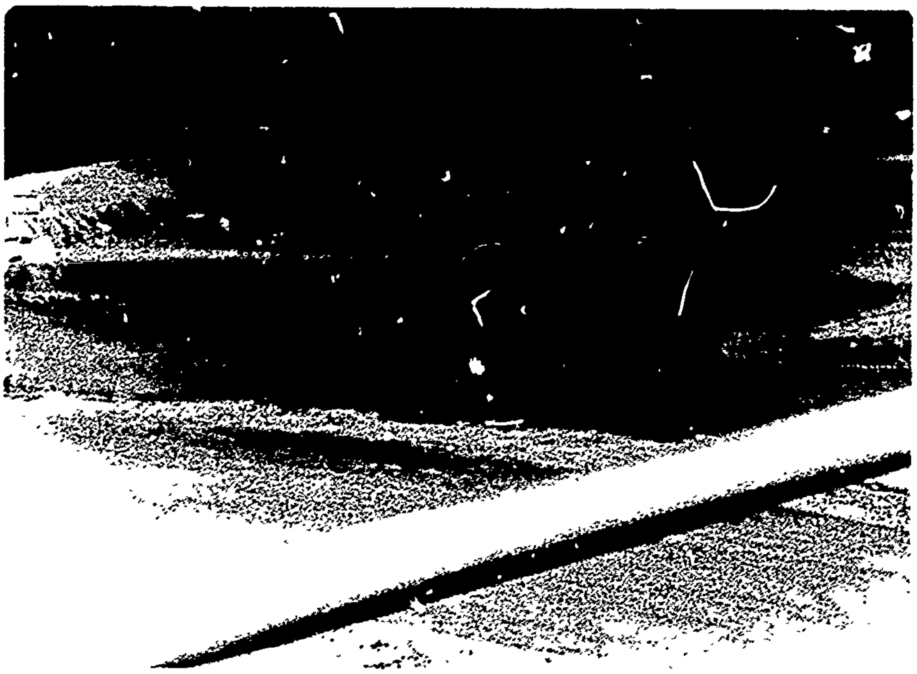
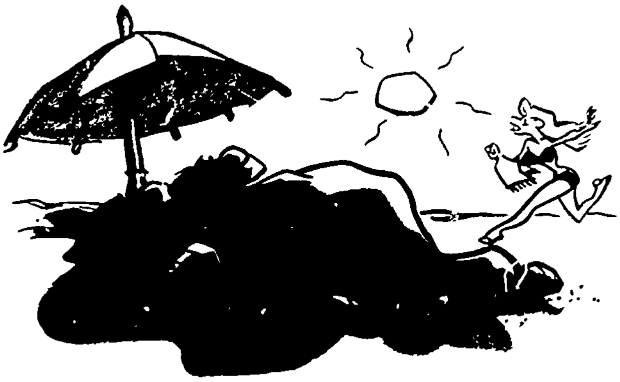
[5] *Portions of this section were prepared by Jim Beard.*

[6] *Supernatant (sue-per-NAY-tent) Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.*



17.6 Photo of sludge drying beds



procedure will work as long as the solids content of the applied sludge is at least 2 to 3 percent. When drying this type of sludge, large cracks and checks will develop on the surface and extend down through the sludge to the sand. The proper time to remove this dried sludge is when no more than one foot (0.3 m) has accumulated and dried into a checkered pattern A piece of dry sludge can then be picked up off the sand. The dried sludge can easily be removed with a front-end loader onto a dump truck and be hauled off to a landfill. However, the operator must exercise extreme caution so that only the dried sludge is picked up with the minimum possible disturbance to the sand and aggregate. The loader bucket should be operated carefully since there may be only about ten inches (36 cm) of sand cover over the underdrains. The loader bucket capacity should be limited to one or two cubic yards of sludge. Concrete tracks should be provided for larger equipment to collect the dried sludge.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 204.

17.6A What is the minimum recommended number of solar drying beds?

17.6B Describe a typical sludge drying bed.

17.6C When is the proper time to remove dried sludge from the drying bed?

17.6D What precautions must be exercised when operating a front-end loader to remove sludge from a drying bed?

17.62 Belt Filter Presses

Continuous-belt filter presses are popular because of their relative ease of operation, low energy consumption, small land requirements, and their ability to produce a relatively dry filter cake (material removed from the filter press has about 35 to 40 percent solids). There are two primary mechanisms by which free water is separated from the sludge solids in a belt press:

1. Gravity drainage, and
2. Pressure dewatering.

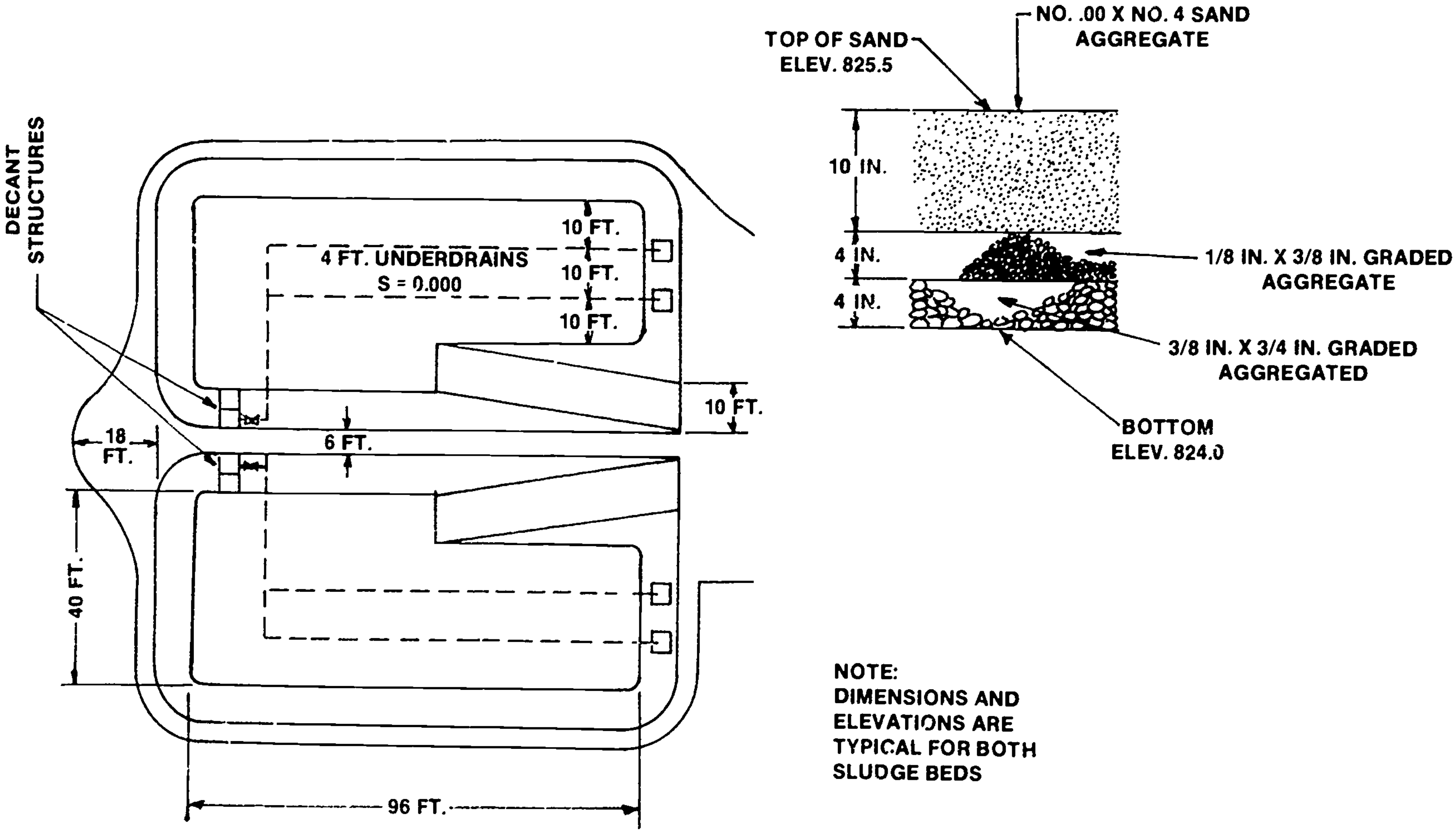
Sludge is conveyed and dewatered between two endless belts (Figure 17.9) After the sludge is initially mixed with a polymer in a rotary drum conditioner, it is dewatered in three distinct zones:

1. A horizontal zone for gravity drainage,
2. A vertical sandwich draining zone, and
3. A final dewatering zone containing an arrangement of staggered rollers which produce a multiple-shear force action which squeezes out the remaining free water.

Each belt is washed with a high pressure/low volume water spray.

17.63 Centrifuges

Centrifuges have been used to dewater municipal sludges for some time. Problems with the earlier units included erosion of surfaces hit by high speed particles, and poor



NOTE:
DIMENSIONS AND ELEVATIONS ARE TYPICAL FOR BOTH SLUDGE BEDS

Fig. 17.7 Sludge drying beds

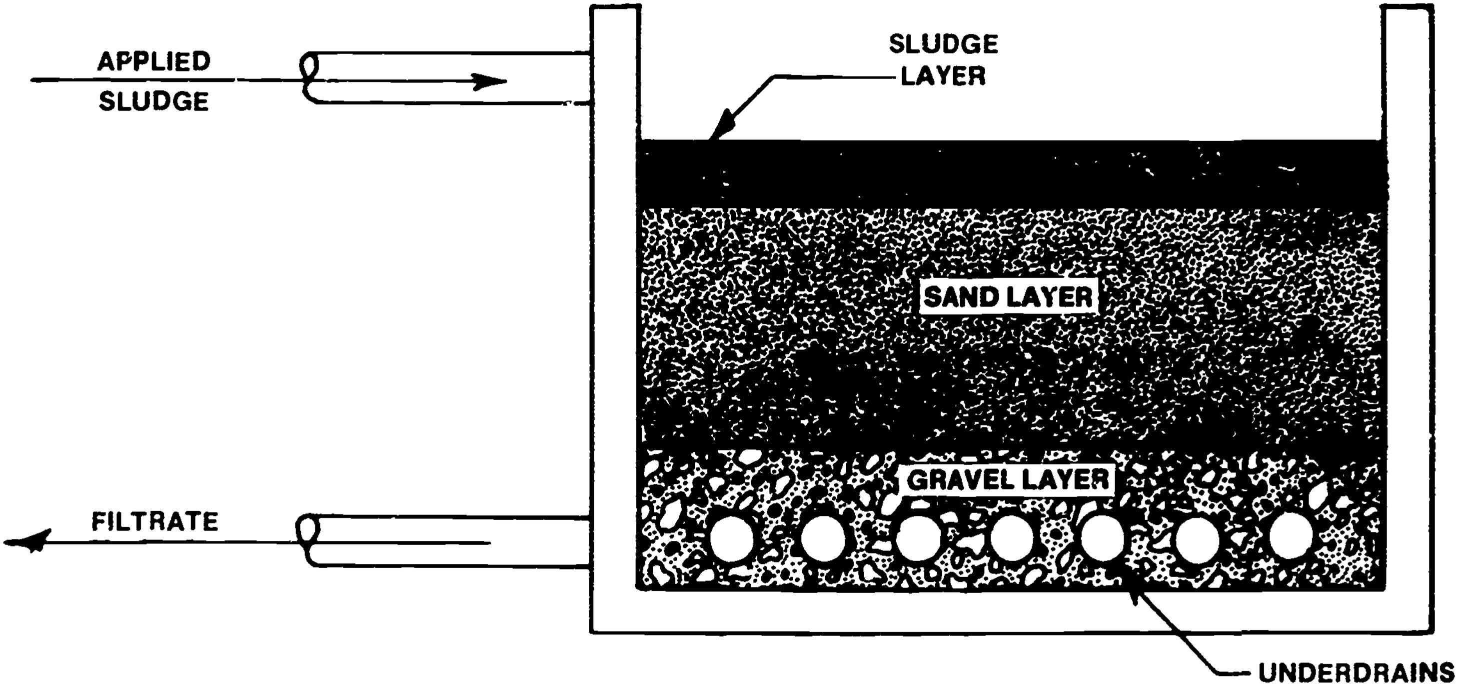


Fig. 17.8 Sectional view of sludge drying bed

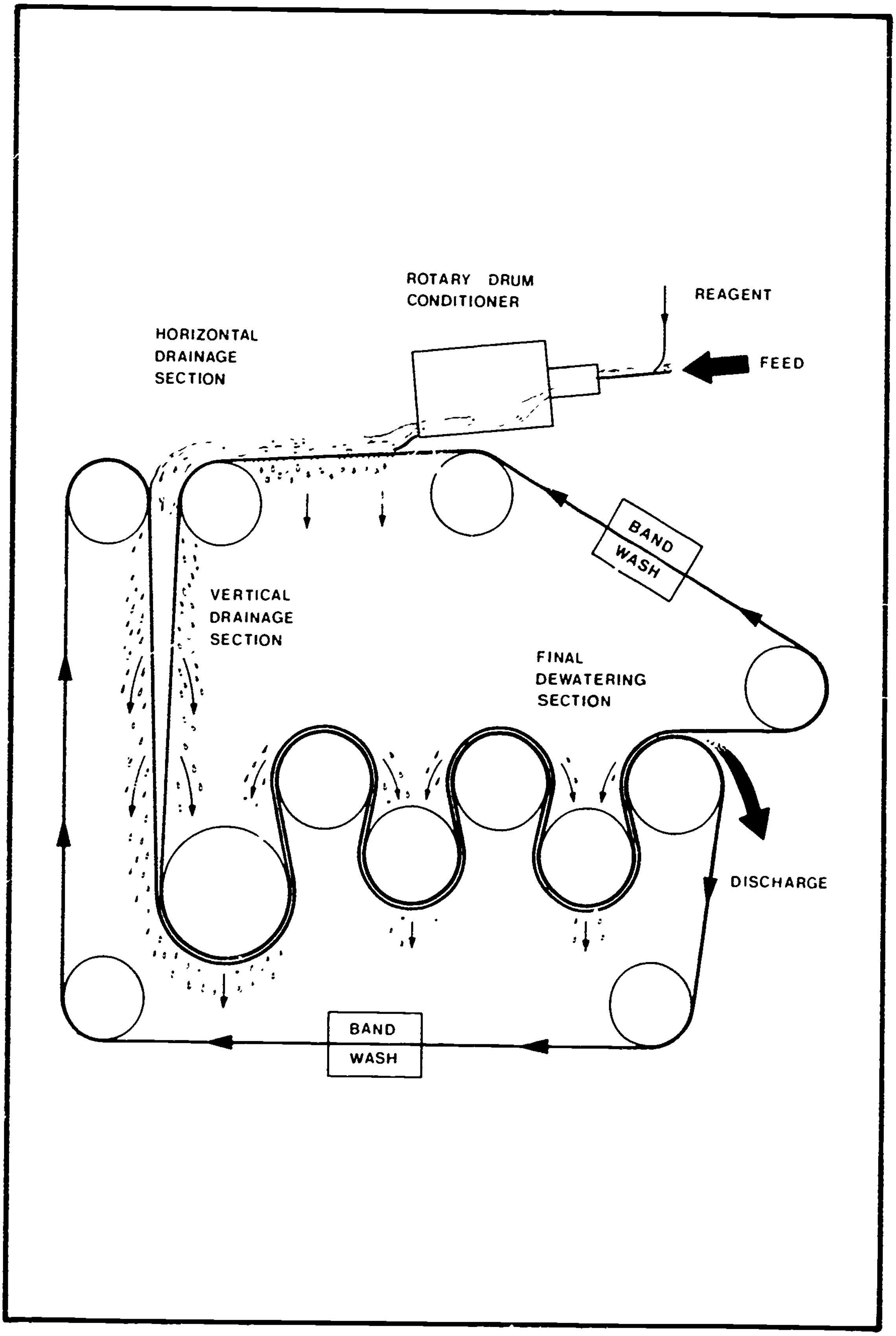


Fig. 17.9 Flow diagram of Winklepress
(Permission of Ashbrook-Simon-Hartley)

performance capacity Design improvements and the use of polymers have generally eliminated these problems. The principal advantage of this dewatering technique is that the density of the sludge cake can be varied from a thickened liquid slurry to a dry cake. The major limitation of using centrifuges is high energy consumption.

There are two basic types of centrifuges, the scroll type and the basket type. The scroll centrifuge operates continuously, while the basket centrifuge is a batch type unit Solids capture is generally greater with the basket centrifuge.

In the scroll centrifuge (Figure 17.10), solids are introduced horizontally into the center of the unit. The spinning action forces the solids against the outer wall of the bowl, where they are transported to the discharge end by a rotating screw conveyor. Clear supernatant liquid is discharged over an adjustable weir on the opposite end of the unit.

In the basket centrifuge (Figure 17.11), sludge is introduced vertically into the bottom of the bowl and the supernatant is discharged over a weir at the top of the bowl. When the solids concentration in the supernatant becomes too high, the operation is stopped and the dense solids cake is removed by a knife unloader.

17.64 Filter Presses

Filter presses have been successfully used to process difficult-to-dewater sludges (alum sludges). These machines are best suited for sludges with a high specific resistance (the internal resistance of a sludge cake to the passage of water). Filter presses produce very dry cakes, a clear filtrate, and have a very high solids capture.

A filter press consists of a series of vertical plates covered with cloth which supports and retains the filter cake (Figure 17.12). These plates are rigidly held in a frame. Sludge is fed into the press at increasing pressures for about half an hour. The plates are then pressed together for one to four hours at pressures as high as 225 psi (15.8 kg/sq cm or 1,551 kiloPascals). Water passes through the cloth while the solids are retained, forming a cake which is removed when the press is depressurized.

17.65 Vacuum Filters

Vacuum filtration was once the main chemical sludge dewatering process. However, its use has declined due to development of devices such as the belt press which consumes less energy, is less sensitive to polymer dosage, and does not require use of a precoat (a substance applied to the filter before applying sludge for dewatering).

A vacuum filter consists of a cylindrical drum which rotates partially submerged in a tank of chemically conditioned sludge (Figure 17.13). As the drum slowly rotates, a vacuum is applied under the filter medium (belt) to form a cake on the surface. As the belt rotates suction is maintained to promote additional dewatering. As the belt passes the top of the drum, it separates from the drum and passes over a small-diameter roller for discharge of the cake. The belt is then washed before it re-enters the vat. A precoat of diatomaceous earth is required to dewater gelatinous alum sludge.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 204.

17.6E List the methods available for dewatering sludges.

17.6F List the major advantages and limitations of using centrifuges to dewater sludges.

17.6G When is a precoat of diatomaceous earth required on vacuum filters?

17.7. DISCHARGE INTO COLLECTION SYSTEMS (SEWERS)

The easiest method of sludge disposal would be to send the sludge down the wastewater collection (sewer) system. This does create some complications even if the wastewater treatment plant has the capacity to handle the load. The fees charged by the wastewater treatment plant could be prohibitive. The charges are usually based upon annual flow, chemical or biochemical oxygen demand, suspended solids, and peak and average discharge. There are also increased monitoring requirements and costs associated with a sewer discharge. The water treatment plant must have a holding tank so that the sludge can be released at a uniform rate throughout the day or released only during the wastewater treatment plant's low-flow period.

Brine from ion exchange units may be discharged into wastewater collection systems. Usually the brine is discharged during the day to take advantage of high flows for dilution. When you plan such a discharge, notify the operator of the downstream wastewater treatment plant to be sure you won't create any unnecessary problems.

QUESTIONS

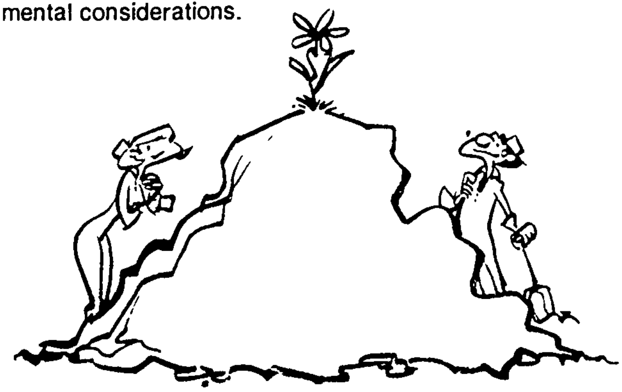
Write your answers in a notebook and then compare your answers with those on page 204.

17.7A What are the complications of discharging sludge to sewers?

17.7B When is brine from ion exchange units usually discharged into wastewater collection systems?

17.8 DISPOSAL OF SLUDGE[7]

Sludge is commonly disposed of in sanitary landfills. Other methods of ultimate disposal include land application and sanitary sewers. The method of disposal depends on the source and type of sludge, as well as economic and environmental considerations.



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[7] *Portions of this section were obtained from ILLINOIS EPA SLUDGE REGULATION GUIDANCE DOCUMENT, Illinois Environmental Protection Agency, 2220 Churchill Road, Springfiled, Illinois 62706.*

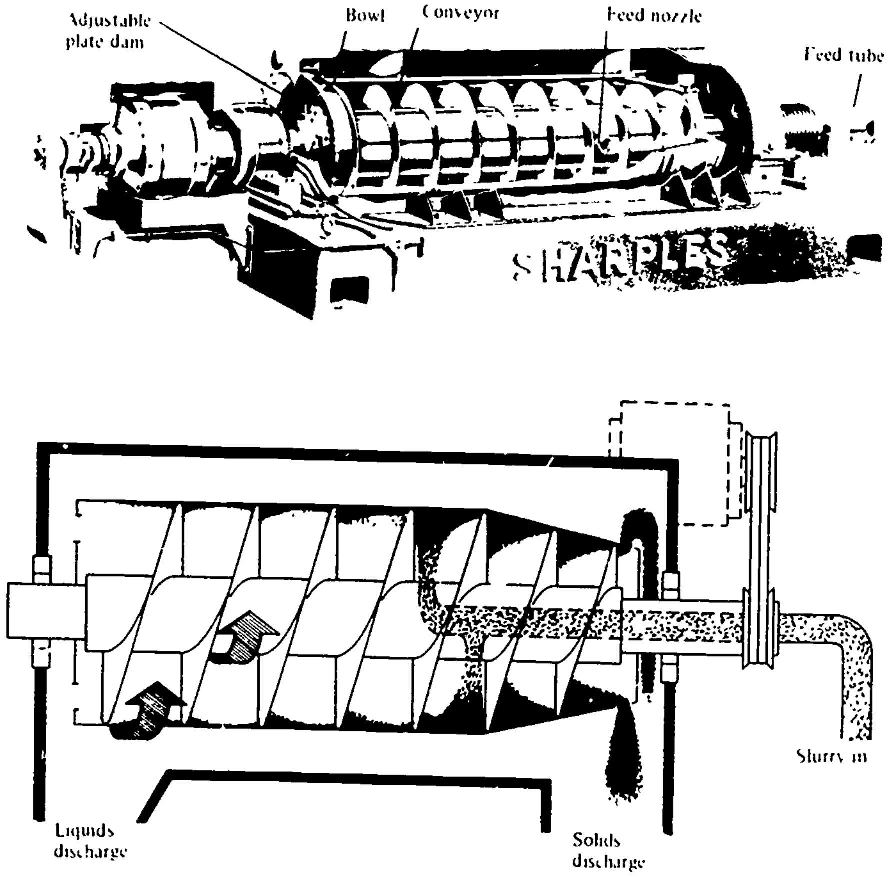


Fig. 17.10 Solid-bowl scroll centrifuge
(Permission of Sharples-Stokes Division, Pennwalt Corporation)

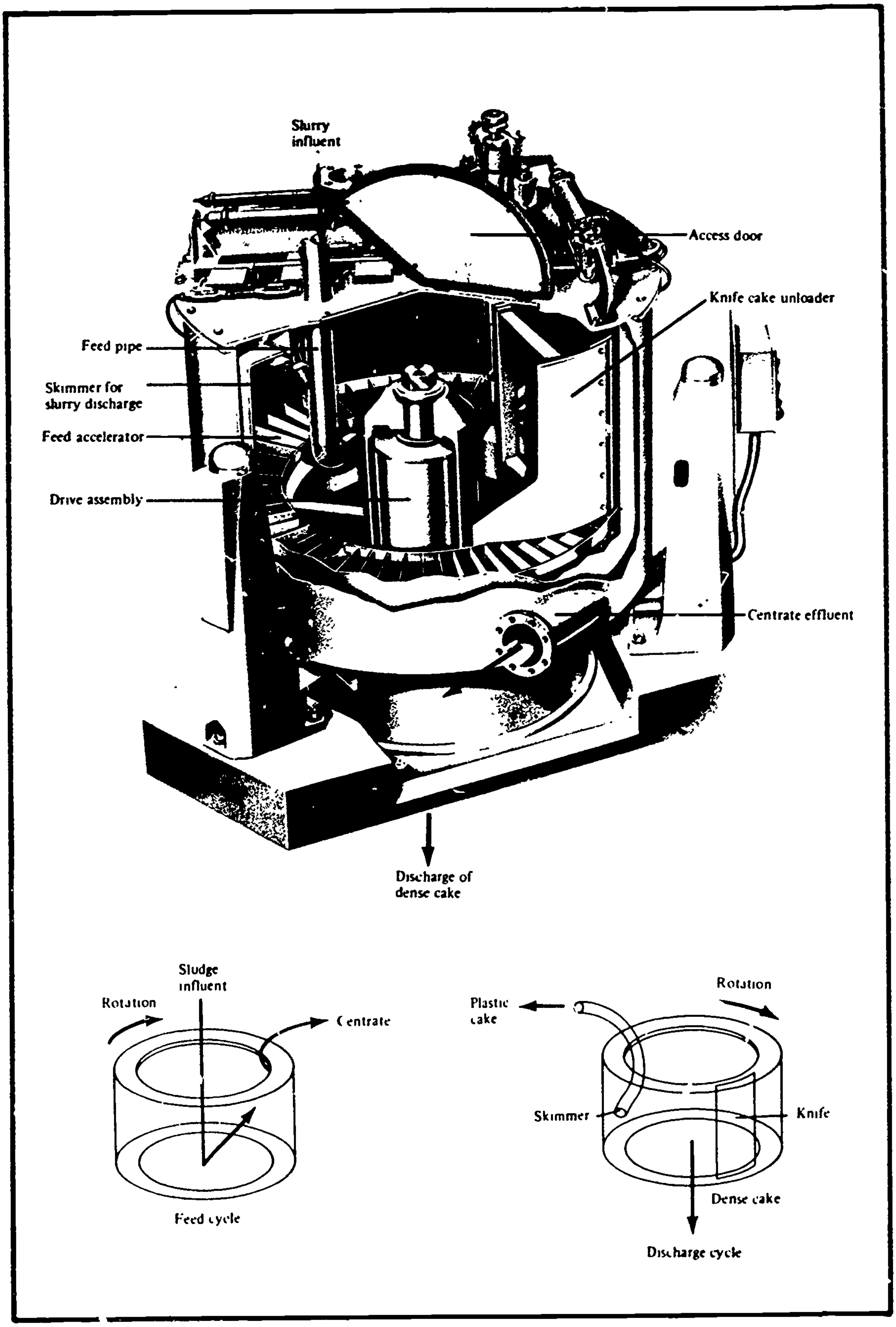


Fig. 17.11 Imperforate basket centrifuge

(Permission of Sharples-Stokes Division, Pennwalt Division)

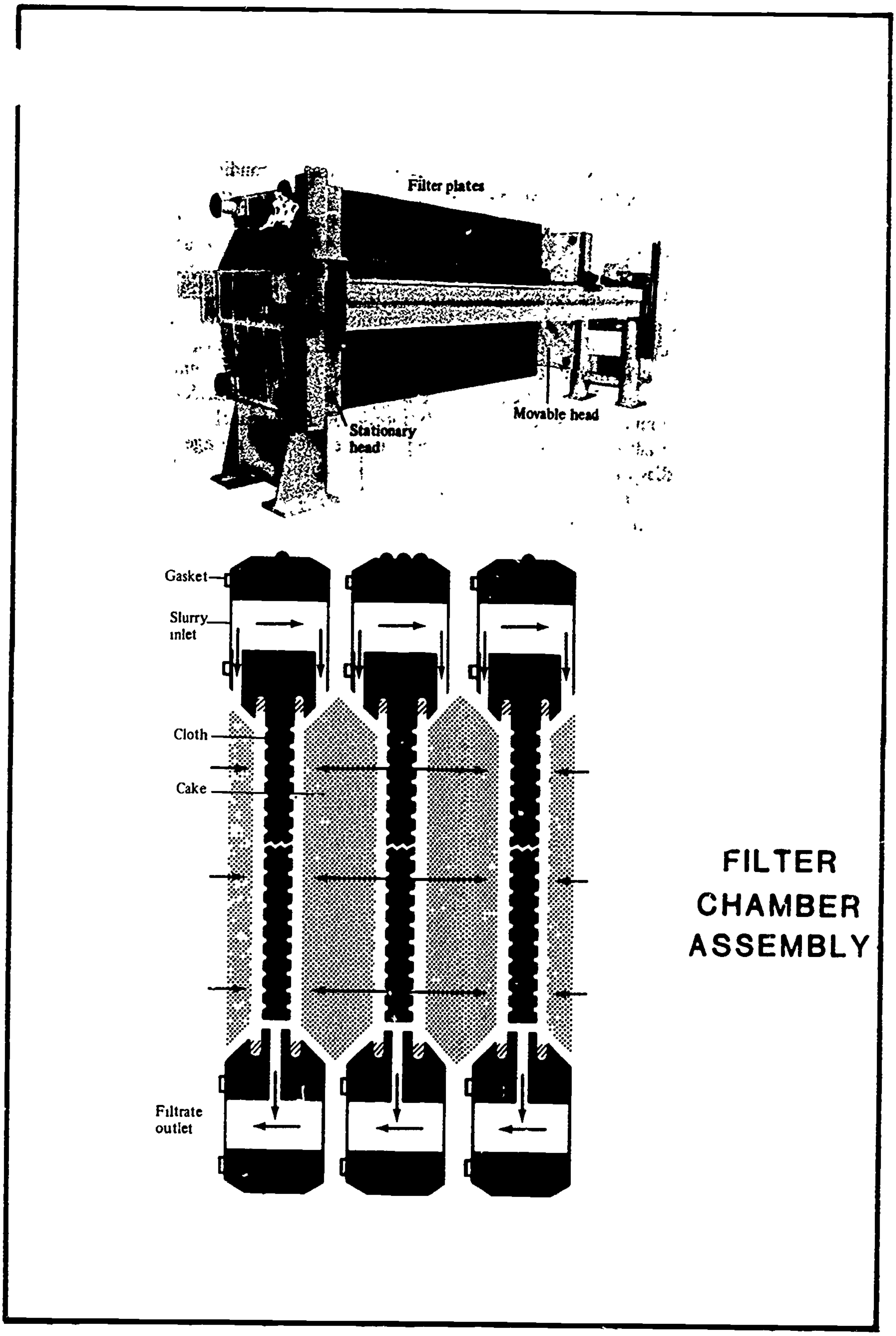


Fig. 17.12 Filter press

(Permission of Shriver Division, Eimco Process Equipment Co.)

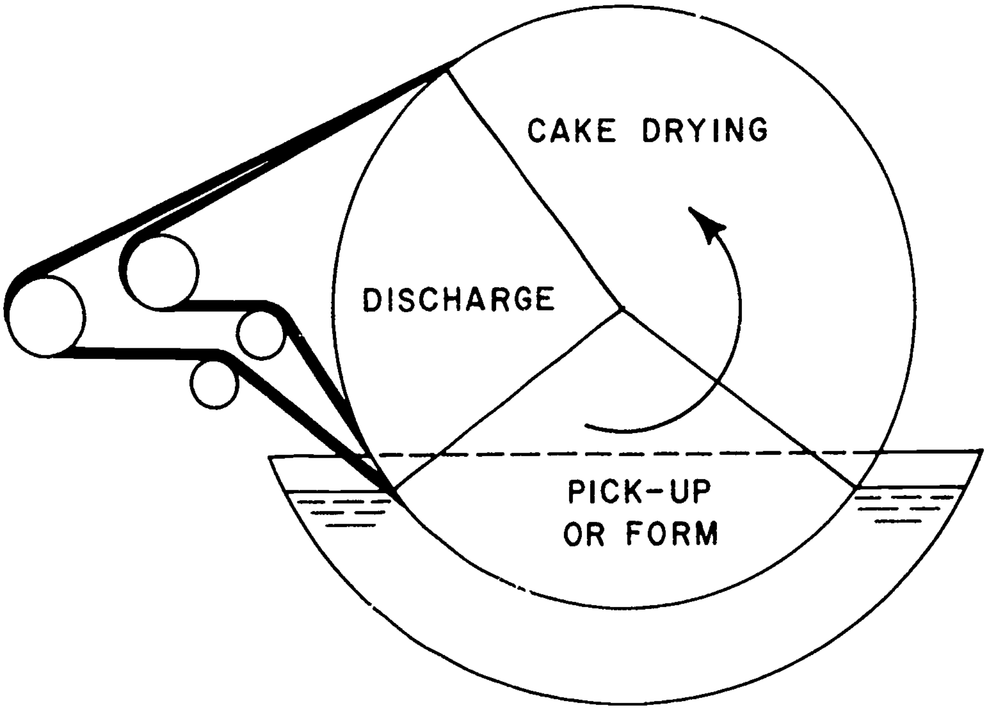


Fig. 17.13 Operating zones of a vacuum filter

(Permission of Metropolitan Water District of Southern Californ a)

Water treatment plant lime sludge is an excellent liming agent for agricultural purposes. Lime sludge must be applied at a rate to achieve the best soil pH for optimum crop yield. Optimum levels of nitrogen and phosphorus are also important to achieve high crop yields.

The application of nitrogen fertilizers cause a reduction in soil pH. If optimum soil pH conditions do not exist, crop yields will be reduced. Therefore, sufficient quantities of lime must be applied as a means of counteracting the fertilizer applications.

Lime softening sludges can also aid in the reclamation of spoiled lands by neutralizing acid soils. Disposal of lime softening sludge on strip mine land will help minimize the discharge of acidic compounds and low pH drainage waters.

Although most lime softening sludges are an excellent liming agent for agricultural and land reclamation purposes, some lime softening sludges must be disposed of in a sanitary landfill due to the lack of availability of agricultural land or excessive costs. Landfilling of lime softening sludge is a practical alternative where this method is cost-effective (minimum cost of disposal).

Alum sludge has a tendency to cause soils to harden and does not provide any beneficial value. For this reason water treatment plant alum sludge must not be applied to agricultural land. The sludge may be applied to a dedicated land disposal site. The sludge is applied to the land and disked into the soil. Landfilling is another method of ultimate disposal of alum sludge

Some water treatment plants use a slow sand filter or settling pond for the treatment of iron filter backwash wastewater. The slow sand filter must be cleaned occasionally by removing the top 2 to 3 inches (50 to 75 mm) of sand and iron sludge. The material removed must be disposed of in a sanitary landfill.

Water treatment plants which soften water by the ion exchange (zeolite) softening method produce a wastewater which has high concentrations of total dissolved solids and chloride compounds. Ion exchange softening wastes should not be discharged untreated into low flow streams. The wastewater treatment processes capable of reducing the total dissolved solids and chloride concentrations to acceptable levels are very energy consumptive and expensive. Ion exchange softener regeneration wastewater may be very carefully and slowly discharged into a sanitary sewer system. The operator at the wastewater treatment plant must be notified in advance.

If a sanitary sewer system is not available for the disposal of ion exchange softening wastes, holding tanks should be installed to store the liquid from the regeneration and rinse cycles. This liquid should be ultimately disposed of in a sanitary landfill.

Filter backwash wastewater may be recycled through the water treatment plant, placed in wastewater storage ponds for additional treatment and disposal or discharged into a sanitary sewer. The remainder of this section discusses some of the procedures used by operators to dispose of sludges.

Wet sludge can be disposed of in an open field by use of spray bars or dumped out for landfill (Figure 17.14). When releasing the wet sludge at one spot, the back of the truck should face downhill so it will drain faster and be emptied out completely (Figure 17.15). This practice will also reduce the chances of the truck getting stuck in the sludge. Usually it takes about 10 minutes to empty a truck.

Sometimes individuals will request the sludge for fill and some contractors have used the sludge to mix with decomposed granite (DG) (a type of rock found in some regions) for fill purposes.

Sludge drying beds for sedimentation tank wastes also can be used to dry sludge from nearby backwash recovery ponds, but this requires the sludge to be handled for a second time. An open field spray bar application is one method for disposing of backwash recovery sludges because after a few weeks, the residual is hardly noticeable. PVC pipe may be used to dispose of backwash recovery sludges instead of using a spray bar.

Where sludge is repeatedly spread in a single landfill site, be prepared to disc the sludge in with the native soil because it is unsightly. Obviously a location as close to the plant as possible would be the most cost-effective solution.

In plants with a size range from 5 to 10 MGD (19 to 38 MLD), it will take four operators approximately two days to complete the job of draining and cleaning a sedimentation tank or a backwash recovery pond and disposing of the sludge

In plants where a backwash pond is not available, the sludge can be moved to a sump. A smaller suction hose must be used to empty small sumps; instead of the 6 inch (150 mm) hose, use either a 3 or 4 inch (75 or 100 mm) hose. With a smaller suction hose, it will take 25 minutes or more to fill the vacuum tank. Five or six operators will be needed to keep the sump filled. Of course, during the time that the truck is on the road to the dump site and back again, the operators are standing by and the sludge cannot be moved. If two trucks were used, this disadvantage could be overcome, but the cost may also increase. Obviously, the larger the sump and the truck's tank, the cheaper the operation from the standpoint of labor costs.

Plants of one MGD (3.8 MLD) capacity may be able to use some of the local septic tank pumpers or vacuum trucks to an advantage. Such companies usually have made arrangements for the use of dump sites that may be used to dispose of the sludge they pump.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 204.

17.8A List the methods of ultimate sludge disposal.

17.8B Why should sludge be disposed of as close as possible to the water treatment plant?

17.9 EQUIPMENT

17.90 Vacuum Trucks

The use of a vacuum truck is highly recommended because these trucks develop the fewest problems with clogging. The larger the suction pipe the better. Any object

Fig. 17.14 *Use of sludge for a landfill*

Fig. 17.15 *Emptying sludge from a truck*

smaller than the hose size can be readily sucked through unless there are too many objects in the sludge. Wedging of several rocks or sticks can occur, slowing up the process of sludge removal. Obviously any object that is sighted should be removed by hand picking and tossed out. Any well operated plant should be void of these solids, but they are sometimes accidentally dropped in or thrown in by vandals. Leaves and other small objects that may get by the plant inlet screens are not too much of a problem unless an excessive amount exists. Under these conditions, the heavily accumulated portions should be scooped out to prevent any clogging of drain pipes or suction hoses.

17.91 Sludge Pumps

Many small treatment plants exist, especially in rural areas, where disposal of sludge would appear less troublesome. A couple of thousand gallons of sludge can be moved by gravity or pumped out to an open field and disked. Even a quarter of an acre can handle many years of dried sludge from a small plant. Unfortunately, most of these plants do not have the land available, so the sludge in its wet form must be hauled out to a disposal site or a small lagoon or pond must be excavated for sludge collection. If sludge must be moved wet, use a sludge pump[8] to pump it into a tank or hire a septic tank pumper. Septic tank pumps, especially the suction hose, must be thoroughly rinsed and disinfected before use in any water treatment plant facilities. This applies also to all tools and equipment used.

A sludge pump can be an advantage over a self-priming centrifugal pump because of its large suction and discharge hose (usually three inches (75 mm) in diameter). These pumps are rated at about 60 GPM (3.8 L/sec) and can handle more solids. However, there are also self-priming types of wastewater pumps available that are designed so that solids do not actually pass through the impellers. These pumps may be used to pump sludges from water treatment plants. In either case, an excessive amount of foreign solids other than sludge itself can cause some pumping problems.

Wet sludge from a sedimentation tank will flow through pipes by gravity even if there are some ups and downs in the line provided the sludge is under some head. If difficulty arises, add some water for dilution or raise the end of the suction hose closer to the surface of the sump where the sludge is more diluted.

Because of the differences in volume between wet and dried sludge, it is always preferable to contain the wet sludge at the plant for drying. If the plant water source is a canal or reservoir close to the site, construct a small pond parallel to it and return the supernatant to the source for recycling by removing baffle boards. Only fresh backwash wastewater should be recycled. Water separated or drained from old sludge can cause serious problems if recycled. This water is likely to be septic and could cause taste and odor problems. Also this water will contain millions of bacteria and microorganisms which should not be recycled through a water treatment plant.

If necessary, semi-dry or dried sludge can be hauled out of the pond.

17.10 PLANT DRAINAGE WATERS

There are several sources of drainage waters in a water treatment plant which must be properly handled and disposed of. These sources include the laboratory, shops and plant drainage water from leaks and spills. If continuous sampling pumps provide the lab with continuous flowing water from various plant processes, this water could be discharged to a sewer. Any reagents, toxics or potentially pathogenic wastes from the lab must be properly treated and packaged before ultimate disposal in landfills. Drainage waters from leaks and other sources in the plant may be discharged to sewers. These drainage waters may be recycled through the plant; however, extreme caution must be exercised at all times to avoid contributing to taste, odor, or health hazards as well as operational problems.

17.11 MONITORING AND REPORTING

The location of the water treatment plant and the methods used to ultimately dispose of the process wastes will dictate the monitoring and reporting requirements. These reporting requirements may be established by local or state health or pollution control agencies. Monitoring and reporting will usually involve measuring and recording volumes of sludges or brines, percent solids and other measurements which will prove that these processes are not creating any adverse environmental impacts.

17.12 ADDITIONAL READING

1. *PROCESSING WATER TREATMENT PLANT SLUDGES. AWWA Computer Services, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 20108. Price, members, $10.50; nonmembers, $13.00.*

QUESTIONS

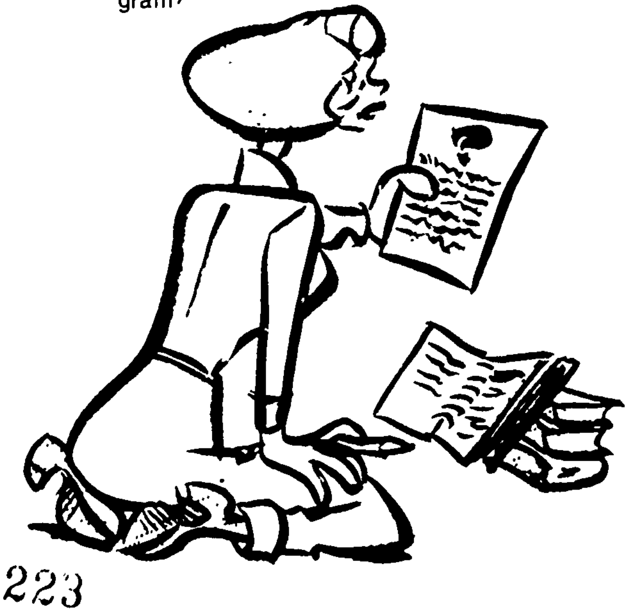
Write your answers in a notebook and then compare your answers with those on page 204.

17.9A How do objects that plug sludge suction hoses get into water treatment plants?

17.9B What type of pump can be used to pump sludge into a tank on a truck?

17.10A List the sources of plant drainage waters.

17.11A What factors will dictate your monitoring and reporting requirements for your sludge disposal program?



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[8] *Types of sludge pumps include types of diaphragm, nonclog, and progressive cavity pumps.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 17. HANDLING AND DISPOSAL OF PROCESS WASTES

Work these discussion and review questions before continuing with the Objective Test on page 204. The purpose of these questions is to indicate to you how well you understand the material in the chapter. Write the answers to these questions in your notebook.

1. The amount of sludge produced by a conventional water filtration plant depends on what factors?
2. What items should be considered when determining the frequency of cleaning a sedimentation basin?
3. What happens to the water separated from sludges in backwash recovery ponds or lagoons?
4. Why are at least three sludge drying beds installed at water treatment plants?
5. What precautions must be taken before draining a tank?
6. What duties should be performed by operators as the sludge is being drained from a sedimentation tank?
7. How would you fill a sedimentation tank after the tank has been emptied, inspected and the necessary repairs completed?
8. How is sludge from the lime-soda softening process dewatered?
9. Why should the back of the sludge truck face downhill when releasing wet sludge at one point?
10. What is the purpose of monitoring and reporting for a sludge disposal program?

SUGGESTED ANSWERS

Chapter 17. HANDLING AND DISPOSAL OF PROCESS WASTES

Answers to questions on page 183.

17.0A Strict laws are needed regarding the disposal of process wastes to prevent rivers and streams from becoming more polluted. These laws are designed to prevent any waste discharge that could discolor, pollute or generally be harmful to aquatic or plant life or the environment.

17.0B If a discharge results from the disposal of process wastes, such water quality indicators as pH, turbidity, TDS, settleable solids and any other harmful materials may require monitoring.

Answers to questions on page 184.

17.1A Sludge is removed from sedimentation tanks by mechanical rakes or scrapers which periodically draw out sludge from a hopper or a vacuum-type sludge removal device may be used.

17.1B Sludge is removed from upflow solids-contact units through sludge drawoff lines which must be monitored.

Answers to questions on page 185.

17.2A A source water stabilizing reservoir can reduce the volume of sludge handled by reducing the turbidity in the water being treated. Lower turbidities reduce the amount of alum required and thus the volume of sludge that settles out.

17.2B If a plant does not have sludge drying beds or lagoons, the raw or wet sludge can be pumped into a vacuum tank truck and hauled to a site where the sludge can be spread out on land to dry or dumped in a landfill.

Answers to questions on page 185.

17.3A Sludge may be dewatered by the use of belt presses, centrifuges, filter presses, vacuum filters, solar lagoons and sand drying beds.

17.3B Sedimentation tanks should be inspected and repaired (if necessary) when the tanks are drained and cleaned.

Answers to questions on page 187.

17.4A Sludge must be removed manually from tanks without mechanical or vacuum-type sludge collectors. The tanks must be drained and then operators must push the sludge to the drain lines with squeegees or the sludge must be pumped out into tank trucks.

17.4B When draining a sedimentation tank, do not drain the settled water above the sludge to the lagoons or sludge drying beds. Divert or pump this water to sedimentation tanks that are in operation, to the headworks for reprocessing, or return the water to the source.

17.4C Whenever an operator enters a closed tank (confined space), be sure that:

1. No gasoline engines are operated in the tank,
2. Adequate ventilation of clean air is provided at all times.
3. Clean running water is available to wash down boots and equipment when leaving the tank, and
4. Use the buddy system Someone must be outside the tank and watching anyone inside the tank.

Answers to questions on page 190.

17.5A Time is critical if backwash recovery ponds are used to handle sludge from sedimentation basins, because you want to avoid having to backwash the filters while you are draining a sedimentation tank.

17.5B The suction pipe for the backwash recovery pump must be floated near the surface of the pond so that any excess water can be recycled, but the sludge will not be pumped out of the pond.

17.5C Lime-soda softening sludge can be disposed of ultimately by

1. Covering the lagoon with soil,
2. Hauling the dried sludge to a landfill, or
3. Spreading on agricultural soils to adjust the pH for optimum crop yields.

Answers to questions on page 191.

17.6A The minimum recommended number of solar drying lagoons is three.

17.6B Sludge drying beds are made with underdrains covered with gradations of aggregate and sand. The drains terminate into a sump where recovery pumps can return the water drained from the sludge back to the plant to be reprocessed.

17.6C The proper time to remove sludge from the drying bed is when one foot of sludge has accumulated and a checkered-shaped piece of dry sludge can be picked up off the sand.

17.6D When operating a front-end loader to remove sludge from a drying bed, be careful so only the dried sludge is picked up with a minimum of disturbance to the sand and aggregate. The loader bucket capacity should be limited to one or two cubic yards of sludge because there may be only about 14 inches of sand cover over the underdrains.

Answers to questions on page 195.

17.6E Sludges may be dewatered using: (1) solar lagoons, (2) sand drying beds, (3) belt presses, (4) centrifuges, (5) filter presses, and (6) vacuum filters.

17.6F The principal advantage of using centrifuges to dewater sludges is that the density of the sludge cake can be varied from a thickened liquid slurry to a dry cake. The major limitation of using centrifuges is high energy consumption.

17.6G A precoat of diatomaceous earth is required to dewater gelatinous alum sludge.

Answers to questions on page 195.

17 7A The complications of discharging sludge to sewers include:

1. Fees charged by wastewater treatment plants could be very high,
2. Increased monitoring requirements and costs,
3. A holding tank may be necessary so the sludge is released at a uniform rate.
4. Possibility of causing a sewer blockage, and
5. Wastewater treatment plant will have to handle and dispose of sludge.

17 7B Brine from ion exchange units is usually discharged into wastewater collections during the day to take advantage of high flows for dilution.

Answers to questions on page 200.

17 8A Methods of ultimate sludge disposal include:

1. Wet sludge can be disposed of on open fields,
2. Wet or dry sludge can be dumped in landfills, and
3 Lime softening sludges may be sold to improve the pH of agricultural soils

17.8B Sludge should be disposed of as close as possible to the water treatment plant to reduce hauling costs.

Answers to questions on page 202.

17 9A Objects that plug sludge suction hoses get into water treatment plants by being accidentally dropped in or thrown in by vandals.

17.9B A diaphragm pump can be used to pump sludge into a tank on a truck.

17.10A Sources of plant drainage waters include the laboratory, shops and plant drainage water from leaks and spills.

17.11A Monitoring and reporting requirements for a sludge disposal program are dictated by the location of your water treatment plant and the methods used to ultimately dispose of your process wastes.

OBJECTIVE TEST

Chapter 17. HANDLING AND DISPOSAL OF PROCESS WASTES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Many articles and books have been written on sludge handling and disposal.

   1. True
   2. False

2 Frequently water treatment plants will use a sedimentation tank as a backwash recovery area

   1. True
   2 False

3 Ultimately process wastes must be disposed of in a manner that will not harm the environment.

   1 True
   2 False

4 Wet sludge can easily be removed from drying beds by a front-end loader.
   1. True
   2. False

5. After draining a sedimentation tank, allow the sludge to dry on the equipment so the sludge can be easily removed.
   1. True
   2. False

6. Sludge that settles out near the entrance to the sedimentation tank is more dense than the rest of the sludge.
   1 True
   2. False

7. The sale of lime sludge as an agricultural liming agent can help offset sludge handling and disposal costs.
   1. True
   2 False

8. Brine from ion exchange units is usually discharged into sewers at night during low flow periods.
   1. True
   2. False

9 Wet sludge from a sedimentation tank can flow through pipes by gravity.
   1. True
   2. False

10. Wet sludge should be dewatered or dried at the plant before being hauled away.
   1. True
   2 False

MULTIPLE CHOICE

11. Sources of process wastes include
   1. Disinfection.
   2. Filter backwash.
   3. Grit basins
   4. Ion exchange softening.
   5 Lime-soda softening.

12. Sludges may be dewatered by
   1. Centrifuging.
   2. Drying.
   3. Filter pressing.
   4. Flocculating.
   5. Lagooning.

13. Sludges and brines may be ultimately disposed of in
   1. Lakes.
   2 Landfills.
   3. Rivers.
   4. Streams.
   5. Wastewater collection systems.

14 The frequency of draining and cleaning a sedimentation tank will depend on
   1. Backwash rate of rapid sand filters.
   2. Detention time in sand filters.
   3. Time required to drain and clean tank.
   4. Volume of sludge in tank.
   5 Volume of treated water in distribution system pipes.

15 How freqently are sedimentation tanks usually drained and cleaned?
   1. Weekly
   2. Monthly
   3. Quarterly
   4. Semi-annually
   5. Annually

16. Treatment processes used in water treatment plants to reduce the volume of sludge that must be handled and ultimately disposed of include
   1. Conditioning.
   2. Dewatering.
   3. Digesting.
   4. Flocculating.
   5. Thickening.

17. Methods of ultimate sludge disposal will depend on
   1. Distance to disposal site.
   2. Land available.
   3. Quality of product water.
   4. Sludge moisture content
   5. Volume of sludge.

18. The frequency of removal of dried sludge will depend on
   1. Drying conditions (weather).
   2. Number of operators at the plant.
   3. Size of drying beds.
   4. Time available for operators to do job.
   5. Volume of sludge produced.

19. When draining a sedimentation tank, the settled water above the sludge should be
   1. Diverted to the clear well.
   2 Diverted to the headworks for reprocessing.
   3 Emptied onto the sludge drying beds.
   4. Pumped to a sedimentation tank in operation.
   5 Recycled to the solar drying ponds.

20. The easiest way to dispose of sludge from a sedimentation tank is to
   1. Discharge sludge to the sewer.
   2 Divert sludge to backwash recovery ponds.
   3. Haul sludge to landfill.
   4. Pump sludge to drying beds.
   5. Spread sludge over land.

21. When releasing wet sludge at one point, the back of the sludge truck should face downhill so the
   1. Spray bars will not become plugged.
   2. Tank will empty completely.
   3. Tank will empty faster.
   4. Truck will not become stuck in the sludge.
   5. Water will flow out before the sludge.

End of Objective Test

CHAPTER 18

MAINTENANCE

by

Parker Robinson

TABLE OF CONTENTS

Chapter 18 Maintenance

LESSON 2

LESSON 3

LESSON 4

LESSON 5

OBJECTIVES

Chapter 18. MAINTENANCE

Following completion of Chapter 18, you should be able to:

1 Develop a maintenance program for your plant, including equipment, buildings, grounds, channels, and tanks;

2. Start a maintenance recordkeeping system that will provide you with information to protect equipment warranties, to prepare budgets, and to satisfy regulatory agencies;

3. Schedule maintenance of equipment at proper time intervals;

4. Perform maintenance as directed by manufacturers;

5. Recognize symptoms that indicate equipment is not performing properly, identify the source of the problem, and take corrective action;

6. Recognize the serious consequences that could occur when inexperienced, unqualified or unauthorized persons attempt to troubleshoot or repair electrical panels, controls, circuits, wiring or equipment;

7. Communicate with electricians by indicating possible causes of problems in electrical panels, controls, circuits, wiring, and motors;

8 Properly select and use the following pieces of equipment (if qualified and authorized):

   a. Voltage tester,

   b. Ammeter,

   c. Megger, and

   d. Ohm meter;

9. Safely operate and maintain auxiliary electrical equipment, including during standby and emergency situations;

10. Describe how a pump is put together;

11. Discuss the application or use of different types of pumps;

12. Start and stop pumps;

13. Maintain the various types of pumps;

14. Operate and maintain a compressor;

15. Develop and conduct an equipment lubrication program; and

16. Start up, operate, maintain and shut down gasoline engines, diesel engines, heating, ventilating and air conditioning systems.

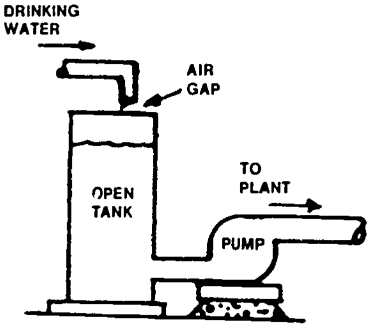
NOTE: Special maintenance information is given in the previous chapters on treatment processes where appropriate.

GLOSSARY

Chapter 18. MAINTENANCE

AIR GAP

An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water.



AIR GAP

ALTERNATING CURRENT (A.C.) ALTERNATING CURRENT (A.C.)

An electric current that reverses its direction (positive/negative values) at regular intervals.

AMPERAGE (AM-purr-age) AMPERAGE

The strength of an electric current measured in amperes. The amount of electric current flow, similar to the flow of water in gallons per minute.

AMPERE (AM-peer) AMPERE

The unit used to measure current strength The current produced by an electromotive force of one volt acting through a resistance of one ohm.

AMPLITUDE AMPLITUDE

The maximum strength of an alternating current during its cycle, as distinguished from the mean or effective strength.

AXIAL TO IMPELLER AXIAL TO IMPELLER

The direction in which material being pumped flows around the impeller or parallel to the impeller shaft.

AXIS OF IMPELLER AXIS OF IMPELLER

An imaginary line running along the center of a shaft (such as an impeller shaft).

BRINELLING (bruh-NEL-ing) BRINELLING

Tiny indentations (dents) high on the shoulder of the bearing race or bearing. A type of bearing failure.

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic. This concentrates corrosion on auxiliary anodic parts which are deliberately allowed to corrode instead of letting the structure corrode.

CAVITATION (CAV-uh-TAY-shun) CAVITATION

The formation and collapse of a gas pocket or bubble on the blade of an impeller or the gate of a valve. The collapse of this gas pocket or bubble drives water into the impeller or gate with a terrific force that can cause pitting on the impeller or gate surface. Cavitation is accompanied by loud noises that sound like someone is pounding on the impeller or gate with a hammer.

CIRCUIT CIRCUIT

The complete path of an electric current, including the generating apparatus or other source, or, a specific segment or section of the complete path.

CIRCUIT BREAKER CIRCUIT BREAKER

A safety device in an electrical circuit that automatically shuts off the circuit when it becomes overloaded. The device can be manually reset.

CONDUCTOR CONDUCTOR

A substance, body, device or wire that readily conducts or carries electrical current.

COULOMB (COO-lahm) COULOMB

A measurement of the amount of electrical charge conveyed by an electric current of one ampere in one second. One coulomb equals about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons).

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving non-potable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

CURRENT CURRENT

A movement or flow of electricity. Water flowing in a pipe is measured in gallons per second past a certain point, not by the number of water molecules going past a point. Electric current is measured by the number of coulombs per second flowing past a certain point in a conductor. A coulomb is equal to about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons). A flow of one coulomb per second is called one ampere, the unit of the rate of flow of current.

CYCLE CYCLE

A complete alternation of voltage and/or current in an alternating current (A.C.) circuit.

DATEOMETER (day-TOM-uh-ter) DATEOMETER

A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.

DIRECT CURRENT (D.C.) DIRECT CURRENT (D.C.)

Electrical current flowing in one direction only and essentially free from pulsation.

ELECTROLYTE (ee-LECK-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROMOTIVE FORCE (E.M.F.) ELECTROMOTIVE FORCE (E.M.F.)

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See VOLTAGE.

ELECTRON ELECTRON

An extremely small, negatively-charged particle, the part of an atom that determines its chemical properties.

END BELLS END BELLS

Devices used to hold the rotor and stator of a motor in position.

FUSE FUSE

A protective device having a strip or wire of fusible metal which, when placed in a circuit, will melt and break the electrical circuit if heated too much. High temperatures will develop in the fuse when a current flows through the fuse in excess of that which the current will carry safely.

GROUND GROUND

An expression representing an electrical connection to earth or a large conductor which is at the earth's potential or neutral voltage.

HERTZ (HURTS) HERTZ

The number of complete electromagnetic cycles or waves in one second of an electrical or electronic circuit. Also called the frequency of the current. Abbreviated Hz.

HYGROSCOPIC (HI-grow-SKOP-ick) HYGROSCOPIC

Absorbing or attracting moisture from the air.

JOGGING JOGGING

The frequent starting and stopping of an electric motor.

LEAD (LEE-d) LEAD

A wire or conductor that can carry electricity.

MANDREL (MAN-drill) MANDREL

A special tool used to push bearings in or to pull sleeves out.

MEG MEG

A procedure used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEGGER.

MEGGER (from megohm) MEGGER

An instrument used for checking the insulation resistance on motors, feeders, buss bar systems, ground, and branch circuit wiring. Also see MEG

MEGOHM MEGOHM

Meg means one million, so 5 megohms means 5 million ohms. A megger reads in millions of ohms.

MULTI-STAGE PUMP MULTI-STAGE PUMP

A pump that has more than one impeller. A single-stage pump has one impeller.

OHM OHM

The unit of electrical resistance The resistance of a conductor in which one volt produces a current of one ampere.

POLE SHADER POLE SHADER

A copper bar circling the laminated iron core inside the coil of a magnetic starter.

POWER FACTOR POWER FACTOR

The ratio of the true power passing through an electric circuit to the product of the voltage and amperage in the circuit. This is a measure of the lag or load of the current with respect to the voltage. In alternating current the voltage and amperes are not always in phase; therefore, the true power may be slightly less than that determined by the direct product.

PRUSSIAN BLUE PRUSSIAN BLUE

A blue paste or liquid (often on a paper like carbon paper) used to show a contact area. Used to determine if gate valve seats fit properly.

RADIAL TO IMPELLER RADIAL TO IMPELLER

Perpendicular to the impeller shaft. Material being pumped flows at right angle to the impeller.

RESISTANCE RESISTANCE

That property of a conductor or wire that opposes the passage of a current, thus causing electrical energy to be transformed into heat.

ROTOR ROTOR

The rotating part of a machine. The rotor is surrounded by the stationary (non-moving) parts (stator) of the machine.

SEIZE UP SEIZE UP

Seize up occurs when an engine overheats and a part expands to the point where the engine will not run. Also called "freezing."

SHEAVE (SHE-v) SHEAVE

V-belt drive pulley which is commonly made of cast iron or steel.

SHIM SHIM

Thin metal sheets which are inserted between two surfaces to align or space the surfaces correctly. Shims can be used anywhere a spacer is needed. Usually shims are 0.001 to 0.020 inches thick.

SINGLE-STAGE PUMP SINGLE-STAGE PUMP

A pump that has only one impeller. A multi-stage pump has more than one impeller.

STATOR STATOR

That portion of a machine which contains the stationary (non-moving) parts that surround the moving parts (rotor).

STETHOSCOPE STETHOSCOPE

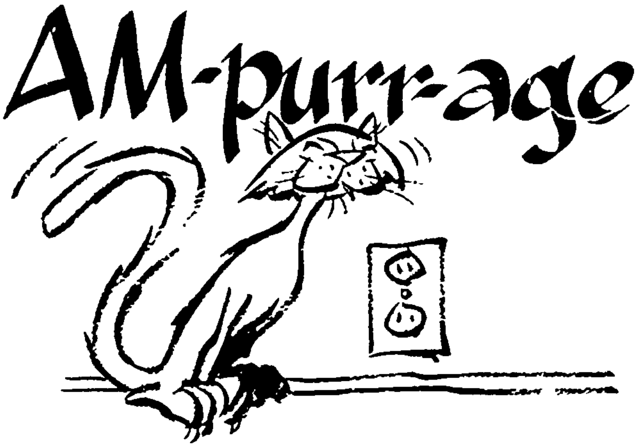
An instrument used to magnify sounds and convey them to the ear.

VOLTAGE VOLTAGE

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See ELECTROMOTIVE FORCE (E.M.F.).

WATER HAMMER WATER HAMMER

The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressure can do serious damage to the system.



CHAPTER 18. MAINTENANCE

(Lesson 1 of 5 Lessons)

18.0 TREATMENT PLANT MAINTENANCE — GENERAL PROGRAM

A water treatment plant operator has many duties. Most of them have to do with the efficient operation of the plant. An operator has the responsibility to produce a water that will meet all the requirements established for the plant. By doing this, the operator develops a good working relationship with the regulatory agencies, water users, and plant neighbors.

Another duty an operator has is that of *PLANT MAINTENANCE*. A good maintenance program is a must in order to maintain successful operation of the plant. A successful maintenance program will cover everything from mechanical equipment to the care of the plant grounds, buildings, and structures.

Mechanical maintenance is of prime importance as the equipment must be kept in good operating condition in order for the plant to maintain peak performance. Manufacturers provide information on the mechanical maintenance of their equipment. You should thoroughly read their literature on your plant equipment and *UNDERSTAND* the procedures. Contact the manufacturer or the local representative if you have any questions Follow the instructions very carefully when performing maintenance on equipment. You also must recognize tasks that may be beyond your capabilities or repair facilities, and you should request assistance when needed.

For a successful maintenance program, your supervisors must understand the need for and benefits from equipment that operates continuously as intended Disabled or improperly working equipment is a threat to the quality of the plant output, and repair costs for poorly maintained equipment usually exceed the cost of maintenance.

18.00 Preventive Maintenance Record

Preventive programs help operating personnel keep equipment in satisfactory operating condition and aid in detecting and correcting malfunctions before they develop into major problems.

A frequent occurrence in a preventive maintenance program is the failure of the operator to record the work after it is completed. When this happens the operator must rely on memory to know when to perform each preventive maintenance function. As days pass into weeks and months, the preventive maintenance program is lost in the turmoil of everyday operation.

The only way an operator can keep track of a preventive maintenance program is by *GOOD RECORDKEEPING*. Whatever record system is used, it should be kept up to date on a daily basis and not left to memory for some other time. Equipment service record cards (Figure 18.1) are easy to set up and require little time to keep up to date.

An EQUIPMENT SERVICE CARD (master card) should be filled out for each piece of equipment in the plant. Each card should have the equipment name on it, such as Raw Water Intake Pump No. 1

1 List each required maintenance service with an item number.

2 List maintenance services in order of frequency of performance. For instance, show daily service as items 1, 2, and 3 on the card; weekly items as 4 and 5; monthly items as 6, 7, 8, and 9; and so on.

3 Describe each type of service under work to be done.

Make sure all necessary inspections and services are shown. For reference data, list paragraph or section numbers as shown in the pump maintenance section of this lesson (Section 18.23, p. 265) Also list frequency of service as shown in the time schedule columns of the same section. Under time, enter day or month service is due. Service card information may be changed to fit the needs of your plant or particular equipment as recommended by the equipment manufacturer. Be sure the information on the cards is complete and correct.

The *SERVICE RECORD CARD* should have the date and work done, listed by item number and signed by the operator who performed the service. Some operators prefer to keep both cards clipped together, while others place the service record card near the equipment.

When the service record is filled, it should be filed for future reference and a new card attached to the master card. The *EQUIPMENT SERVICE CARD* tells what should be done and when, while the *SERVICE RECORD CARD* is a record of what you did and when you did it.

18.01 Library of Manufacturers' Operation and Parts Manuals

A plant library can contain helpful information to assist in plant operation. Material in the library should be cataloged and filed for easy use. Items in the library should include:

EQUIPMENT SERVICE CARD

EQUIPMENT. #1 Raw Water Intake Pump

Item No.	Work to be Done	Reference[a]	Frequency	Time
1	Check water seal and packing gland	Par. 1	Daily	
2	Listen for unusual noises	Par. 6	Daily	
3	Operate pump alternately	Par. 1	Weekly	Monday
4	Inspect pump assembly	Par. 1	Weekly	Wednesday
5	Inspect and lube bearings	Par. 1	Quarterly	1-4-7-10[b]
6	Check operating temperature of bearings	Par. 1	Quarterly	1-4-7-10[b]
7	Check alignment of pump and motor	Par. 1	Semi-Ann.	4 & 10
8	Inspect and service pumps	Par. 1	Semi-Ann.	4 & 10
9	Drain pump before shutdown	Par. 1		

SERVICE RECORD CARD

EQUIPMENT: #1 Raw Water Intake Pump

Date	Work Done (Item No.)	Signed	Date	Work Done (Item No.)	Signed
1-5-84	1-2-3	J.B.			
1-6-84	1-2	J.B.			
1-7-84	1-2-4-5-6	R.W.			

[a] Par. 1 refers to Paragraph 1 in Section 18.23 of this manual Par. 6 is also in Section 18.23.

[b] 1-4-7-10 represent the months of the year when the equipment should be serviced — 1-January, 4-April, 7-July, and 10-October.

Fig. 18.1 Equipment service card and service record card

1. Plant operation and maintenance instruction manuals,
2. Plant plans and specifications,
3. Manufacturers' instructions,
4. Reference books on water treatment,
5. Professional journals and publications,
6. First-aid book,
7. Reports from other plants, and
8. A dictionary.

18.02 Emergencies

If your plant has not developed procedures for handling potential emergencies, do it *NOW*. Emergency procedures must be established for operators to follow when emergencies are caused by the release of chlorine, hazardous or toxic chemicals into the raw water supply, power outages or broken transmission lines or distribution mains. These procedures should include a list of emergency phone numbers located near a telephone that is unlikely to be affected by the emergency.

1. Police
2. Fire
3. Hospital and/or Physician
4. Responsible Plant Officials
5. Local Emergency Disaster Office
6. CHEMTREC (800) 424-9300
7. Emergency Team (if your plant has one)

The CHEMTREC toll-free number may be called at any time. Personnel at this number will give information on how to handle emergencies created by hazardous materials and will notify appropriate emergency personnel.

An emergency team for your plant may be trained and assigned the task of responding to SPECIFIC EMERGENCIES such as chlorine leaks. This emergency team must meet the following strict specifications at all times.

1. Team personnel must be physically and mentally qualified.
2. Proper equipment must be available at all times, including:
   a. Protective equipment, including self-contained breathing apparatus,
   b. Repair kits, and
   c. Repair tools.
3. Proper training must take place on a regular basis and include instruction about:
   a. Properties and detection of hazardous chemicals,
   b. Safe procedures for handling and storage of chemicals,
   c. Types of containers, safe procedures for shipping containers, and container safety devices, and
   d. Installation of repair devices.
4. Team members must be exposed regularly to simulated field emergencies or practice drills. Team response must be carefully evaluated and any errors or weaknesses corrected

5 Emergency team performance must be reviewed annually on a specified date. Review must include:
   a. Training program,
   b. Response to actual emergencies, and
   c. Team physical and mental examinations.

WARNING. One person should never be permitted to attempt an emergency repair alone. Always wait for trained assistance. Valuable time could be lost rescuing a foolish individual rather than repairing or correcting a serious emergency.

For additional information on emergencies, see Chapter 7, Disinfection, Section 7.52, "Chlorine Leaks," Chapter 10, Plant Operation, Section 10.9, "Emergency Conditions and Procedures," and Chapter 23, Administration, Section 23 3, "Contingency Planning for Emergencies." Chapter 23 contains information on what to do if a toxic substance gets into your water supply.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 323.

18.0A Why should you plan a good maintenance program for your treatment plant?

18.0B What general items would you include in your maintenance program?

18.0C Why should you have a good recordkeeping system for your maintenance program?

18.0D What is the difference between an *EQUIPMENT SERVICE CARD* and *SERVICE RECORD CARD*?

18 0E Prepare a list of emergency phone numbers for your treatment plant.

18 0F What items should be included in the training program for an emergency team?

18.1 ELECTRICAL EQUIPMENT

18.10 Beware of Electricity

18.100 Attention

A. *DO NOT ATTEMPT TO INSTALL, TROUBLESHOOT, MAINTAIN, REPAIR OR REPLACE ELECTRICAL EQUIP-*

MENT, PANELS, CONTROLS, WIRING OR CIRCUITS UNLESS YOU

1 *KNOW WHAT YOU ARE DOING,*

2. *ARE QUALIFIED, AND*

3. *ARE AUTHORIZED.*

Section 18 11, Electrical Fundamentals, is presented to provide you with an understanding and awareness of electricity. *THE PURPOSE OF THE SECTION IS TO HELP YOU PROVIDE ELECTRICIANS WITH THE INFORMATION THEY WILL NEED WHEN YOU CONTACT THEM AND REQUEST THEIR ASSISTANCE. YOU MUST BE EXTREMELY FAMILIAR WITH ELECTRICITY BEFORE ATTEMPTING ANY MAJOR REPAIRS.*

B. Due to the wide variety of equipment and manufacturers in the water treatment field, detailed procedures for the maintenance of some types of equipment were very difficult to include in this chapter. Also manufacturers are continually improving their products and some details would soon be out of date *FOR DETAILS CONCERNING THE OPERATION, MAINTENANCE AND REPAIR OF A PARTICULAR PIECE OF EQUIPMENT, REFER TO THE O & M INSTRUCTIONS MANUAL OR CONTACT THE MANUFACTURER.*

C Effective equipment maintenance is the key to successful system performance. The better your maintenance, the better your facilities will perform. Abuse your equipment and facilities and they will abuse you Everyone must realize that if the equipment can't work, no one can work

18.101 Recognize Your Limitations

In the water departments of all cities, there is a need for maintenance operators to know something about electricity. Duties could range from repairing a tail light on a trailer or vehicle to repairing complex pump controls and motors. *VERY FEW MAINTENANCE OPERATORS DO THE ACTUAL ELECTRICAL REPAIRS OR TROUBLESHOOTING BECAUSE THIS IS A HIGHLY SPECIALIZED FIELD AND UNQUALIFIED PEOPLE CAN SERIOUSLY INJURE THEMSELVES AND DAMAGE COSTLY EQUIPMENT.* For these reasons, you must be familiar with electricity, *KNOW THE HAZARDS*, and *RECOGNIZE YOUR OWN LIMITATIONS* when you must work with electrical equipment.

Most municipalities employ electricians or contract with a commercial electrical company that they call when major problems occur. However, the maintenance operator should be able to *EXPLAIN HOW THE EQUIPMENT IS SUPPOSED TO WORK AND WHAT IT IS DOING OR IS NOT DOING WHEN IT FAILS.* After studying this section, you should be able to tell an electrician what appears to be the problem with electrical panels, controls, circuits and equipment.

The need for safety should be apparent. If proper safe procedures are not followed in operating and maintaining the various electrical equipment used in water treatment facilities, accidents can happen that cause injuries, permanent disability, or loss of life. Some of the serious accidents that have happened and could have been avoided occurred when machinery was not shut off, locked out, and tagged properly (Figure 18.2) Possible accidents include:

1. Maintenance operator could be cleaning pump and have it start, thus losing an arm, hand, or finger,
2. Electrical motors or controls not properly grounded could lead to possible severe shock, paralysis, or death, and
3. Improper circuits such as a wrong connection, safety devices jumped, wrong fuses, or improper wiring can cause fires or injuries due to incorrect operation of machinery

Another consideration for having a basic working knowledge of electricity is to prevent financial losses resulting from motors burning out and from damage to equipment, machinery and control circuits. Additional costs result when damages have to be repaired, including payments for outside labor

WARNING

DO NOT TOUCH EQUIPMENT IN ELECTRICAL PANELS, CONTROLS, CIRCUITS, WIRING OR EQUIPMENT UNLESS YOU ARE QUALIFIED AND AUTHORIZED. BY THE TIME YOU FIND OUT WHAT YOU DON'T KNOW ABOUT ELECTRICITY, YOU COULD FIND YOURSELF TOO DEAD TO USE THE KNOWLEDGE.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 323

18.10A Why must unqualified or inexperienced people be extremely careful when attempting to troubleshoot or repair electrical equipment?

18.10B What could happen when machinery is not shut off, locked out, and tagged properly?

18.11 Electrical Fundamentals

18.110 Introduction

This section contains a basic introduction to electrical terms and information plus directions on how to troubleshoot problems with electrical equipment.

Most electrical equipment used in water treatment plants is labeled with name plate information indicating the proper voltage and allowable current in amps.

18.111 Volts

Voltage (E) is also known as Electromotive Force (E.M.F.), and is the electrical pressure available to cause a flow of

DANGER

MAN WORKING ON LINE

DO NOT CLOSE THIS SWITCH WHILE THIS TAG IS DISPLAYED

SIGNATURE

This is the ONLY person authorized to remove this tag

Note: Tag also should include: TIME OFF ______________
DATE ________________

Fig. 18.2 Typical warning tag
(Source Industrial Indemnity/Industrial Underwriters/Insurance Cos)

current (amperage) when an electrical circuit is closed.[1] This pressure can be compared with the pressure or force that causes water to flow in a pipe Some pressure in a water pipe is required to make the water move The same is true of electricity. A force is necessary to push electricity or electric current through a wire This force is called voltage. There are two types of current Direct Current (D C) and Alternating Current (A.C.).

18.112 Direct Current (D.C.)

Direct Current (D.C) flows in one direction only and is essentially free from pulsation. Direct current is seldom used in water treatment plants except in electronic equipment, some control components of pump drives and stand-by lighting Direct current is used exclusively in automotive equipment, certain types of welding equipment, and a variety of portable equipment. Direct current is found in various voltages such as 6 volts, 12 volts, 24 volts, 48 volts, and 110 volts All batteries are direct current. D.C. voltage can be measured by holding the positive and negative leads of a D C voltmeter on the corresponding terminals of the D.C. device such as a battery. Direct current usually is not found in higher voltages (over 24 volts) around plants except in motor-generator sets. Care must be taken when installing battery cables and wiring that Positive (+) and Negative (−) poles are connected properly to wires marked (+) and (−). If not properly connected, you could get an arc of electricity across the unit that could cause an explosion

18.113 Alternating Current (A.C.)

An alternating current circuit is one in which the voltage and current periodically change direction and *AMPLITUDE*.[2] In other words, the current goes from zero to maximum strength, back to zero and to the same strength in the opposite direction. Most A.C. circuits have a frequency of 60 *CYCLES*[3] per second. "Hertz" is the term we use to describe the frequency of cycles completed per second so our A.C. voltage would be 60 Hertz (Hz).

Alternating current is classified as:

a. Single phase,

b. Two phase. and

c Three phase, or polyphase.

The most common of these are single phase and three phase. The various voltages you probably will find on your job are 110 volts, 120 volts, 208 volts, 220 volts, 240 volts, 277 volts, 440 volts, 480 volts, 2400 volts and 4160 volts.

Single-phase power is found in lighting systems, small pump motors, various portable tools and throughout our homes This power is usually 120 volts and sometimes 240 volts Single phase means that only one phase of power is supplied to the main electrical panel at 240 volts and has three wires or leads. Two of these leads have 120 volts each, the other lead is neutral and usually is coded white. The neutral lead is grounded. Many appliances and power tools have an extra ground (commonly a green wire) on the case for additional protection.

Three-phase power is generally used with motors and transformers found in water treatment plants, and usually is 208, 220, 240 volts, or 440, 460, 480 and 550 volts. Higher voltages are used in some pump stations. Three phase is used when higher power requirements or larger motors are used because efficiency is usually higher and motors require less maintenance. Generally speaking, all motors above two horsepower are three phase unless there is a problem with the power company getting three phase to the installations. Three-phase power usually is brought in to the point of use with three leads. There is power on all three leads and the fuse switches will generally appear as shown in Figure 18.3.

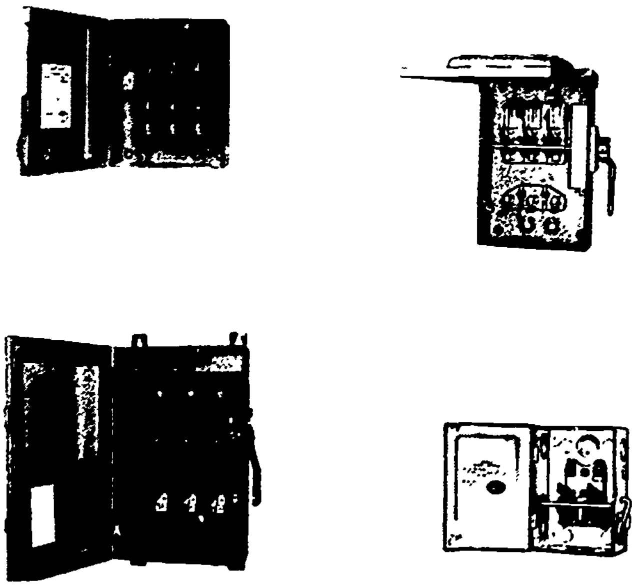


Fig. 18.3 Fuse switches

(Courtesy of Consolidated Electrical Distributors, Inc)

When making voltage measurements on three-phase power circuits, take three readings: (1) between lead 1 and lead 2, (2) between 1 and 3, and (3) between 2 and 3. The imbalance between readings should not exceed five percent of the average of the three readings and the average should not be below the nominal voltage (208, 220, 240, 460) nor should it exceed the nominal voltage by more than five percent. Voltages that do not meet these limits will place undue stress on electrical equipment, especially motors.

---

[1] *Electricians often talk about closing an electrical circuit. This means they are closing a switch that actually connects circuits together so electricity can flow through the circuit. Closing an electrical circuit is like opening a valve on a water pipe.*

[2] *Amplitude The maximum strength of an alternating current during its cycle, as distinguished from the mean or effective strength.*

[3] *Cycle. A complete alternation of voltage and/or current in an alternating current (A.C.) circuit.*

When there is power in three leads and a fourth lead is brought in, it is a neutral lead. Incoming power goes through a meter and then some type of disconnecting switch. This switch could be a fuse switch or a circuit breaker. The purpose of the disconnect switch is to open whenever a short or fault occurs and thus protect both the electrical circuits and electrical equipment.

Circuit breakers (Figure 18.4) are used to protect electrical circuits from overloads. Most circuit breakers are metal conductors that de-energize the main circuit when excess current passes through a metal strip causing it to overheat and open the main circuit.

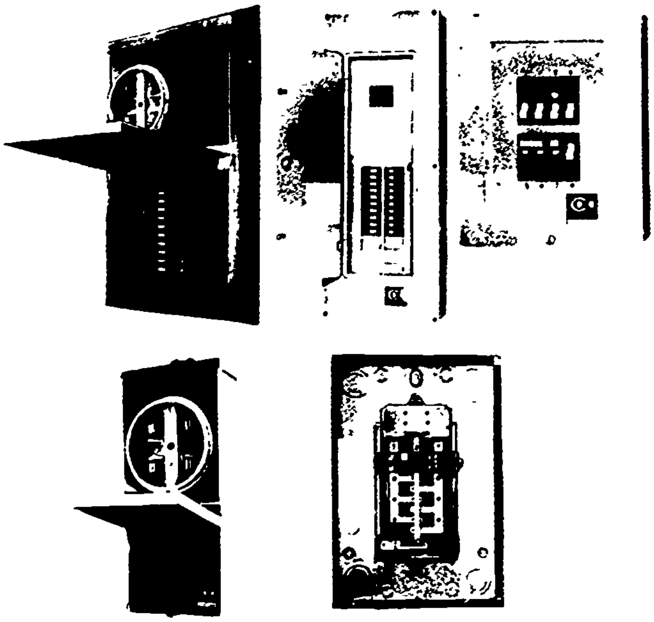


Fig. 18.4 Circuit breakers
(Courtesy of Consolidated Electrical Distributors Inc.)

Two-phase systems will not be discussed because they are seldom found in water treatment facilities.

18.114 Amps

An Ampere (I) is the practical unit of electric current. This is the current produced by a pressure of one volt in a circuit having a resistance of one ohm. Amperage is the measurement of current or electron flow and is an indication of work being done or "how hard the electricity is working."

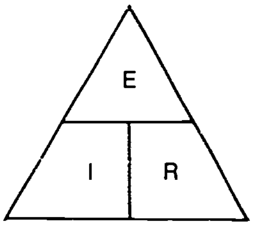
In order to understand amperage, one more term must be explained. The *OHM* is the practical unit of electrical resistance (R). "Ohm's Law" states that in a given electrical circuit the amount of current (I) in amperes is equal to the pressure in volts (E) divided by the resistance (R) in ohms. The following three formulas are given to provide you with an indication of the relationships among current, resistance and EMF (electromotive force).

$$\text{Current, amps} = \frac{\text{EMF, Volts}}{\text{Resistance, ohms}} \qquad \left(I = \frac{E}{R}\right)$$

$$\text{EMF, Volts} = (\text{Current, amps})(\text{Resistance, ohms}) \qquad (E = IR)$$

$$\text{Resistance, ohms} = \frac{\text{EMF, Volts}}{\text{Current, amps}} \qquad \left(R = \frac{E}{I}\right)$$

These equations are used by electrical engineers for calculating circuit characteristics. If you memorize the following relationship, you can always figure out the correct formula.



To use the above triangle you cover up the term you don't know or are trying to find out with your finger. The relationship between the other two known terms will indicate how to calculate the unknown. For example, if you are trying to calculate the current, cover up I. The two knowns (E and R) are shown in the triangle as E/R. Therefore, I = E/R. The same procedure can be used to find E when I and R are known or to find R when E and I are known.

18.115 Watts

Watts (W) and kilowatts (kW) are the units of measurement of the rate at which power is being used or generated. In D.C. circuits, watts (W) equal the voltage (E) multiplied by the current (I).

$$\text{Power, watts} = (\text{Current, amps})(\text{Electromotive Force, volts})$$

$$\text{or P, watts} = (\text{I, amps})(\text{E, volts})$$

In A.C. polyphase circuits the formula becomes more complicated because of the inclusion of two additional factors. First, there is the square root of 3, for three-phase circuits which is equal to 1.73. Secondly, there is the power factor which is the ratio of the true or actual power passing through an electrical circuit to the product of the voltage times the amperage in the circuit. For standard three-phase induction motors the power factor will be somewhere near 0.9. The formula for power input to a three-phase motor is:

$$\text{Power, kilowatts} = \frac{(\text{E volts})(\text{I, amps})(\text{Power Factor})(1.73)}{1000\ \text{watts/kilowatt}}$$

Since 0.746 kilowatts equal 1.0 horsepower, then the power output of a motor is

$$\text{Power Output horsepower} = \frac{(\text{Power Input, kilowatts})(\text{Efficiency, \%})}{(0.746\ \text{kilowatts/horsepower})(100\%)}$$

18.116 Power Requirements

Power requirements (Pr) are expressed in kilowatt hours 500 watts for two hours or one watt for 1000 hours equals one kilowatt hour The power company charges so many cents per kilowatt hour.

Power req., kW-hr = (Power, kilowatts) (Time, hours)

Pr, kW-hr = (P, kW) (T, hr)

18.117 Conductors and Insulators

A material, like copper, which permits the flow of electrical current is called a conductor. Material which will not permit the flow of electricity, like rubber, is called an insulator. Such material when wrapped or cast around a wire is called insulation. Insulation is commonly used to prevent the loss of electrical flow by two conductors coming into contact with each other.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 323.

18.11A What are two types of current?

18.11B Amperage is a measurement of what?

18.11C How can you determine the proper voltage and allowable current in amps for a piece of equipment?

18.12 Tools, Meters and Testers

WARNING

NEVER ENTER AN ELECTRICAL PANEL OR ATTEMPT TO TROUBLESHOOT OR REPAIR ANY PIECE OF ELECTRICAL EQUIPMENT OR ANY ELECTRICAL CIRCUIT UNLESS YOU ARE QUALIFIED AND AUTHORIZED.

18.120 Voltage Testing

In order to maintain, repair, and troubleshoot electrical equipment and circuits, the proper tools are required. You will need a *VOLTAGE TESTER* to check for voltage. There are several types on the market and all of them work. They are designed to be used on energized circuits and care must be exercised when testing. By holding one lead on ground and the other on a power lead, you can determine if the circuit is energized.

Be sure the voltage tester that you are using has sufficient range to measure the voltage you would expect to find. In other words do not use a tester with a limit of 600 volts on a circuit that normally is energized at 2300 volts. With the voltage tester you can tell if the current is A.C. or D.C. and the intensity or voltage which will probably be one of the following: 120, 207, 230, 460, 2400, or 4160.

Do not work on any electrical circuits unless you are qualified and authorized. Use a voltage tester and other circuit testers to determine if a circuit is energized, or if all voltage is off. This should be done after the main switch is turned off to make sure it is safe to work inside the electrical panel. Always be aware of the possibility that even if the disconnect to the unit you are working on is off, the control circuit may still be energized if the circuit originates at a different distribution panel. Also a capacitor in the unit may have sufficient energy stored to cause considerable harm to an operator, such as a power factor correction capacitor on a motor. Test for voltage both before and during the time the switch is pulled off to have a double check. This procedure ensures that the voltage tester is working and that you have good continuity to your tester. Use circuit testers to measure voltage or current characteristics to a given piece of equipment and to make sure that you have or do not have a "live" circuit.

Besides using the voltage tester for checking power, it can be used to test for open circuits, blown fuses, single phasing of motors, grounds, and many other uses. Some examples are illustrated in the following paragraphs.

In the circuit shown below (Figure 18.5), test for power by holding one lead of the tester on point "A," and the other at point "B." If no power is indicated, the switch is open or faulty. Sketch shows switch in "open" position.

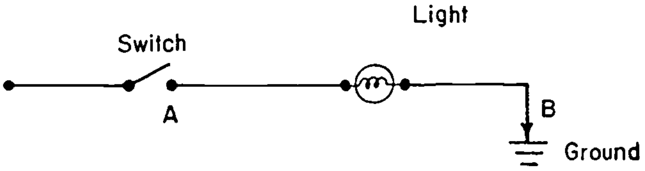


Fig. 18.5 Single-phase circuit (switch in open position)

To test for power at Point "A" and Point "B" in Figure 18.6, open the switch as shown. Using a volt meter or voltage tester, connect a lead on Line 1 and a lead on Line 2, at points A and B, between the fuses and the load. Bring the voltage tester and leads out of the panel and close the panel door as far as possible without cutting or damaging the meter leads. Some switches cannot be closed if the panel door is open. The panel door is closed when testing because hot copper sparks could seriously injure you when the circuit is energized and the voltage is high. Close the switch.

1. Voltage tester should register at 220 volts. If there is no reading at points "A" and "B," the fuse or fuses could be blown.
2. Move voltage tester to L1 and L2. If there is still no reading on the voltage tester, check for an open switch in another location, or call the power company to find out if power is out.

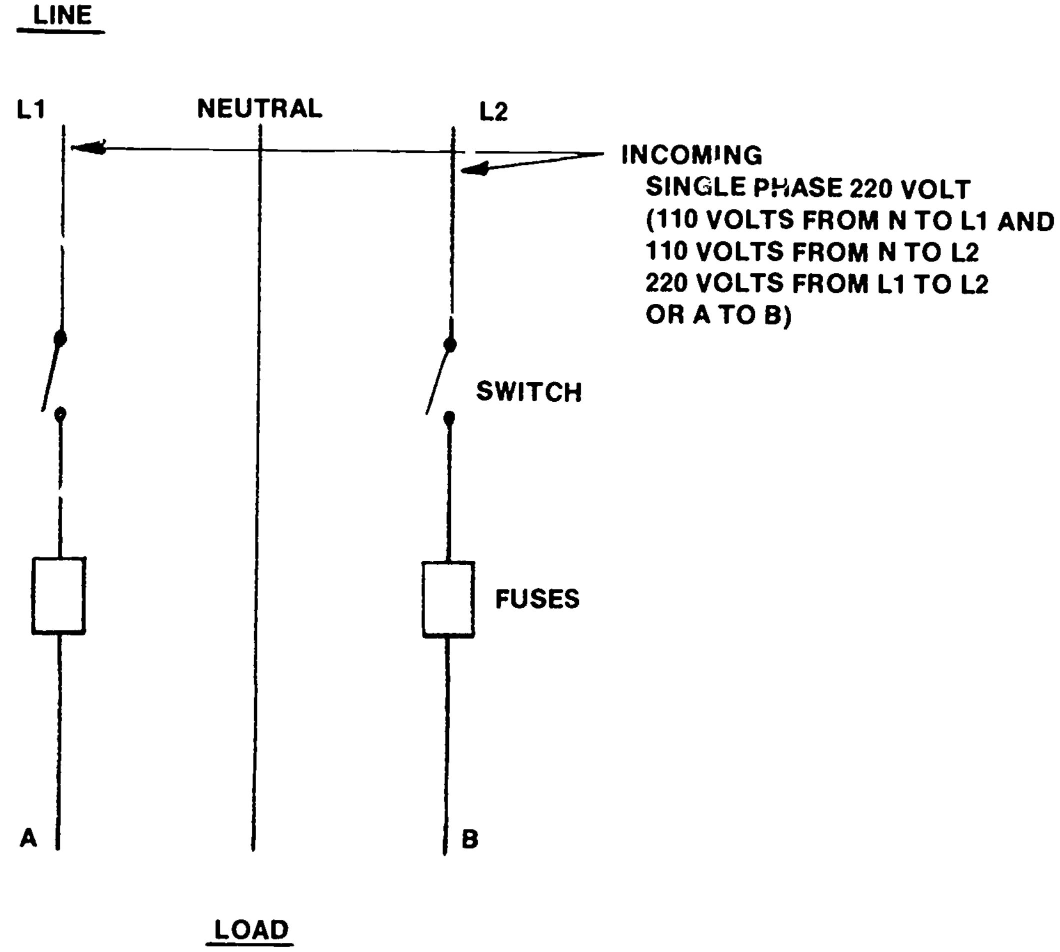


Fig. 18.6 Single-phase, three lead circuit

3. If a 220 volt reading is registered at L1 and L2, move the test leads to point "A," and the "neutral" lead If a reading of 110 volts is observed, the fuse on line "A" is okay. If there isn't a voltage reading, the fuse on line "A" could be "blown." Move the lead from line "A" to line "B." Observe the reading. If 110 volt power is not observed, the fuse on line "B" could be "blown." Another possibility to consider is that the neutral line could be broken. Under these conditions, if there is voltage on line "A" and the fuse on line "B" is blown, voltage may appear on line "B."

WARNING

TURN OFF POWER AND BE SURE THAT THERE IS NO VOLTAGE IN EITHER POWER LINE BEFORE CHANGING FUSES. Use a *FUSE PULLER*. Test circuit again in the same manner to make sure fuses or circuit breakers are okay. 220 volts power or voltage should be present between points "A" and "B." If fuse or circuit breaker trips again, shut off and determine the source of the problem.

Referring to Figure 18.7, test for voltage in three-phase circuits as follows — with the switch closed and the load disconnected, check for voltage (probably either 220 or 440) between points A3-B3, A3-C3, and between B3-C3. A zero voltage reading on any or all of the three tests indicates a problem ahead of this location that could be at another switch or a power company problem. Assuming normal readings were found at A3, B3, and C3, repeat the three readings at points A2, B2, and C2 with the switch closed. Any zero voltage readings are an indication of a defective

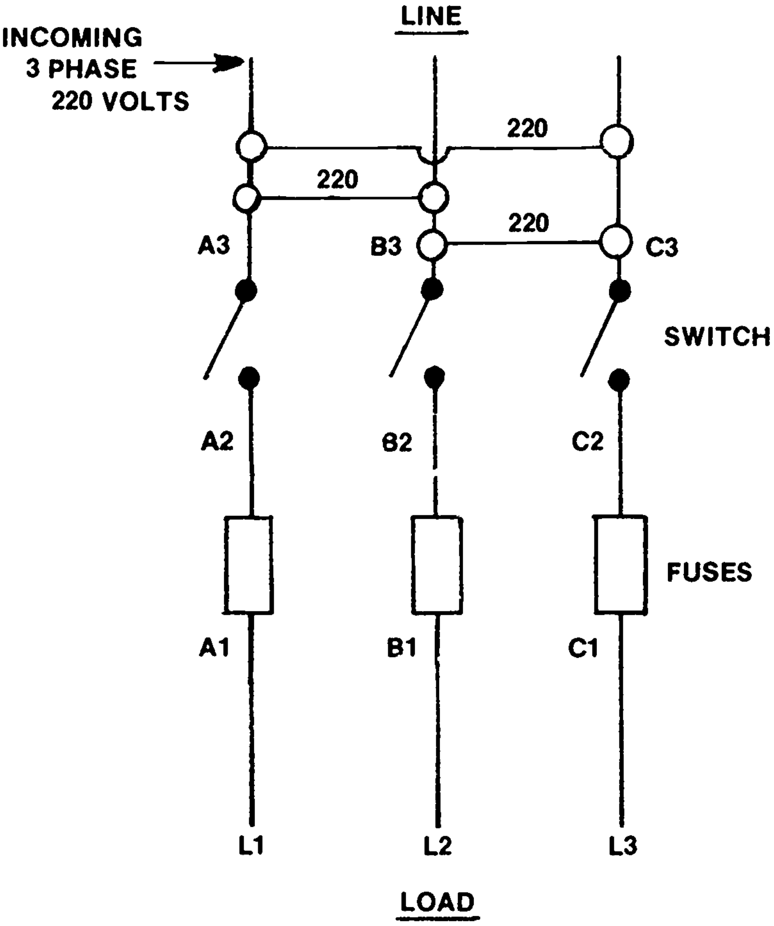


Fig. 18.7 Three-phase circuit, 220 volts

switch. Assuming normal readings were found at A2, B2, and C2, repeat the three readings at points A1, B1, and C1 with the switch closed. If any two voltage readings are zero, one fuse is blown and it will be the one in the line that was common to the two zero readings. If all three voltage readings are zero, either two or three fuses are blown. To determine which fuses are blown, refer to Table 18.1. Note that a zero voltage reading indicates a blown fuse.

TABLE 18.1 LOCATING A BLOWN FUSE

Blown Fuse In Line	Use Either Test
L1	A1-B2 or A1-C2
L2	B1-A2 or B1-C2
L3	C1-A2 or C1-B2

Another way of checking the fuses with the load connected on this three-phase circuit would be to take your voltage tester and place one lead on the bottom and one lead on the top of each fuse. You should NOT get a voltage reading on the voltmeter. This is because electricity takes the path of least resistance. If you get a reading across any of the fuses (top to bottom), that fuse is bad.

ALWAYS MAKE SURE THAT WHEN YOU USE A VOLTMETER IT IS SET FOR THE PROPER VOLTAGE. IF VOLTAGE IS UNKNOWN AND THE METER HAS DIFFERENT SCALES THAT ARE MANUALLY SET, ALWAYS START WITH THE HIGHEST VOLTAGE RANGE AND WORK DOWN. Otherwise the voltmeter could be damaged. Look at the equipment instruction manual or name plate for the expected voltage. Actual voltage should not be much higher than given unless someone goofed when the equipment was wired and inspected.

18.121 Ammeter

Another meter used in electrical maintenance and testing is the *AMMETER*. The ammeter records the current or "amps" flowing in the circuit. There are several types of ammeters, but only two will be discussed in this section. The ammeter generally used for testing is called a "clamp on" type. The term "clamp on" means that it can be clamped around a wire supplying a motor, and no direct electrical connection need be made. Each "leg" or lead on a three-phase motor must be individually checked.

The first step should be to read the motor name plate data and find what the amperage reading should be for the particular motor or device you are testing. After you have this information, set the ammeter to the proper scale. Set it on a higher scale than necessary if the expected reading is close to the top of the meter scale. Place the clamp around one lead at a time. Record each reading and compare with the name plate rating. If the readings are not similar to the name plate rating, find the cause, such as low voltage, bad bearings, poor connections or excessive load. If the ammeter readings are higher than expected, the high current could produce overheating and damage the equipment. Try to find the problem and correct it.

Current imbalance is undesirable because it causes uneven heating in a motor that can shorten the life expectancy of the insulation. However, a small amount of current imbalance is to be expected in the leads to a three-phase motor. This imbalance can be caused by either peculiarities in the motor or by a power company imbalance. To isolate the cause, make the following test. Note that this test should be done by a qualified electrician. Refer to Figure 18.8.

If the current on Lines L1, L2, and L3 are about the same both before and after the wiring change, this is an indication that the imbalance is being caused by the power company and they should be asked to make adjustments to correct the condition. However, if the current reading followed the motor terminal (T) numbers rather than the power line (L) numbers, the problem is within the motor and there isn't much that can be done except contact the motor manufacturer for a possible exchange.

When using a clamp on ammeter, be sure to set the meter on a high enough range or scale for the starting current if you are testing during startup. Starting currents range from 500 to 700 percent higher than running currents and using

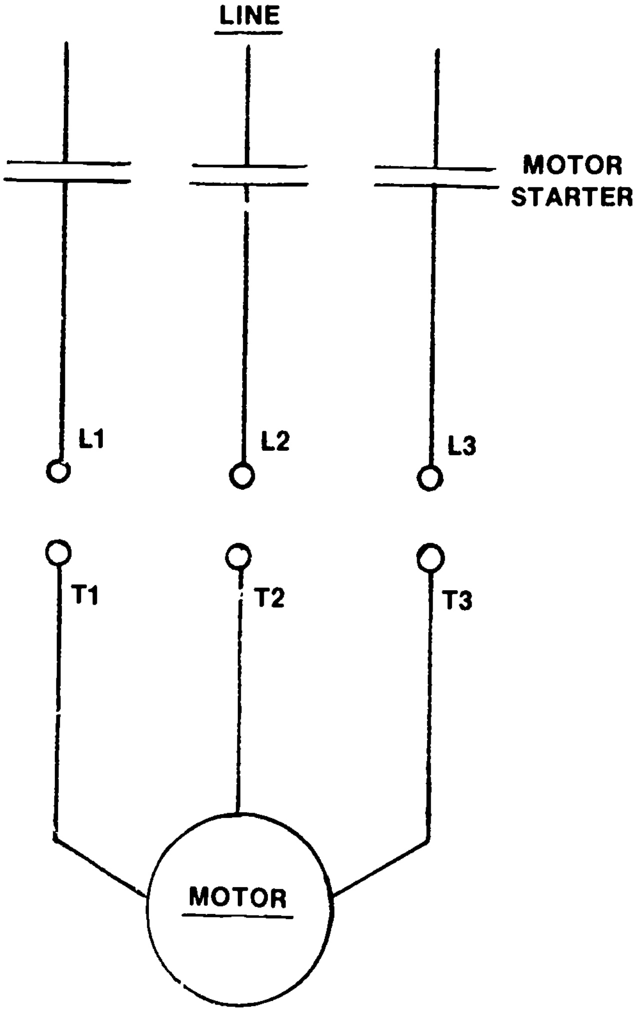


Fig. 18.8 Determination of current imbalance

1. With the motor wired to its starter, L1 to T1, L2 to T2 and L3 to T3, measure and record the amperage on L1, L2 and L3.
2. De-energize the circuit and reconnect the motor as follows: L1-T3, L2-T1, L3-T2. This wiring change will not change the direction of the rotation of the motor.
3. Start up the motor and again measure and record the amperage on L1, L2, L3.

too low a range can ruin an expensive and delicate instrument Newer clamp on ammeters automatically adjust to the proper range and can measure both starting or peak current and normal running current.

Another type of ammeter is one that is connected in line with the power lead or leads Generally they are not portable and are usually installed in a panel or piece of equipment They require physical connections to put them in series with the motor or apparatus being tested Current transformers (CT) are commonly used with this type of ammeter so that the meter does not have to conduct the full motor current These ammeters are usually more accurate than the clamp on type and are used in motor control centers and pump panels

18.122 Megger

A MEGGER is a device used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring.

WARNING

USE A MEGGER ONLY ON DE-ENERGIZED CIRCUITS OR MOTORS.

There are three general types of meggers crank operated, battery operated, and instrument There are two leads to connect One lead is clamped to a ground lead and the other to the lead you are testing The readings on the megger will range from "0" (ground) to Infinity (perfect), depending on the condition of your circuit.

The megger is usually connected to a motor terminal at the starter, and the other lead to the ground lead. Results of this test indicate if the insulation is deteriorating or cut

Insulation resistance of electrical equipment is affected by many variables such as the equipment design, the type of insulating material used, including binders and impregnating compounds, the thickness of the insulation and its area, cleanliness (or uncleanliness), moisture, and temperature For insulation resistance measurements to be conclusive in analyzing the condition of equipment being tested, these variables must be taken into consideration.

Such factors as the design of the equipment, the kind of insulating material used, and its thickness and area cease to be variables after the equipment has been put into service, and minimum insulation resistance values can be established within reasonable tolerances. The variables that must be considered after the equipment has been put into service, and at the time that the insulation resistance measurements are being made, are uncleanliness, moisture, temperature, and damage such as fractures

The most important requirements in the reliable operation of electrical equipment are cleanliness and the elimination of moisture penetration into the insulation. This is merely good housekeeping but it is essential in the maintenance of all types of electrical equipment. The very fact that insulation resistance is affected by moisture and dirt, with due allowances for temperature, makes the "megger" insulation test the valuable tool which it is in electrical maintenance. The test is an indication of cleanliness and good housekeeping as well as a detector of deterioration and impending trouble

Several criteria for "minimum values" of insulation resistance have been developed. These values should be provided by the equipment manufacturer and should serve as a guide for equipment in service. However, periodic tests on equipment in service will usually reveal readings considerably higher than the suggested minimum safe values Records of periodic tests must be kept, because persistent downward trends in insulation resistance usually give fair warning of impending trouble, even though the actual values may be *HIGHER* than the suggested minimum safe values.

Also, allowances must be made for equipment in service showing periodic test values *LOWER* than the suggested minimum safe values, so long as the values remain stable or consistent In such cases, after due consideration has been given to temperature and humidity conditions at the time of the test, there may be no need for concern. *THIS CONDITION MAY BE CAUSED BY UNIFORMLY DISTRIBUTED LEAKAGES OF A HARMLESS NATURE, AND MAY NOT BE THE RESULT OF A DANGEROUS LOCALIZED WEAKNESS* Here again, records of insulation resistance tests over a period of time reveal changes which may justify investigation. The "trend of the curve" may be more significant than the numerical values themselves

For many years ONE *MEGOHM*[4] has been widely used as a fair allowable lower limit for insulation resistance of ordinary industrial electrical equipment rated up to 1000 volts. This value is still recommended for those who may not be too familiar with insulation resistance testing practices, or who may not wish to approach the problem from a more technical point of view

For equipment rated above 1000 volts, the "one megohm" rule is usually stated. "A minimum of one megohm per thousand volts" Although this rule is somewhat arbitrary, and may be criticized as lacking an engineering foundation, it has stood the test of a good many years of practical experience. This rule gives some assurance that equipment is not too wet or not too dry and has saved many an unnecessary breakdown.

More recent studies of the problem, however, have resulted in formulas for minimum values of insulation resistance that are based on the kind of insulating material used and the electrical and physical dimensions of the types of equipment under consideration[5]

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[4] *Megohm Meg means one million, so 5 megohms means 5 million ohms A megger reads in millions of ohms*

[5] *Portions of the preceding paragraphs were taken from INSTRUCTION MANUAL FOR MEGGER INSULATION TESTERS, No 21-J, pages 42 and 43, published by Biddle Instruments, c/o Advertising Department, 510 Township Line Road, Blue Bell, Pennsylvania 19422. For additional information see Biddle's publication, A STITCH IN TIME, price $2.00*

Motors and wirings should be megged at least once a year, and twice a year if possible. The readings taken should be recorded and plotted in some manner so that you can determine when insulation is breaking down. Meg motors and wirings after a pump station has been flooded. If insulation is wet, excessive current could be drawn and cause pump motors to "kick out"

18.123 Ohm Meters

OHM METERS, sometimes called circuit testers, are valuable tools used for checking electrical circuits. An ohm meter is used only when the electrical circuit is *OFF*, or de-energized The ohm meter supplies its own power by using batteries An ohm meter is used to measure the resistance (ohms) in a circuit These are most often used in testing the control circuit components such as coils, fuses, relays, resistors, and switches. They are used also to check for continuity An ohm meter has several scales which can be used Typical scales are: R × 1, R × 10, R × 1,000, and R × 10,000. Each scale has a level of sensitivity for measuring different resistances. To use an ohm meter, set the scale, start at the low point (R × 1), and put the two leads across the part of the circuit to be tested such as a coil or resistor and read the resistance in ohms. A reading of infinity would indicate an open circuit, and a "0" would read no resistance. These usually would be used only by skilled technicians because they are very delicate instruments.

All meters should be kept in good working order and calibrated periodically They are very delicate, susceptible to damage, and should be well protected during transportation. When readings are taken, they should always be recorded on a machinery history card for future reference. Meters are a good way to determine pump and equipment performance. *NEVER USE A METER UNLESS QUALIFIED AND AUTHORIZED.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 323.

18.12A How can you determine if there is voltage in a circuit?

18.12B What are some of the uses of a voltage tester?

18.12C What precautions should be taken before attempting to change fuses?

18.12D How do you test for voltage with a voltmeter when the voltage is unknown?

18.12E What could be the cause of amp readings different from the name plate rating?

18.12F How often should motors and wirings be megged?

18.12G An ohm meter is used to check the ohms of resistance in what control circuit components?

18.13 Switch Gear

18.130 Equipment Protective Devices

Electricity needs safety devices to protect operators and equipment Water systems have pressure valves, pop offs and different safety equipment to protect the pipes and equipment. So must electricity have safety devices to contain the voltage and amperage that comes in contact with the wiring and equipment. The first piece of equipment which must be protected is the main electrical panel or control unit where the power enters. This protection is provided by either fuses or a circuit breaker

18.131 Fuses

Let's start with fuses The power company has installed fuses on their power poles to protect their equipment from damage We also must install something to protect the main control panel and wiring from damage due to excessive voltage or amperage

A *FUSE* is a protective device having a strip or wire of fusible metal which, when placed in a circuit, will melt and break the electrical circuit when subjected to an excessive temperature This temperature will develop in the fuse when a current flows through the fuse in excess of what the circuit will carry safely This means that the fuse must be capable of de-energizing the circuit before any damage is done to the wiring it is safely protecting. Fuses are used to protect operators, main circuits, branch circuits, heaters, motors, and various other electrical equipment.

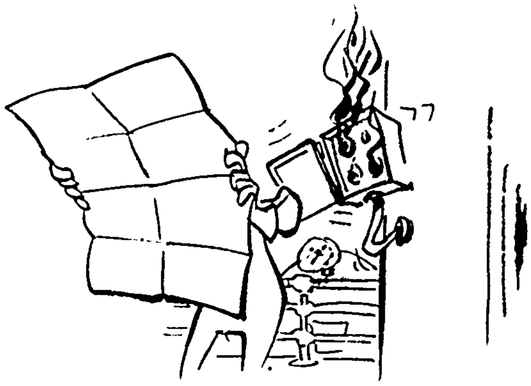
There are several types of fuses, each being used for a certain type of protection. Some of these are:

1 CURRENT-LIMITING FUSES. These fuses open so quickly while clearing a short-circuit current that the potential fault current is not allowed to reach its peak. They are used to protect power distribution circuits.

2 DUAL-ELEMENT FUSES: These fuses provide a time delay in the low overload range and a fast acting element for short-circuit protection. These fuses are used for motor protection circuits.

There are many other types of fuses used for special application, but the above are the most common.

A fuse must NEVER be by-passed or jumped. This is the only protection the circuit has; without it, serious damage to equipment and possible injury to operators can occur. Make sure that all fuses are replaced with the proper size and type indicated for that circuit. If you have any doubt, check the electrical prints or contact your electrical engineer.



18.132 Circuit Breakers

The CIRCUIT BREAKER (Figure 18.4) is another safety device and is used in the same place as a fuse. Most circuit breakers consist of a switch that opens automatically when the current or the voltage exceeds or falls below a certain limit. Unlike a fuse that has to be replaced each time it "blows," a circuit breaker can be reset after a short delay to allow time for cooling. This is done by moving the handle to the "off" position or slightly past, and then moving it back to the "on" position. Also, unlike a fuse, a circuit breaker can be visually inspected to find out if it has been tripped. The handle will be at the mid position between "on" and "off." Several different types of circuit breakers are being used today and each one is selected for a special protective purpose.

18.133 Overload Relays

Three-phase motors are usually protected by OVERLOAD relays. This is accomplished by having heater strips, bimetal, or solder pots which open on current rise (overheating), and open the control circuit. This in turn opens the power control circuit, which de-energizes the starter and stops power to the motor. Such relays are also known as heaters or thermal overloads. Sizing of these overloads is very critical and should coincide with the name plate rating on the motor. Sizing depends on the service factor of the electric motor. Usually they range from 100 to 110 percent of the motor name plate ratings and should never exceed 125 percent (usually 115 percent) of the motor rating. For example, if the motor is rated for 10 amps, the overloads should be sized from 10 to 11 amps.

Again, *NEVER INCREASE THE RATING OF THE OVERLOAD HEATERS BECAUSE OF TRIPPING. YOU SHOULD FIND THE PROBLEM AND REPAIR IT.* There are many other protective devices for electricity such as motor winding thermostats, phase protectors, low voltage protectors, and ground fault protectors. Each has its own special applications and should never be tampered with or jammed.

GROUND is an expression representing an electrical connection to earth or a large conductor which is at the earth's potential or neutral voltage. Motor frames and all electrical tools and equipment enclosures should be connected to ground. This is generally referred to simply as grounding, or equipment ground.

The third prong on cords from electric hand tools is the equipment ground and must never be removed. When an adapter is used with a two-prong receptacle, the green wire on the adapter should be connected under the center screw on the receptacle cover plate. Many times equipment grounding, especially at home, is achieved by connecting onto a water pipe or drain rather than a rod driven into the ground. This practice generally is not recommended when plastic pipes and other non-conducting pipe materials are used unless it is known that the piping is all metal and not interrupted. Also corrosion can be accelerated pipes of different metals are used. A rod driven into dry ground isn't very effective as a ground.

18.134 Motor Starters

A motor starter is a device or group of devices which are used to connect the electrical power to a motor. These starters can be either manually or automatically controlled.

Manual and magnetic starters range in complexity from a single "on-off" switch, to a sophisticated automatic device using timers and coils. The simplest motor starter is used on single-phase motors where a circuit breaker is turned on and the motor starts. This type of starter also is used on three-phase motors of smaller horsepower. These are used on fan motors, machinery motors, and several others where it isn't necessary to have automatic control.

MAGNETIC STARTERS (Figures 18.9 and 18.10) are commonly used to start pumps, compressors, blowers, and anything where automatic or remote control is desired. They permit low power circuits to energize the starter of equipment at a remote location or to start larger starters (Figure 18.11). A magnetic starter is operated by electromagnetic action This starter has contractors and they operate by energizing a coil which closes the contact, thus starting the motor The circuit which energizes the starter is called the control circuit and it may operate on a lower voltage (115 volts) than the motor. Whenever a starter is used as a part of an integrated circuit (such as for flow, pressure or temperature control), a magnetic starter or controller is necessary.

Magnetic starters are sized for their voltage and horsepower ratings These are divided into classes The most common starter is Class "A." A Class "A" starter is an 'Alternating Current air-break and oil immersed manual, or magnetic controller for service on 600 volts or less. It is capable of interrupting operating overloads up to and including 10 times their normal motor rating, but not short circuits or faults beyond operating overloads."

Additional class information can be found in electrical catalogs, manuals and manufacturers' brochures.

There are a number of different types of three-phase magnetic motor starters available. The simplest and most common is the "across-the-line" full voltage starter. This starter consists of three contacts, a magnetic actuating device, and overload detection. This starter subjects the power system to the full surge current on startup and may cause the lights in the treatment plant to dim momentarily.

To reduce the in-rush current when starting polyphase motors, a number of other types of starters are available.

1. Auto-Transformer Type Reduced Voltage Starters. These begin the motor start sequence by applying a reduced voltage to the motor for a few seconds. The voltage is controlled by a time delay relay within the starter. The reduced voltage is obtained from transformers that are a part of the starter. These transformers are designed to operate for only a few seconds at a time and can easily be burned out if the motor is started too frequently.
2. Solid State Reduced Voltage Starters. These starters do the same job as the auto-transformer type reduced voltage starters but they do not need transformers because the voltage and current are electrically controlled.
3. Part Winding Starters. These starters are used with special motors that have two separate sets of windings on the same motor frame. By energizing the windings about one second apart, the in-rush current is limited to about half that of a normal motor with a full voltage starter.
4. Wye-Delta Starters. These starters are used with motors that have all leads brought out to the terminal box. The motor is first started with wye connected coils and switched over to a delta connection for running. The result is the same as if you used a reduced voltage starter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 323.

18 13A What are two types of safety devices found in main electrical panels or control units?

18.13B What are fuses used to protect?

18.13C Why must a fuse never be by-passed or jumped?

18.13D How does a circuit breaker work?

18.13E How are motor starters controlled?

18.13F When are magnetic starters used?

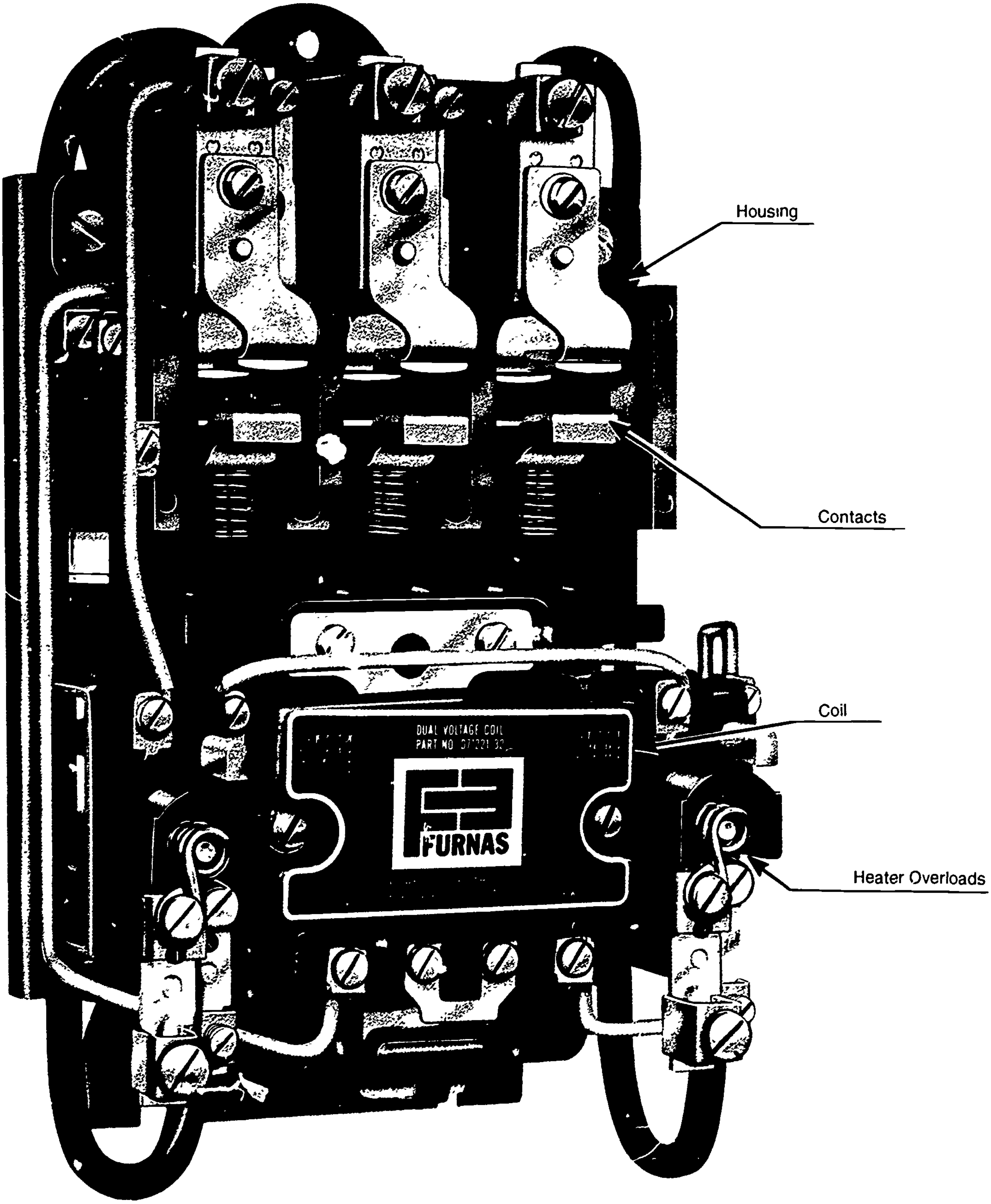


Fig. 18.9 Three-phase magnetic starter
(Courtesy of Furnas Electric Company)

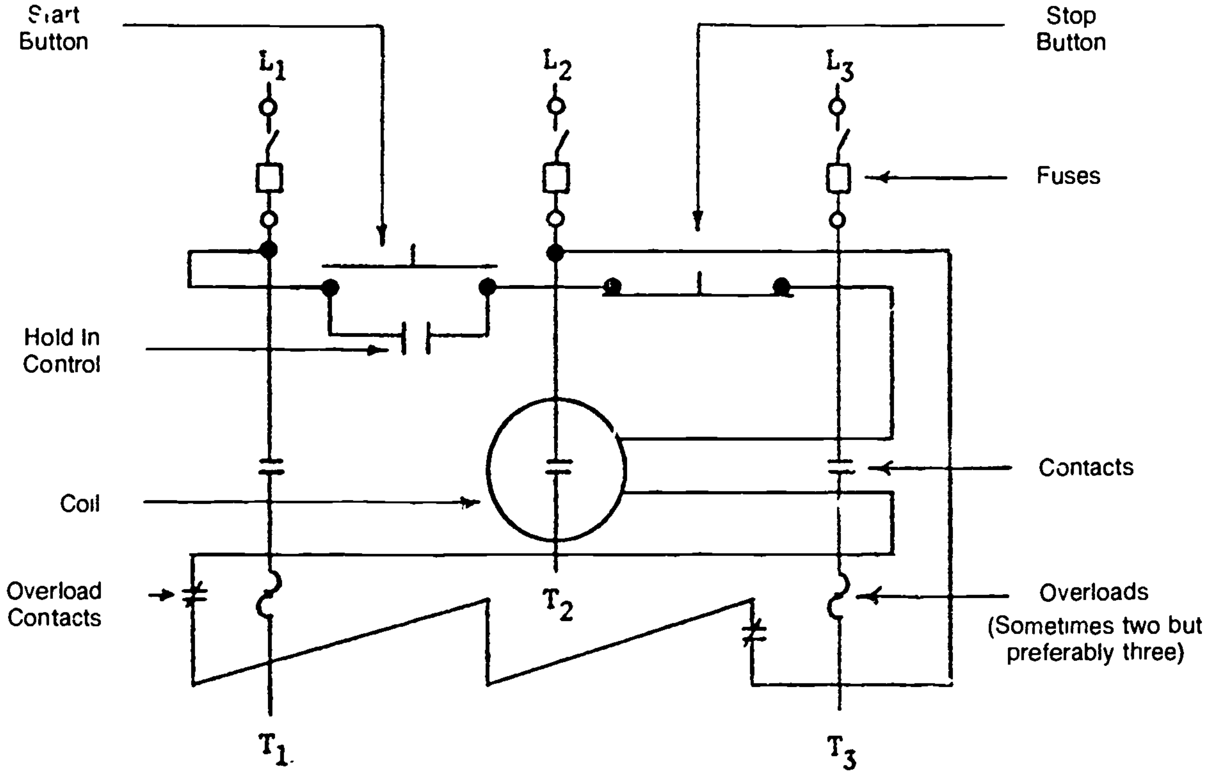


Fig. 18.10 Wiring diagram of three-phase magnetic starter

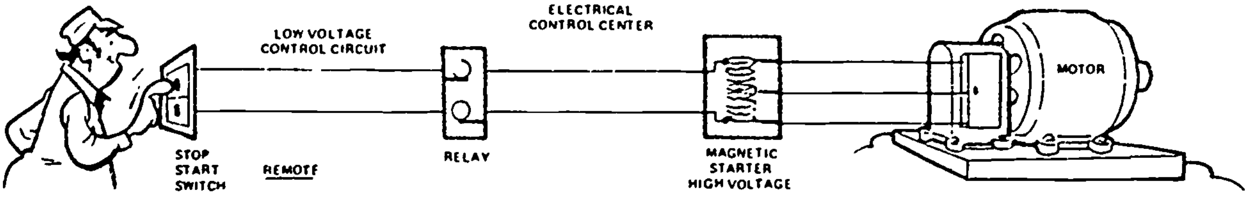


Fig. 18.11 Application of magnetic starter

18.14 Electric Motors

18.140 Classification

Electric motors are the machines most commonly used to convert electrical energy into mechanical energy. A motor usually consists of a *STATOR,*[6] *ROTOR,*[7] *END BELLS,*[8] and windings. The rotor has an extending shaft which allows a machine to be coupled to it.

Motors are of many different types (Figure 18.12), such as, squirrel cage induction motors, wound rotor motors, synchronous motors and many others. The most common of these is the squirrel cage induction motor. Some pumping stations use wound rotor induction motors when speed control is needed

Three-phase electric motors are used for operating pumps, compressors, fans and other machinery. Motors are generally trouble free and, when lubricated properly, cause very few problems The amperage and voltage readings on motors should be taken periodically to insure proper operation

Motors are classified by NEMA (National Electrical Manufacturers Association) with code letters from A through V with "A" having the lowest starting torque and in-rush current and "V" having the highest starting torque and in-rush current The most commonly available motors have code letters from "F" through "L" which have in-rush currents on start of from 500 to 1000 percent of full load.

Another important consideration in selecting a motor is the class of insulation. This determines how hot a motor may operate and is listed as degree rise on the motor nameplate (Figure 18.13).

Motor insulation classes are as follows:

Class	Temperaturing Rating
A	105°C (221°F)
B	130°C (266°F)
F	155°C (311°F)
H	180°C (356°F)

At present most motors are Class B insulated. Try to keep the actual operating temperature below the temperature rating or limit in order to prolong the life of the insulation.

All of this information can be found on the motor name plate and should be taken into consideration when evaluating a motor. Most of the trouble encountered with electrical motors results from bad bearings, shorted windings due to insulation breakdown or excessive moisture.

All of the information on the motor name plate (Figure 18.13) should be recorded and placed in a file for future reference. Many times the name plate is painted, corroded or missing from the unit when the information is needed to repair the motor or replace parts. Also record the date of installation and service startup. See Section 18.142, "Recordkeeping," for a typical data sheet for recording the essential information. This information also should be on the manufacturer's data sheet and in the instruction manual. Compare the information for consistency and file in an appropriate location. Be sure you have the correct serial and/or model numbers.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18 14A How is electrical energy converted into mechanical energy?

18.14B What are the important parts of an electric motor?

18 14C How can motors be kept trouble free?

18.14D What should be done with motor name plate data?

18.141 Troubleshooting

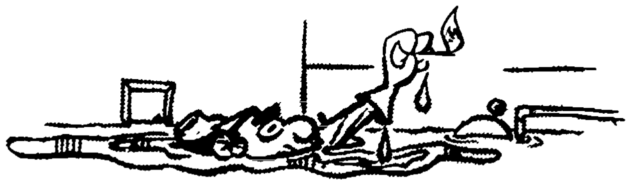
Practical step-by-step procedures combined with a common sense approach is the key to effective troubleshooting.

"NEVER TAKE ANYTHING FOR GRANTED"

A. Gather preliminary information. The first step in troubleshooting any motor control which has developed trouble is to understand the circuit operation and other related functions. In other words, what is supposed to happen, operate, and so forth when it's working right? Also, what is it doing now? The qualified maintenance operator should be able to do the following:

   1. *KNOW WHAT SHOULD HAPPEN WHEN A SWITCH IS PUSHED:* When switches are pushed or tripped, know what coils go in, contacts close, relays operate, and motors run.

   2. *EXAMINE ALL OTHER FACTORS:* What other unusual things are happening in the plant now that this circuit doesn't work properly? Lights dimmed, other pumps stopped, lights went out when it broke, everything was flooded, operators were hosing down area, and many other possible factors.



   3. *ANALYZE WHAT YOU KNOW:* What part of it is working correctly? Is switch arm tripped? Is it a mechanical failure or an electrical problem caused by a mechanical failure?

   4. *SELECT SIMPLE PROCEDURES:* To localize the problem, select logical ways that can be simply and quickly accomplished.

   5. *MAKE A VISUAL INSPECTION:* Look for burned wires, loose wires, area full of water, coil burned, contacts loose, or strange smells.

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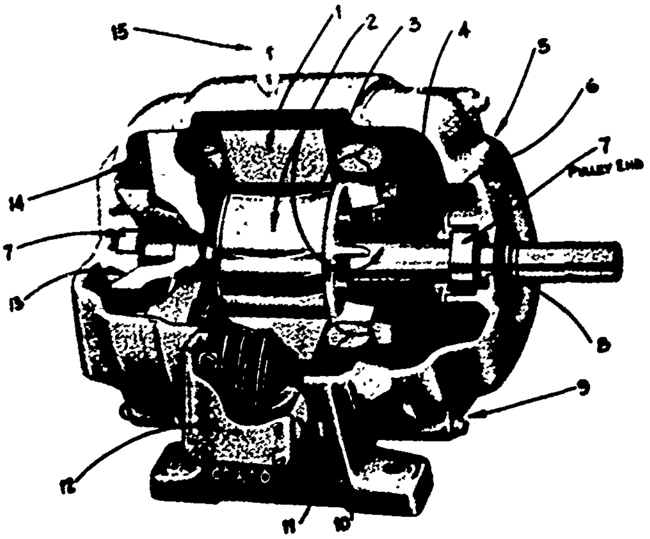
[6] *Stator That portion of a machine which contains the stationary (non-moving) parts that surround the moving parts (rotor).*

[7] *Rotor The rotating part of a machine. The rotor is surrounded by the stationary (non-moving) parts (stator) of the machine.*

[8] *End Bells. Devices used to hold the rotor and stator of a motor in position.*

DRIP PROOF

ITEM NO.	PART NAME
1	Wound Stator w/ Frame
2	Rotor Assembly
3	Rotor Core
4	Shaft
5	Bracket
6	Bearing Cap
7	Bearings
8	Seal, Labyrinth
9	Thru Bolts/Caps
10	Seal, Lead Wire
11	Terminal Box
12	Terminal Box Cover
13	Fan
14	Deflector
15	Lifting Lug



TOTALLY ENCLOSED FAN COOLED

ITEM NO.	PART NAME
1	Wound Stator w/ Frame
2	Rotor Assembly
3	Rotor Core
4	Shaft
5	Brackets
6	Bearings
7	Seal, Labyrinth
8	Thru Bolts/Caps
9	Seal, Lead Wire
10	Terminal Box
11	Terminal Box Cover
12	Fan, Inside
13	Fan, Outside
14	Fan Grill
15	Fan Cover
16	Fan Cover Bolts
17	Lifting Lug

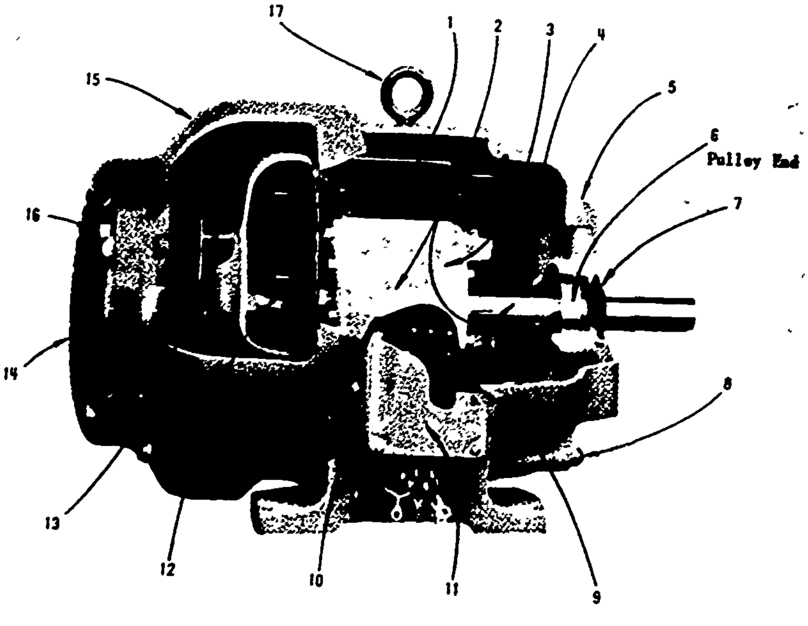
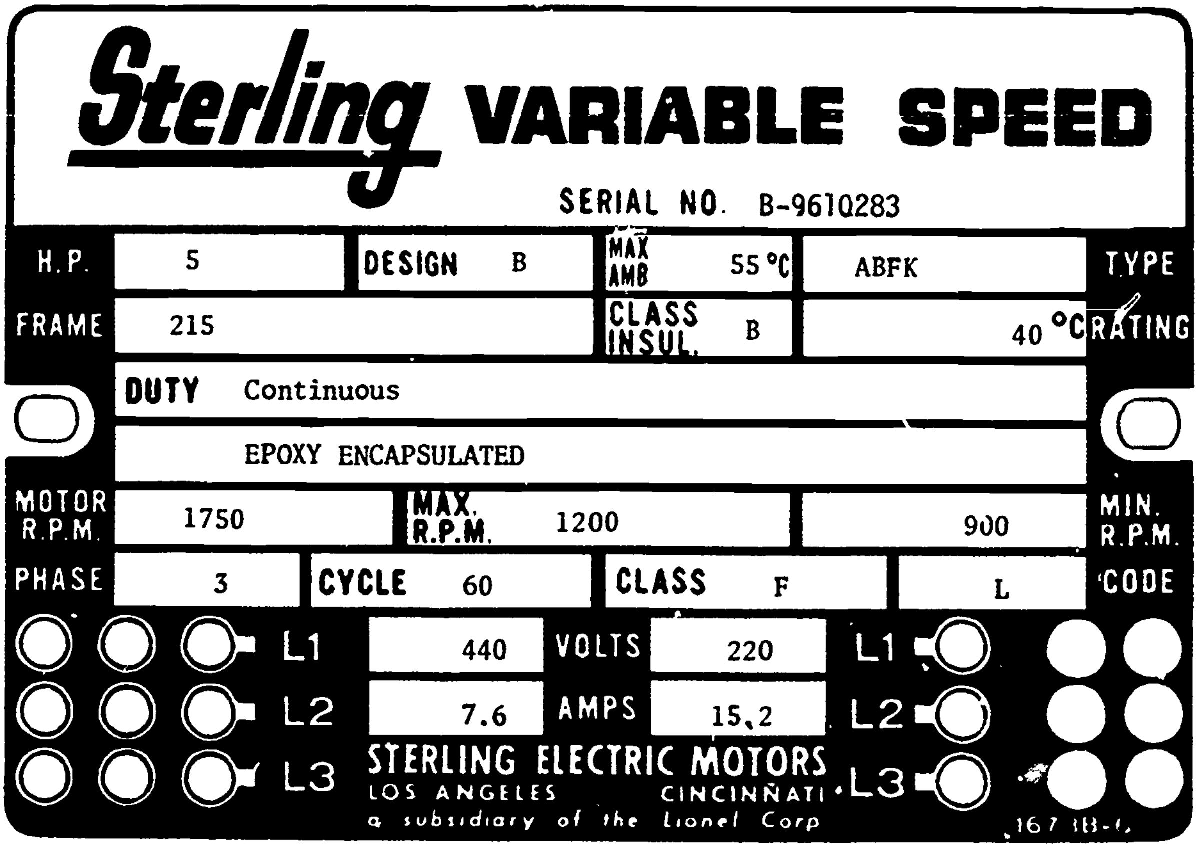


Fig. 18.12 Typical motors

(Courtesy of Sterling Power Systems, Inc.)



Sterling VARIABLE SPEED

SERIAL NO. B-9610283

H.P.	5	DESIGN	B	MAX AMB	55 °C	ABFK	TYPE
FRAME	215			CLASS INSUL.	B	40 °C	RATING
	DUTY	Continuous					
		EPOXY ENCAPSULATED					
MOTOR R.P.M.	1750	MAX. R.P.M.	1200			900	MIN. R.P.M.
PHASE	3	CYCLE	60	CLASS	F	L	CODE

L1	440	VOLTS	220	L1
L2	7.6	AMPS	15.2	L2
L3				L3

STERLING ELECTRIC MOTORS
LOS ANGELES CINCINNATI
a subsidiary of the Lionel Corp

167 1B-6

NOTE 1. The motor for this unit is rated at 1750 RPM and the maximum speed for the variable drive unit is 1200 RPM.

2. The 40°C rating is the allowable operating temperature above ambient temperature.

Fig. 18.13 Typical nameplate
(Courtesy of Sterling Power Systems, Inc.)

6 *CONVERGE ON SOURCE OF TROUBLE:* Mechanical or electrical. Motor or control, whatever it might be Electrical problems result from some type of mechanical failure.

7 *PINPOINT THE PROBLEM.* Exactly where is the problem and what do you need for repair?

8. *FIND THE CAUSE.* What caused the problem? Moisture, wear, poor design, voltage, or overloading.

9. *REPAIR THE PROBLEM AND ELIMINATE THE CAUSE IF POSSIBLE.* If the problem is inside switch gear or motors, call an electrician. Give the electrician the information you have regarding the equipment. Do not attempt electrical repairs unless qualified and authorized, otherwise you could cause excessive damage to yourself and to the equipment.

B Some of the things to look for when troubleshooting are given in the remainder of this section.

18.142 Recordkeeping

Records are a very important part of electrical maintenance They must be accurate and complete. Whenever something is changed, repaired, or tested, it should be recorded on a material history card of some type. Pages 242 and 243 are examples of typical record sheets

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18 14E What is the key to effective troubleshooting?

18.14F What are some of the steps that should be taken when troubleshooting electrical equipment?

18 14G What kind of information should be recorded regarding electrical equipment?

ELECTRIC MOTOR TROUBLESHOOTING

1. Contacts

Trouble	Possible Causes	Remedy
Contact chatter	1. Broken *POLE SHADER*[9]	1. Replace
	2. Poor contact in control circuit.	2. Improve contact or use holding circuit interlock
	3. Low voltage	3. Correct voltage condition. Check momentary voltage dip.
Welding or freezing	1. Abnormal surge of current.	1. Use larger contactor and check for grounds, shorts, or excessive motor load current.
	2. Frequent *JOGGING.*[10]	2. Install larger device rated for jogging service or caution operator.
	3. Insufficient contact pressure.	3. Replace contact spring; check contact carrier for damage.
	4. Contacts not positioning properly.	4. Check for voltage dip during startup.
	5. Foreign matter preventing magnet from seating.	5. Clean contacts.
	6. Short circuit	6. Remove short fault and check that fuse or breaker are right.
Short contact life or overheating of tips	1. Contacts poorly aligned, spaced or damaged.	1. Do not file silver-faced contacts. Rough spots or discoloration will not harm contacts.
	2. Excessively high currents.	2. Install larger device. Check for grounds, shorts, or excessive motor currents.
	3. Excessive starting and stopping of motor.	3. Caution operators. Check operating controls.
	4. Weak contact pressure.	4. Adjust or replace contact springs.
	5. Dirty contacts.	5. Clean with approved solvent.
	6. Loose connections.	6. Check terminals and tighten.
Coil. overheated	1. Starting coil may not kick out	1. Repair coil.
	2. Overload won't let motor reach minimum speed.	2. Remove overload.
	3. Over voltage or high ambient temperature.	3. Check application and circuit.
	4. Incorrect coil	4. Check rating and if incorrect, replace with proper coil.
	5. Shorted turns caused by mechanical damage or corrosion.	5. Replace coil.
	6. Undervoltage, failure of magnet to seal it.	6. Correct system voltage.
	7. Dirt or rust on pole faces increasing air gap.	7. Clean pole faces

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[9] *Pole Shader. A copper bar circling the laminated iron core inside the coil of a magnetic starter.*

[10] *Jogging. The frequent starting and stopping of an electric motor.*

ELECTRIC MOTOR TROUBLESHOOTING (Continued)

Trouble	Possible Causes	Remedy
Overload relays tripping	1 Sustained overload	1. Check for grounds. shorts or excessive motor currents Mechanical overload
	2. Loose connection on all or any load wires.	2 Check, clean, and tighten.
	3 Incorrect heater	3. Replace with correct size heater unit.
	4. Fatigued heater blocks.	4. Inspect and replace
Failure to trip overload relay	1. Mechanical binding, dirt, or corrosion.	1 Clean or replace.
	2. Wrong heater, or heaters omitted and jumper wires used	2. Check ratings Apply heaters of proper rating.
	3. Motor and relay in different temperatures	3. Adjust relay rating accordingly, or install temperature compensating relays.
2. Magnetic and Mechanical Parts		
Noisy magnet (humming)	1 Broken shading coil.	1. Replacing shading coil.
	2. Magnet faces not mating.	2. Replace magnet assembly or realign
	3. Dirt or rust on magnet faces.	3 Clean and realign.
	4. Low voltage.	4. Inspect system voltage and voltage dips during starting.
Failure to pick up and seal	1. Low voltage	1 Inspect system voltage and correct.
	2. Coil open or shorted.	2. Replace.
	3. Wrong coil.	3. Check coil number and voltage rating.
	4. Mechanical obstruction	4. With power off, check for free movement of contact and armature assembly. Repair.
Failure to drop out	1. Gummy substance on pole	1. Clean with solvent.
	2. Voltage not removed from coil.	2. Check coil circuit.
	3. Worn or rusted parts causing binding.	3. Replace or clean parts as necessary.
	4. Residual magnetism due to lack of air gap in magnet path.	4. Replace worn magnet parts or align if possible.
	5 Welded contacts.	5 Replace contacts.

TROUBLESHOOTING GUIDE FOR ELECTRIC MOTORS

Symptoms	Cause	Result*	Remedy
1 Motor does not start. (Switch is on and not defective)	a Incorrectly connected.	a Burnout.	a Connect correctly per diagram on motor
	b. Incorrect power supply.	b Burnout	b Use only with correctly rated power supply.
	c. Fuse out, loose or open connection.	c Burnout	c Correct open circuit condition.
	d Rotating parts of motor may be jammed mechanically	d. Burnout	d. Check and correct: 1. Bent shaft. 2. Broken housing. 3. Damaged bearing. 4. Foreign material in motor.
	e. Driven machine may be jammed.	e. Burnout	e Correct jammed condition.
	f. No power supply.	f. None.	f Check for voltage at motor and work back to power supply.
	g. Internal circuitry open.	g Burnout.	g. Correct open circuit condition.
2 Motor starts but does not come up to speed	a. Same as 1-a, b, c above.	a. Burnout.	a. Same as 1-a, b, c above.
	b Overload.	b. Burnout.	b. Reduce load to bring current to rated limit. Use proper fuses and overload protection.
	c. One or more phases out on a 3 phase motor.	c. Burnout.	c. Look for open circuits.
3 Motor noisy electrically.	a. Same as 1-a, b, c above.	a. Burnout	a. Same as 1-a, b, c above.
4. Motor runs hot (exceeds rating).	a. Same as 1-a, b, c above.	a. Burnout.	a. Same as 1-a, b, c above.
	b. Overload.	b. Burnout.	b. Reduce load.
	c. Impaired ventilation.	c. Burnout.	c Remove obstruction.
	d. Frequent start or stop	d. Burnout	d. 1. Reduce number of starts or reversals. 2. Secure proper motor for this duty.
	e. Misalignment between rotor and stator laminations.	e. Burnout	e. Realign.
5 Noisy (mechanically)	a. Misalignment of coupling or sprocket.	a. Bearing failure, broken shaft, stator burnout due to motor drag.	a. Correct misalignment.
	b. Mechanical unbalance of rotating parts.	b. Same as 5-a.	b. Find unbalanced part, then balance.
	c. Lack or improper lubricant.	c. Bearing failure	c. Use correct lubricant, replace parts as necessary.
	d. Foreign material in lubricant.	d. Same as 5-c.	d. Clean out and replace bearings.
	e. Overload.	e. Same as 5-c.	e. Remove overload condition. Replace damaged parts.
	f. Shock loading.	f. Same as 5-c.	f. Correct causes and replace damaged parts.
	g. Mounting acts as amplifier of normal noise.	g. Annoying.	g. Isolate motor from base.
	h. Rotor dragging due to worn bearings, shaft or bracket.	h. Burnout.	h. Replacing bearings, shaft or bracket as needed.
6 Bearing failure	a. Same as 5-a, b, c, d, e.	a. Burnout, damaged shaft, damaged housing.	a. Replace bearings and follow 5-a, b, c, d, e.
	b. Entry of water or foreign material into bearing housing.	b. Same as 6-a.	b. Replace bearings and seals and shield against entry of foreign material (water, dust, etc.). Use proper motor.

* Many of these conditions should trip protective devices rather than burn out motors.

TROUBLESHOOTING GUIDE FOR ELECTRIC MOTORS (continued)

Symptom	Caused By	Appearance
1 Shorted motor winding	a Moisture, chemicals, foreign material in motor, damaged winding.	a. Black or burned with remainder of winding good.
2 All windings completely burned	a. Overload.	a. Burned equally all around winding
	b. Stalled.	b. Burned equally all around winding.
	c. Impaired ventilation.	c. Burned equally all around winding
	d. Frequent reversal or starting	d Burned equally all around winding.
	e. Incorrect power.	e. Burned equally all around winding.
3 Single phase condition	a Open circuit in one line. The most common causes are loose connection, one fuse out, loose contact in switch.	a. If 1800 RPM motor — four equally burned groups at 90° intervals. b. If 1200 RPM motor — six equally burned groups at 60° intervals c. If 3600 RPM motor — two equally burned groups at 180°. NOTE: If Y-connected each burned group will consist of two adjacent phase groups. If delta-connected each burned group will consist of one phase group.
4 Other	a. Improper connection b Ground.	a Irregularly burned groups or spot burns.

Many burnouts occur within a short period of time after motor is started up This does not necessarily indicate that the motor was defective, but usually is due to one or more of the above mentioned causes The most common of these are improper connections, open circuits in one line, incorrect power supply or overload

TROUBLE-REMEDY CHART FOR INDUCTION MOTORS

A. Motor will not start.

Overload control tripped. Wait for overload to cool, then try to start again. If motor still does not start, check for the causes outlined below.

1. Open fuses: test fuses.
2. Low voltage: check name plate values against power supply characteristics. Also check voltage at motor terminals when starting motor under load to check for allowable voltage drop.
3. Wrong control connections: check connections with control wiring diagram.
4. Loose terminal-lead connection: turn power off and tighten connections.
5. Drive machine locked: disconnect motor from load. If motor starts satisfactorily, check driven machine.
6. Open circuit in stator or rotor winding: check for open circuits.
7. Short circuit in stator winding: check for short.
8. Winding grounded: test for grounded wiring
9. Bearing stiff: free bearing or replace.
10. Overload: reduce load.

B. Motor noisy.

1. Three-phase motor running on single phase. stop motor, then try to start. It will not start on single phase. Check for open circuit in one of the lines.
2. Electrical load unbalanced: check current balance.
3. Shaft bumping (sleeve-bearing motor): check alignment and conditions of belt. On pedestal-mounted bearing check cord play and axial centering of rotor.
4. Vibration: driven machine may be unbalanced. Remove motor from load If motor is still noisy, rebalance.
5. Air gap not uniform: center the rotor and if necessary replace bearings.
6. Noisy ball bearing: check lubrication. Replace bearings if noise is excessive and persistent.
7. Rotor rubbing on stator: center the rotor and replace bearings if necessary.
8. Motor loose on foundation: tighten hold-down bolts. Motor may possibly have to be realigned.
9. Coupling loose: insert feelers at four places in coupling joint before pulling up bolts to check alignment. Tighten coupling bolts securely.

C. Motor at higher than normal temperature or smoking. (Measure temperature with thermometer or thermister and compare with name plate value.)

1. Overload: measure motor loading with ammeter. Reduce load.
2. Electrical load unbalance: check for voltage unbalance or single-phasing.
3. Restricted ventilation. clean air passage and windings.
4. Incorrect voltage and frequency: check name plate values with power supply. Also check voltage at motor terminals with motor under full load.
5. Motor stalled by driven tight bearings: remove power from motor. Check machine for cause of stalling.
6. Stator winding shorted or grounded: test windings by standard method.
7. Rotor winding with loose connection: tighten, if possible, or replace with another rotor.
8. Belt too tight: remove excessive pressure on bearings.
9. Motor used for rapid reversing service. replace with motor designed for this service.

D. Bearings hot.

1. End shields loose or not replaced properly: make sure end shields fit squarely and are properly tightened.
2. Excessive belt tension or excessive gear side thrust: reduce belt tension or gear pressure and realign shafts. See that thrust is not being transferred to motor bearing.
3. Bent shaft: straighten shaft or send to motor repair shop.

E. Sleeve bearings.

1. Insufficient oil: add oil — if supply is very low, drain, flush,and refill.
2. Foreign material in oil or poor grade of oil: drain oil, flush, and relubricate using industrial lubricant recommended by a reliable oil manufacturer.
3. Oil rings rotating slowly or not rotating at all: oil too heavy; drain and replace. If oil ring has worn spot, replace with new ring.
4. Motor tilted too far: level motor or reduce tilt and realign if necessary.
5. Rings bent or otherwise damaged in reassembling: replace rings.
6. Rings out of slot (oil-ring retaining clip out of place): adjust or replace retaining clip.
7. Defective bearings or rough shaft: replace bearings. Resurface shaft

F. Ball bearings.

1. Too much grease: remove relief plug and let motor run. If excess grease does not come out, flush and relubricate.
2. Wrong grade of grease: flush bearing and relubricate with correct amount of proper grease.
3. Insufficient grease: remove relief plug and grease bearing.
4. Foreign material in grease: flush bearing, relubricate; make sure grease supply is clean (keep can covered when not in use).

PUMP RECORD CARD

NAME____________ MAKE____________ MODEL____________

TYPE____________ SIZE____________ SERIAL #____________

ORDER NUMBER________ SUPPLIER____________ DATE PURCHASED____________

DATE INSTALLED________ APPLICATION____________ PLANT #____________

Name Plate Data and Pump Info

GPM ________

TDH ________

RPM ________

Gage Press Disc____ ________

Gage Press Suc ____ ________

Shut off Press ____ ________

Suction Head ____ ________

Rotation ____ ________

Impeller Type____________

Impeller Dia.____________

Impeller Clear____________

Coupl Type & Size____________

Front Brg #____________

Rear Brg #____________

Lub Interval____________

Lubricant____________

Wearing Rings____________

Shaft Sleeve Size____________

Pump Shaft Size____________

Pump Keyway____________

____

Other Related Information:

Stuffing Box Data

Diameter______ Depth______

Pack. Size____ Type______

Length______ No. Rings______

Lantern Ring______ Flushed______

Mech. Seal Name______ Size______

Type____________

Pump Materials

Casing____________

Shaft____________ ____________

Wearing Rings Casing ____________

Wearing Rings Impeller____________

Shaft Sleeve____________

Slinger____________

Shims____________ ____________

Gaskets_ ____________

"O" Rings____________

Brg. Seals Front____________

Rear____________

Casing Wear Ring Size ID______

OD____________

Width__ ________

Impeller Wear Ring ID________

OD________

Width________

Motor Data

Name________ Serial #________

H.P.________ Speed________

Ambient°____________

RPM______ Frame________

Volts______ Amps________

Phase_____ Cycle________

Shaft Size______ Key______

Bearing Front____________

Rear____________

Code________ Type________

Amps @ Max.Speed________

Amps @ Shut Off________

Control Data Info

Starter____________

MENA Size____________

Cat. #____________

Heater Size____________

Rated @____________

Control Voltage________

Variable Speed Type________

Speed Max________ ________

Speed Min________

MOTOR STARTERS

Number ____________

Title: ______________________________

Mfg.: ______________ Address ______________

Style: __________ Class __________ Size __________

Type: __________ __________ __________

O.L. HEATERS

Style __________ Code __________

Amps __________ __________

__________ __________

O.L. TRIP UNITS

Mfg: __________ Style: __________

Type: __________ __________

Amps Range: __________ __________

CIRCUIT BREAKER

Mfg: __________ Address ______________

Style: __________ Frame: __________ Volts __________ Amps Setting __________

Cat. No. __________ __________ __________ __________

MOTOR

Number ____________

TITLE ______________________________

Mfg: ______________ Address ______________

HP: ________ Volts: ________ Ser. No. ________ Duty: ________

Phase: ________ Amps: ________ Frame: ________ Temp: ________

Cycles: ________ RPM: ________ Type ________ Class: ________

Code: ________ S.F.: ________ Model ________ Spec.: ________

SO# ________ S# ________ Style: ________ CSA App: ________

Form ________ Spec. ________ Shft. Brg. ________ Rear Brg. ________

50 Cycle Data ______________________________

Suitable for 208V Network: ________

Additional data ______________

____

____

____

Connection Diagram

(6) (5) (4)
(7) (8) (9)
(1) (2) (3)

(6) (5) (4)
(7) (8) (9)
(1) (2) (3)

18.15 Auxiliary Electrical Power

18.150 Safety First

Always remember that a QUALIFIED ELECTRICIAN should perform most of the necessary maintenance and repair of electrical equipment. If you don't know the how, why, and when of the job, don't do it. You could endanger your life as well as your fellow operators. Never attempt work that you are not qualified to do or are not authorized to perform.

18.151 Standby Power Generation

There are three ways of providing standby power. One is by providing the treatment plant with an engine driven generator set. The limit of how much power can be produced is determined only by the size of the generator. The second possibility for standby power is batteries. Batteries should only be considered for low power consumption uses such as emergency lighting, communication, and possibly some control and instrumentation functions. The other possibility for standby power is a connection to an alternate power source, such as a different substation or another power company.

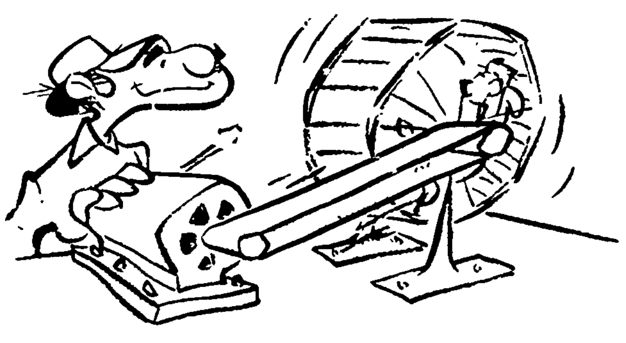
Because the treatment of water is considered a critical service, it is important to be able to provide drinking water even with the loss of commercial power. A power outage of a short duration probably will not have adverse effects on plant operation. The question you must ask yourself is, "Can my plant meet the needs of the public if a 'brown out' or catastrophic event eliminates commercial power for an extended length of time?" If the answer is "no," then perhaps a form of standby power generation should be considered.

The following six conditions must be analyzed to determine the need for and size of standby power generation.

1. Frequency of power outages in last 10 to 15 years.
2. Duration of the power outage in each occurrence.
3. Availability of additional source of power supply from a different substation in the vicinity.
4. Method by which raw water reaches plant (is flow by gravity or by a raw water pumping station?).
5. Total storage capacity of reservoirs in the distribution system.
6. Possibility of obtaining a potable water supply from adjacent cities (is there a reasonably sized pipe connection between your system and the distribution system of an adjacent city?).

If the frequency of power outages is once or twice a year with a 10 to 30 minute duration, the capacity of a standby power generator can be relatively small. The minimum size of a standby power generator may require sufficient capacity to operate essential equipment such as:

1. Coagulant and chlorine feeders,
2. One-third of flocculators,
3. Major electric valve operators and plant control system,
4. One-third of pumping capacity (if necessary), and
5. Minimum lighting.



Where do you begin? You have to consider whether you would like to have all of your facility operating or whether just the vital or key equipment would be sufficient. Since the characteristics and operating conditions of every plant are different, it is extremely difficult to make specific suggestions.

For the sake of illustration, let us pose a hypothetical situation. Consider a 10 MGD (38 MLD) capacity plant with an average flow rate of 6 MGD (23 MLD). Prepare a list of needs that must be met to insure minimal operation:

1. Raw water pumping,
2. Clarification,
3. Clear water pumping,
4. Chlorination, and
5. Minimal lighting.

Calculate the maximum horsepower or total kilowatts necessary to maintain the limited operation:

1. Raw Water Pump — 75 horsepower	56.00 kW
2. Clarification — 2½ horsepower	2.24 kW
3. Clear Water Pump — 40 horsepower	30.00 kW
4 Chlorination — 15 horsepower	11.20 kW
5. Lighting	5.00 kW
	104.44 kW

The minimum power required is 104.44 kW. When sizing a generator for emergency power, you have to make sure that the operator will be able to start the needed motors. Since the locked rotor current of the 75 horsepower induction motor on the raw water pump is approximately four times running current, then the generator must be able to handle 224 kW at that instant. Size the generator not only by total load, but also for the highest horsepower motor being started. Consider the sequence in which motors will be started. The starting of all the motors simultaneously (without sequence starting) would be nearly impossible. Consult experts in power generation for answers to your specific questions regarding your plant because each plant has different needs. If you are considering standby power, shop around and get ideas from the equipment manufacturers. You may be able to reduce the size of the generator by using reduced voltage starters on the larger motors.

After you have determined the size of generator needed, you must be able to connect it to your power distribution system. This may require some sophisticated switch gear. Besides the mechanical functions necessary in connecting the emergency power with your normal system, it is important that the two systems cannot be electrically coupled. (Two electrical systems must be "in phase" with each other before parallel coupling.) For this reason, mechanical interlocks are used to insure that one circuit is always open. A "kirk-key" system, where one key is used for two locks, locking one switch open before the other can be closed, is sometimes used. The manufacturers of most packaged motor-generator systems can provide automatic transfer switches that will automatically start the generator when a power failure occurs and connect the generated power into the plant power distribution wiring.

Looking back at the plant described, a generator of 125 kW with intermittent overload capabilities should handle the load. (Note: This is an assumption. Actual calculation may indicate a different size.) An engine-generation system of this size could handle your minimal power needs. If your water distribution system has ample capacity, it may be possible to cut the plant production rate to reduce power requirements to what can be handled with a smaller capacity generator.

If you do not have standby power generation at your facility, talk to others in the water treatment field who do and obtain ideas and information. After due consideration, take the necessary steps to insure yourself against interrupted power.

Standby power generators should be operated on a regular basis (once a week) to be sure they will operate properly when needed. Be sure to operate your generator at full load for at least an hour. Commercial power into your plant must be shut off to operate standby power at full load.

18.152 Emergency Lighting

The most practical form of emergency lighting in most instances is that provided by battery-powered lighting units. Because they are used primarily for exit lighting, they are more economical than engine-driven power sources. If you have a momentary power outage, the system responds without an engine-generator start-up. All emergency lighting unit equipment is basically the same and consists of a rechargeable battery, a battery charger, low voltage flood lights, and test monitoring and control accessories. Proper selection of a unit for a particular location requires careful consideration of the following items:

1. Initial cost,
2. Types of batteries,
3. Maintenance requirements, and
4. Lighting requirements.

The three types of batteries most commonly used are: lead acid, lead calcium, and nickel cadmium. Because poor battery maintenance is quite common in emergency lighting systems, "maintenance free" batteries are becoming increasingly popular. These batteries can have a gelatin or acid (wet) *ELECTROLYTE.*[11] The gelatin type is completely spillproof and can be handled safely without the dangers of acid spills. These batteries have a shorter life span than the wet type. Since all batteries undergo evaporation, the gelatin electrolyte will be exhausted before that of a battery containing liquid. Wet-type maintenance free batteries require no refilling and, when handled properly, acid spillage is minimal.

In terms of cost, the maintenance-free battery is more expensive; but when you consider the human factor, they may be more reliable and cheaper in the long run. Most systems use a battery charger that monitors the battery voltage. When required, the charger then charges the batteries. In earlier designed units, a trickle charger was used. This constant charging resulted in inoperative batteries in a short time because of overcharging.

The lamps used are normally 6 to 12 volt sealed-beam 25-watt lamps. The light pattern provided is most effective when illuminating a work area. A rule of thumb is that one lamp will be sufficient for about 1,000 square feet, providing that the full light pattern can be used. Consult emergency light level codes (Table 18.2) for your particular application.

When selecting an emergency lighting system, check it very thoroughly to insure that it will give you the protection needed. If it fails to work when the chips are down and the main power is out, you've wasted your money.

18.153 Batteries

This section will discuss wet storage batteries since they are the most prevalent. Automotive and equipment batteries are usually of the lead-acid type. This indicates that the dissimilar plates are made of two types of lead and the electrolyte is sulfuric acid. Wet-type batteries can also be nickel cadmium or nickel iron.

Most batteries are a series of cells enclosed in a common case. Each of these cells develops a potential (voltage) of 2.3 volts per cell when fully charged. Hence, a six-volt battery contains three cells and a 12-volt battery has six cells. The voltage output of a 12-volt battery is 13.8 volts when fully charged. Once a lead-acid battery has been placed in service, the addition of sulfuric acid is not necessary. The water portion of the electrolyte solution evaporates as the battery is charged and discharged. Lost water must be replaced. Deionized or distilled water should be used. Tap water contains impurities that shorten the life span of a battery if used to replace lost water. These minute particles become attached to the lead plates and do not allow the battery to rejuvenate itself fully when charged.

When batteries are placed on charge, remove the cell covers to allow the gas (hydrogen) caused by charging to escape and not to build excessive pressure in the battery. A battery on charge is as lethal as a small bomb if you ignite the gas. Do not smoke or cause electrical arcing near the battery. Do not breath the gas and make sure that the area where a battery is being charged is well ventilated.

The keys to prolonged life of a battery are to keep the electrolyte level above the cell plates, to keep the battery fully charged, and above all, to keep the terminals and top clean. When dirt and residue accumulate on the top of a battery, it forms a path for current to flow between the negative and positive posts. Take a multimeter, connect one lead to the proper post (it will cause up-scale deflection) and slowly slide the other lead across the top of the battery toward the other post. If the top is dirty, the meter will deflect more as you proceed across the top.

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[11] *Electrolyte (ee-LECK-tro-LIGHT). A substance which dissociates (separates) into two or more ions when it is dissolved in water.*

TABLE 18.2 IES RECOMMENDED EMERGENCY LIGHT LEVELS[a]

Hazard requiring visual detection	Slight		High	
NORMAL ACTIVITY LEVEL*	LOW	HIGH	LOW	HIGH
Areas	Conference rooms Reception rooms Exterior floodlighting Closets	Lobbies Corridors Concourse Restrooms, washrooms Telephone switchboard rooms Exterior entrance Exterior floodlighting	Elevators (freight) File rooms Mail rooms Offices Stairways Stockrooms Exterior entrance with stairs	Elevators Escalators Computer rooms Drafting rooms Offices Stairways Transformer vaults Engine rooms Electrical, mechanical, plumbing rooms
Footcandles	0.5	1.0	2.0	5.0
Dekalux	0.54	1.1	2.2	2.2

Minimum illumination for safety of personnel, absolute minimum at any time and at any location on any plane where safety is related to seeing conditions.

* Special conditions may require different levels of illumination. In some cases higher levels may be required as for example where security is a factor In some other cases greatly reduced levels of illumination, including total darkness, may be necessary, specifically in situations involving manufacturing, handling, use, or processing of light-sensitive materials (notably in connection with photographic products). In these situations alternate methods of insuring safe operation must be relied upon.

EMERGENCY LIGHT LEVEL codes and standards vary widely throughout the country Recommended minimum lighting levels of the Illuminating Engineering Society are being considered as a possible standard by ANSI and the Life Safety Code. These are minimum lighting levels recommended for safety of personnel.

[a] Reprinted from December 1978 issue Electrical Construction and Maintenance. Copyright 1978 McGraw-Hill, Inc All rights reserved.

To clean the battery, use a stiff-bristled brush (not a wire brush) and remove the heavy material. Then wash with a solution of baking soda and water (four teaspoons of baking soda to one quart of water). This will remove the acid film from the top and neutralize corrosion on the battery terminals. Rinse with fresh water and dry the top with a dry, lintless cloth. Remove cell caps and wipe between them, then replace. At this time check to be sure that the battery terminals are clean and tight. If a battery is charged, but the terminals are loose, proper voltage and current cannot be delivered.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18 15A Why should a qualified electrician perform most of the necessary maintenance and repair of electrical equipment?

18.15B What is the purpose of a "kirk-key" system?

18 15C Why are battery-powered lighting units considered better than engine-driven power sources?

18.15D Why should the water lost from a lead-acid battery be replaced with deionized or distilled water?

18.16 High Voltage

18.160 Transmission

In general terms, high voltage is the voltage transmitted to the plant site by the utility company. The voltage level can vary, but 12,000 volts is quite common. After the power reaches the plant, it is transformed down to a useable voltage (0 to 480 volts) either through utility-owned or customer-owned transformers. The NEC (National Electrical Code) denotes high voltages as those over 600 volts.

Why have high voltage? Since current (amperes) varies inversely with voltage, a load of 500 amps on the low voltage side of the transformer would create a 20 amp load on the high voltage side of a 12,000 volts/480 volt transformer. Transmission lines would have to be enormous in order to carry the load if a lower voltage were used. Where high voltage cables terminate at a transformer or switch gear, certain conditions must be adhered to. If outdoor transformers are used that have high voltage wires exposed, an eight-foot (2.4 m) high fence is required to prevent accessibility by unqualified or unauthorized persons. Signs attached to the fence must indicate "High Voltage." Specifications for clearances, grounding, access, and enclosures vary with installations. Any modification or repair work must be completed by qualified people only.

18.161 Switch Gear

When we see the term "switch gear," it is usually associated with the equipment used in the interruption, transfer, or disconnecting of voltages over 600 volts. The enclosure is designed and manufactured to safely control high-voltage switching. Most distribution systems have a load-interrupting switch that is capable of disconnecting high voltage lines that are under load. Because of the arc that is caused in breaking the circuit, special "arc shoes" (arc-suppressant devices) are used to ensure that the contact points are not pitted. A keyed lock system is used to prevent opening of the enclosure in the energized state.

Probably the best preventive maintenance that a treatment plant operator can provide for switch gear is to keep the exterior and its surroundings clean. If you encounter difficulties in the course of operating the switches, please obtain qualified help to do the inspection or repairs needed. Check with your particular manufacturer to determine what is needed and when this has to be done to keep your system functioning as designed. If your equipment is in a corrosive atmosphere, it may be necessary to remove it from service and expoxy paint the internal buses. All pivoting points should be lubricated with a lubricant specified by the manufacturer.

18.162 Power Distribution Transformers

If the high voltage transformers are owned by the utility, the inspection and maintenance is carried out by the utility. Any peculiar changes, smells, or noises should be reported to the utility. When transformers are customer owned, a regular inspection program should be established.

Most transformers use an oil to insulate as well as to cool the windings. As heat is generated in the windings, it is transferred to the oil. The oil is then cooled by air passing the cooling fins of the transformer. The primary requirements of the oil are:

1. High dielectric strength;
2. Freedom from inorganic acid, alkali, and sulfur to prevent injury to insulation and conductors;
3. Low viscosity to provide good heat transfer; and
4. Freedom from sludging under normal operation conditions.

The principal causes of deterioration of insulating oil are water and oxidation. The oil may be exposed to moisture through condensation of moist air due to "breathing" of the transformer, especially when the transformer is not continuously in service. The moist air condenses on the surface of the oil and on the inside of the tank. Oxidation causes sludging. The amount of sludge formed in a given oil depends upon the temperature and the time of exposure of the oil to the air. Excessive operating temperatures may cause sludging of any transformer oil. Check with the manufacturer to determine how often the oil should be tested. Oil can be revitalized by a cleaning procedure that is accomplished at the transformer site.

Any symptoms such as unusual noises, high or low oil levels, oil leaks, or high operating temperatures should be investigated at once. If your transformer has a thermometer, it is of the alcohol type and should be replaced with that type only. A mercury-type thermometer could cause insulation failures by reason of proximity of a metallic substance, regardless of whether it is intact or broken.

The tank of every power transformer should be grounded to eliminate the possibility of obtaining static shocks from it or from being injured by accidental grounding of the winding to the case.

If repairs are indicated, use the expertise of a qualified person to ensure that the repairs are made safely as well as correctly. Your life and the lives of others may depend on the use of qualified people.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18.16A Why is electricity transmitted at high voltage?

18.16B What precautions must be taken if outdoor transformers have exposed high voltage wires?

18.16C What kind of maintenance should a treatment plant operator perform on switch gear?

18.16D What symptoms indicate that a power distribution transformer may be in need of maintenance or repair?

18.17 Electrical Safety Check List

Throughout this manual and throughout this chapter the need for electrical safety is always being stressed. This section contains an electrical safety check list which is provided to help you ensure that you have minimized electrical hazards in your plant. This list is provided to make you aware of potential electrical hazards. You should add to the list additional electrical hazards that could injure someone at your water treatment plant.

1. Are there any conduits rusted to the point where they might have lost their explosion proof integrity?
2. Are there any electrical conduit hangers that are rusted so bad that they are allowing the conduit to sag?
3. Are there any fasteners on the conduit hangers that are rusted and allowing the conduit to hang by the wires?
4. Do all of the extension cords and power tools meet code requirements for use in wet areas?
5. Does the agency or utility have a policy covering the proper placement of portable ventilation equipment when operators work inside enclosed tanks, vaults and other confined spaces?
6. Does the agency use proper grounding units (ground fault interruptors) when working in wet areas?
7. Is the grounding of electrical equipment and systems inspected regularly?
8. Are electrical breakers and controls clearly marked?
9. Is there a formal program for locking out, tagging and blockout of electrical devices?

If you can answer these questions properly, you are working in the right direction to minimize electrical hazards in your water treatment plant.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18.17A Why are rusted conduits of concern to a water treatment plant operator?

18.17B What is the purpose of an electrical safety check list?

18.18 Additional Reading.

1. *BASIC ELECTRICITY* by Van Valkenburgn, Nooger & Neville, Inc. Obtain from The Brolet Press, 33 Gold Street, New York, N.Y. 10038. $39.95 for combined Edition of all five volumes.
   a. Volume 1. Price $10.50.
      Where Electricity Comes From
      Electricity in Action
      Current Flow, Voltage, Resistance
      Magnetism, DC Meters

b. Volume 2. Price $10.50
   Direct Current
   Ohm's and Kirchoff's Law
   Electric Power

c. Volume 3. Price $10.50.
   Alternating Current
   Resistance. Inductance. Capacitance in AC
   Reactance
   AC Meters

d. Volume 4. Price $10.50.
   Impedance.
   Alternating Current Circuits
   Series and Parallel Resonance
   Transformers

e. Volume 5. Price $10.50.
   DC Generators and Motors
   Alternators and AC Motors
   Power Control Devices

   NOTE: For an additional $2.00 per volume, you can obtain an "Interactive Self-Learning Package."

f. Other Training Programs
   Basic Electronics, 6 Volumes
   Basic Industrial Electricity, 2 Volumes

2. "Maintenance" by Stan Walton. Volume II. Chapter 15, in *OPERATION OF WASTEWATER TREATMENT PLANTS.* Kenneth D. Kerri. California State University. Sacramento. 6000 J Street. Sacramento. CA 95819. Price for Volume II. $25.00.

3. "Instrumentation" by George Ohara, Chapter 8, in *ADVANCED WASTE TREATMENT*, Kenneth D. Kerri, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819. Price, $20.00.

4. *ELECTRICITY PRINCIPLES AND PRACTICES* by Adams. McGraw-Hill Book Company 8171 Redwood Highway Novato, CA 94547 Price $24.95.

5. "Electrical and Automation," Chapter XII in *WATER DISTRIBUTION OPERATOR TRAINING HANDBOOK*, by I.E. Nichols and B.W. Jex. Obtain from American Water Works Association, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 20103. Price $14.50 for members of AWWA, $17.50 for others.

6. *MAINTENANCE ENGINEERING HANDBOOK* by Higgins, McGraw-Hill Book Company, PO Box 402, Highstown, New Jersey 08520. Price $79.50.

7. *ELECTRICITY FOR WATER AND WASTEWATER TREATMENT PLANT OPERATORS.* Available from National Environmental Training Association, 8687 Via de Ventura, Suite 214, Scottsdale, AZ 85258. Price $181.50.

8. *MECHANICAL MAINTENANCE FOR WATER AND WASTEWATER TREATMENT PLANT OPERATORS.* Available from National Environmental Training Association, 8687 Via de Ventura, Suite 214, Scottsdale, AZ 85258. Price $156.50.

End of Lesson 1 of 5 Lessons on MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 2.

DISCUSSION AND REVIEW QUESTIONS

Chapter 18. MAINTENANCE

(Lesson 1 of 5 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson.

Write the answers to these questions in your notebook.

1. Why should operators thoroughly read and understand manufacturers' literature before attempting to maintain plant equipment?
2. Why must administrators or supervisors be made aware of the need for an adequate maintenance program?
3. What is the purpose of a maintenance recordkeeping program?
4. What items should be included in a plant library?
5. Why should your plant have an emergency team to repair chlorine leaks?
6. Why should one person never be permitted to repair a chlorine leak alone?
7. Why should inexperienced, unqualified or unauthorized persons and even qualified and authorized persons be extremely careful around electrical panels, circuits, wiring and equipment?
8. What protective or safety devices are used to protect operators and equipment from being harmed by electricity?
9. Why must motor name plate data be recorded and filed?
10. What might be the cause of a pump motor failing to start?
11. Why should a water treatment plant have standby power?
12. How would you determine the capacity of standby generation equipment?

CHAPTER 18. MAINTENANCE

(Lesson 2 of 5 Lessons)

18.2 MECHANICAL EQUIPMENT

Mechanical equipment commonly used in water treatment plants is described and discussed in this section. Equipment used with specific treatment processes such as flocculation and filtration is not discussed. You must be familiar with equipment and understand what it is intended to do before developing a preventive maintenance program and maintaining equipment.

18.20 Repair Shop

Many large plants have fully equipped machine shops staffed with competent mechanics. But for smaller plants, adequate macnine shop facilities often can be found in the community. In addition, most pump manufacturers maintain pump repair departments where pumps can be fully reconditioned.

The pump repair shop in a large plant commonly includes such items as welding equipment, lathes, drill press and drills, power hacksaw, flame-cutting equipment, micrometers, calipers, gages, portable electric tools, grinders, a forcing press, metal-spray equipment, and sand-blasting equipment. You must determine what repair work you can and should do and when you need to request assistance from an expert.

Some agencies have their own repair shops or local machine shops rebuild parts rather than buying direct from manufacturers. Many agencies try to select equipment on the basis of the reputations of distributors for supplying repair parts when needed. A parts inventory is essential for key pieces of equipment.

18.21 Pumps

Pumps serve many purposes in water treatment plants. They may be classified by the character of the material handled, such as raw or filtered water. Or, they may relate to the conditions of pumping: high lift, low lift, or high capacity. They may be further classified by principle of operation, such as centrifugal, propeller, reciprocating, and turbine (Figure 18.14).

The type of material to be handled and the function or required performance of the pump vary so widely that the designing engineer must use great care in preparing specifications for the pump and its controls. Similarly, the operator must conduct a maintenance and management program adapted to the peculiar characteristics of the equipment.

18.210 Centrifugal Pumps

A centrifugal pump is basically a very simple device; an impeller rotating in a casing. The impeller is supported on a shaft which is, in turn, supported by bearings. Liquid coming in at the center (eye of the impeller (Figure 18.15)) is picked up by the vanes and by the rotation of the impeller and then is thrown out by centrifugal force into the discharge.

To help you understand how pumps work and the purpose of the various parts, a section titled "Let's Build a Pump" has been included on the following pages. This material has been reprinted with the permission of Allis-Chalmers Corporation, Milwaukee, Wisconsin, Industrial Pump Division, Norwood, Ohio. Originally, the material was printed in Allis-Chalmers Bullet. o. OBX62568.

18.211 Let's Build a Pump!

A student of medicine spends long years learning exactly how the human body is built before attempting to prescribe for its care. Knowledge of *PUMP* anatomy is equally basic in caring for centrifugal pumps!

But whereas the medical student must take a body apart to learn its secrets, it will be far more instructive to us if we put a pump *TOGETHER* (on paper, of course). Then we can start at the beginning — adding each new part as we need it in logical sequence.

As we see *WHAT* each part does, *HOW* it does it . . . we'll see how it must be *CARED FOR!*

Another analogy between medicine and maintenance: there are various types of human bodies, but if you know basic anatomy, you understand them all. The same is true of centrifugal pumps. In building one basic type, we'll learn about *ALL* types.

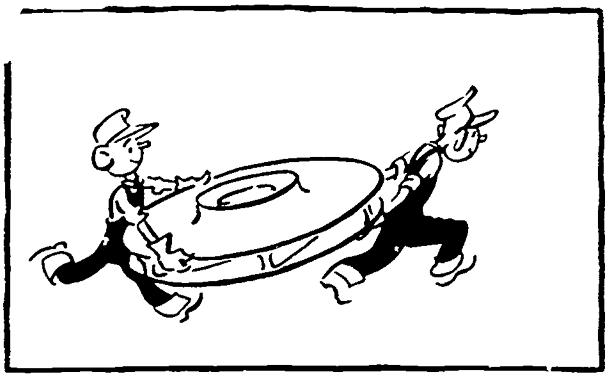
Part of this will be elementary to some maintenance people . . . but they will find it a valuable "refresher" course, and, after all, maintenance just can't be too good.

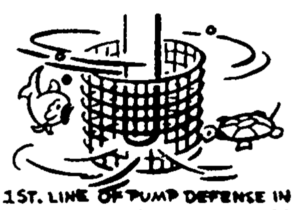
So, with a glance at the centrifugal principle on page 252, let's get on with building our pump . . .

FIRST WE REQUIRE A DEVICE TO SPIN LIQUID AT HIGH SPEED . . .

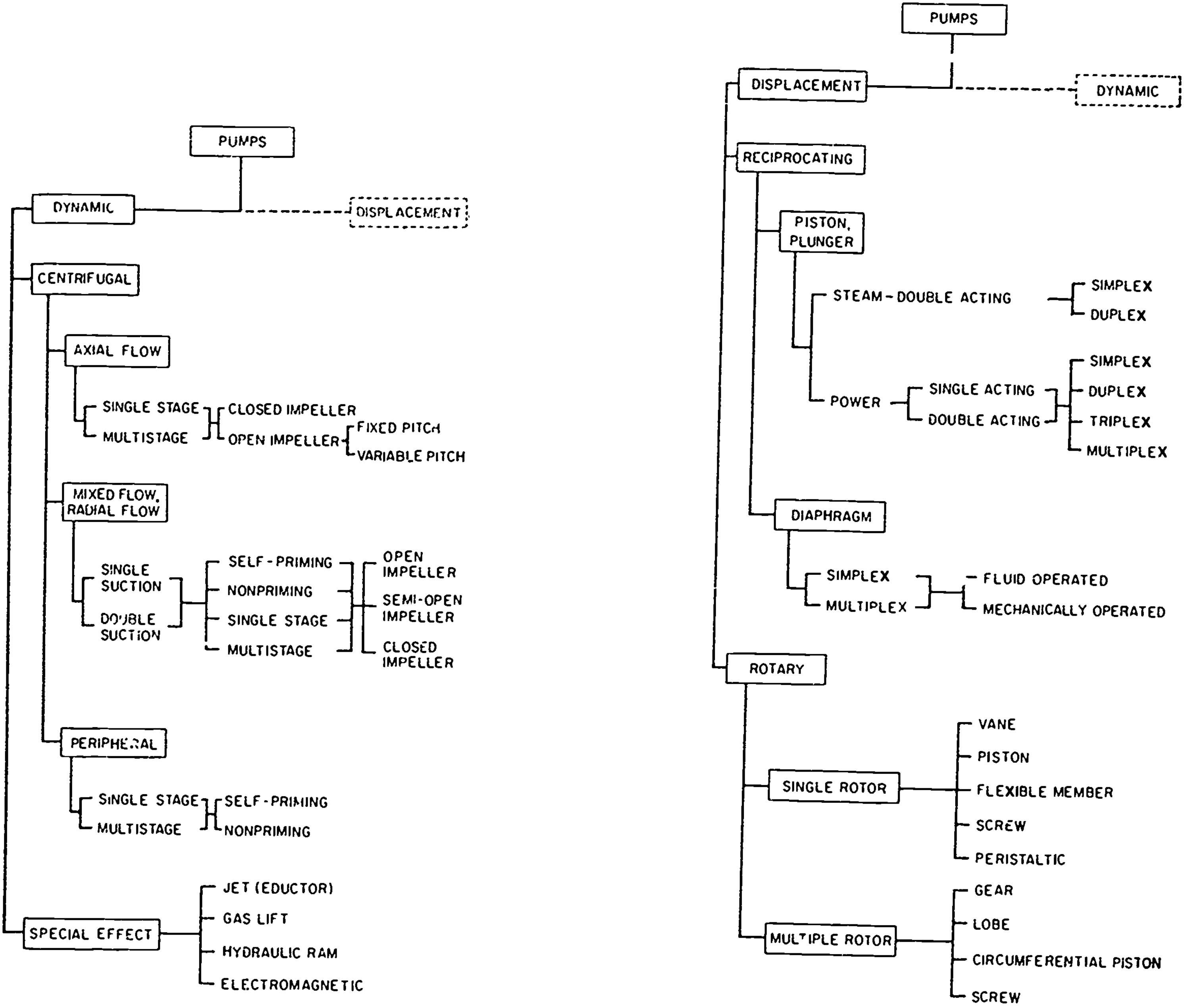
That paddle-wheel device is called the "impeller" . . . and it's the heart of our pump.

Note that the blades curve out from its hub. As the impeller spins, liquid between the blades is impelled outward by centrifugal force.





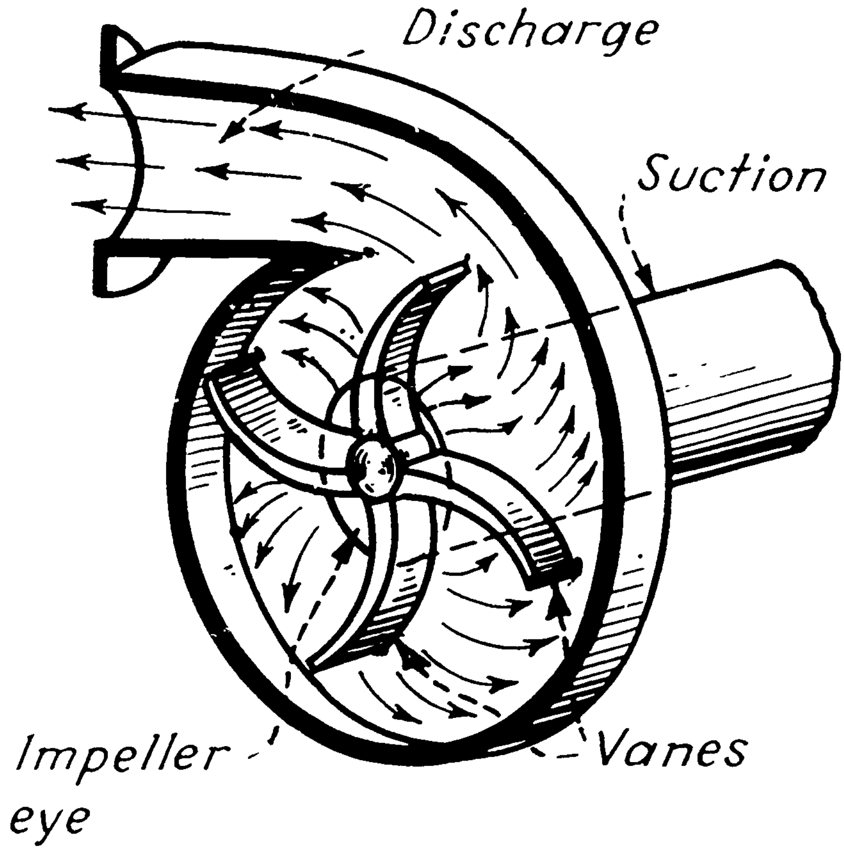
1ST. LINE OF PUMP DEFENSE IN WATER CARRYING STICKS, ETC!



Dynamic types of pumps

Displacement types of pumps

Fig. 18.14 Classification of pumps

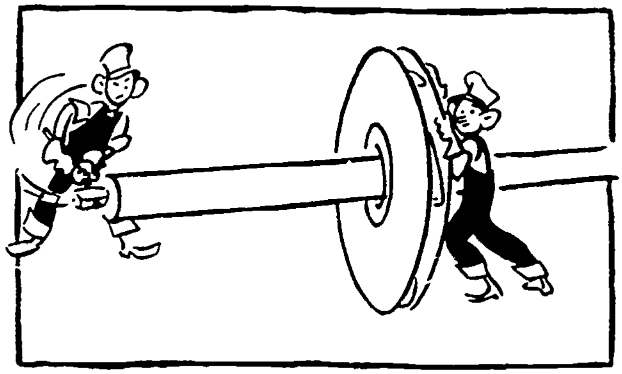


Refer to Fig. 18.18, pages 258 and 259, for location of impeller in pump

Fig. 18.15 Diagram showing details of centrifugal pump impeller
(Source CENTRIFUGAL PUMPS by Karassik and Carter of Worthington Corporation)

Note, too, that our impeller is open at the center — the "eye." As liquid in the impeller moves outward, it will suck more liquid in behind it through this eye . . . *PROVIDED IT'S NOT CLOGGED!*

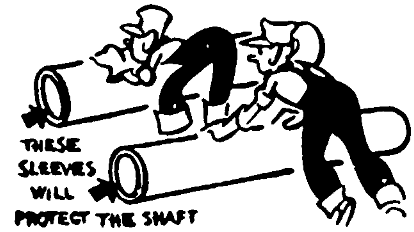
That brings up Maintenance Rule No. 1: if there's any danger that foreign matter (sticks, refuse, etc.) may be sucked into the pump — clogging or wearing the impeller unduly — *PROVIDE THE INTAKE END OF THE SUCTION PIPING WITH A SUITABLE SCREEN.*



NOW WE NEED A SHAFT TO SUPPORT AND TURN THE IMPELLER . . .

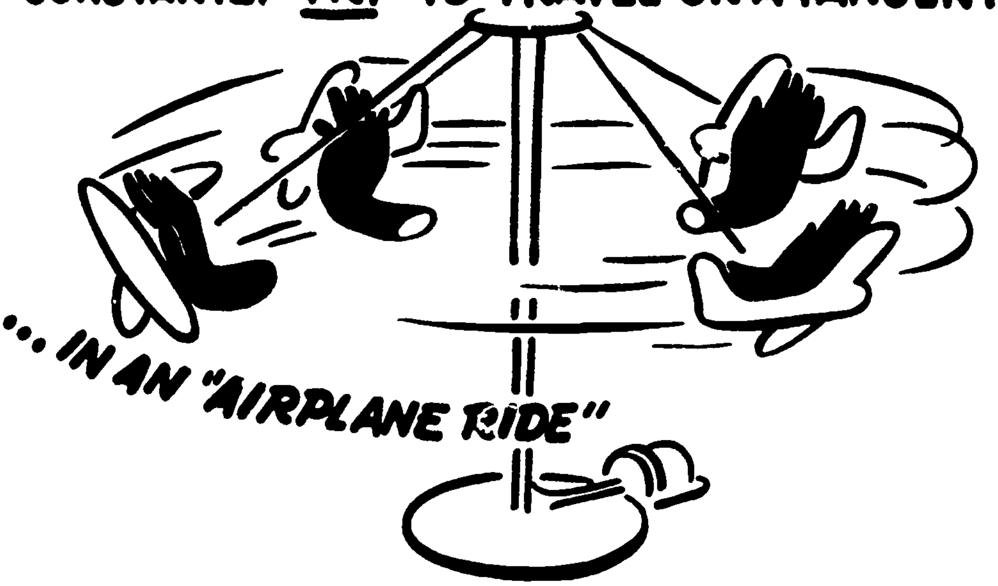
Our shaft looks heavy — and it *IS*. It must maintain the impeller in precisely the right place.

But that ruggedness does *NOT* protect the shaft from the corrosive or abrasive effects of the liquid pumped . . . so we must protect it with sleeves slid on from either end.



CENTRIFUGAL FORCE IN ACTION...

ALL MOVING BODIES TEND TO TRAVEL IN A STRAIGHT LINE. WHEN FORCED TO TRAVEL IN A CURVE, THEY CONSTANTLY *TRY* TO TRAVEL ON A TANGENT...



Centrifugal *force* pushes dummy planes swung in a circle *away* from center of rotation.

Centrifugal *force* tends to push swirling water *outward*... forming vortex in center.

What these sleeves — and the impeller, too — are made of depends on the nature of the liquid we're to pump. Generally they're bronze, but various other alloys, ceramics, glass, or even rubber-coating are sometimes required.

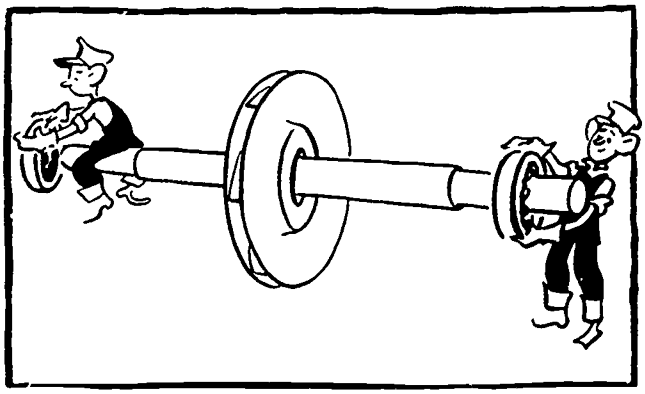
Maintenance Rule No. 2: *NEVER PUMP A LIQUID FOR WHICH THE PUMP WAS NOT DESIGNED.*

Whenever a change in pump application is contemplated and there's any doubt as to the pump's ability to resist the different liquid, *CHECK WITH YOUR PUMP MANUFACTURER!*

WE MOUNT THE SHAFT ON SLEEVE, BALL OR ROLLER BEARINGS . . .

As we'll see later, clearances between moving parts of our pump are *QUITE SMALL.*

If bearings supporting the turning shaft and impeller are allowed to wear excessively and lower the turning units within a pump's closely-fitted mechanism, the life and efficiency of that pump will be seriously threatened.



Maintenance Rule No. 3: *KEEP THE RIGHT AMOUNT OF THE RIGHT LUBRICANT IN BEARINGS AT ALL TIMES. FOLLOW YOUR PUMP MANUFACTURER'S LUBRICATION INSTRUCTIONS TO THE LETTER.*

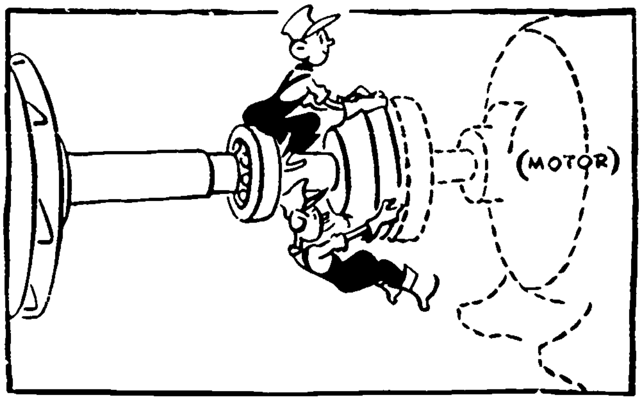
Main points to keep in mind are . . .

1. Although too much oil won't harm sleeve bearings, too much grease in antifriction type bearings (ball or roller) will *PROMOTE* friction and heat. Main job of grease in antifriction bearings is to protect steel elements against corrosion, not friction.
2. Operating conditions vary so widely that no one rule as to frequency of changing lubricant will fit all pumps. So play safe: if anything, change lubricant *BEFORE* it's too worn or too dirty.

TO CONNECT WITH THE MOTOR, WE ADD A COUPLING FLANGE . . .

Some pumps are built with pump and motor on one shaft, of course, and offer no alignment problem.

But our pump is to be driven by a separate motor . . . and we attach a flange to one end of the shaft through which bolts will connect with the motor flange.



USE FEELER GAUGES BETWEEN FLANGES, A STRAIGHT-EDGE ACROSS TOPS AND SIDES.

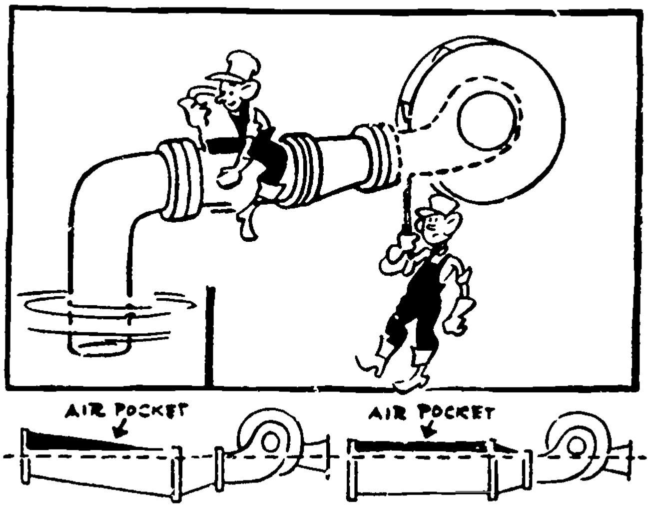
Maintenance Rule No. 4: *SEE THAT PUMP AND MOTOR FLANGES ARE PARALLEL VERTICALLY AND AXIALLY . . . AND THAT THEY'RE KEPT THAT WAY!*

If shafts are eccentric or meet at an angle, every revolution throws tremendous extra load on bearings of both pump and motor. Flexible couplings will *NOT* correct this condition if excessive.

Checking alignment should be regular procedure in pump maintenance. Foundations can settle unevenly, piping can change pump position, bolts can loosen. Misalignment is a *MAJOR* cause of pump and coupling wear.

NOW WE NEED A "STRAW" THROUGH WHICH LIQUID CAN BE SUCKED . . .

Notice two things about the suction piping: 1) the horizontal piping slopes *UPWARD* toward the pump; 2) any reducer which connects between the pipe and pump intake nozzle should be horizontal at the top — (*ECCENTRIC*, not concentric).



ALLOWED BY DOWN-SLOPING PIPE ALLOWED BY TAPERED REDUCER

This up-sloping prevents air pocketing in the top of the pipe which air might be drawn into the pump and cause loss of suction.

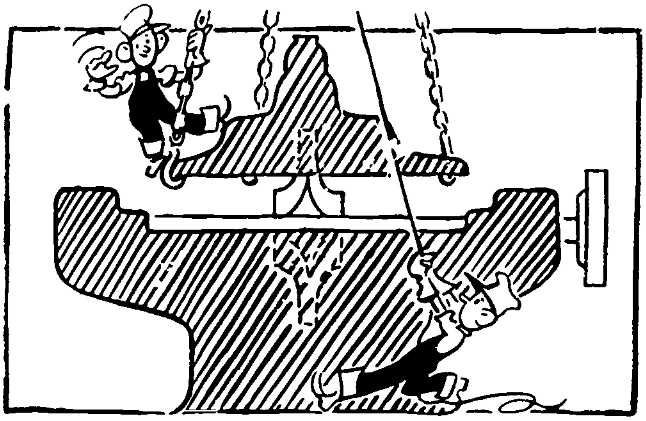
Maintenance Rule No. 5: *ANY DOWNSLOPING TOWARD THE PUMP IN SUCTION PIPING (AS EXAGGERATED IN THE DIAGRAMS ABOVE) SHOULD BE CORRECTED.*

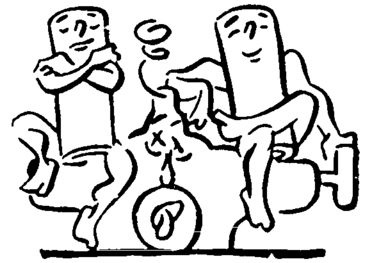
This rule is *VERY* important. Loss of suction greatly endangers a pump . . . as we'll see shortly.

WE CONTAIN AND DIRECT THE SPINNING LIQUID WITH A CASING . . .

We got a little ahead of our story in the previous paragraphs . . . because we didn't yet have the casing to which the suction piping bolts. And the manner in which it is attached is of great importance.

Maintenance Rule No. 6: *SEE THAT PIPING PUTS ABSOLUTELY NO STRAIN ON THE PUMP CASING.*





THE WEIGHT OF PIPING CAN EASILY RUIN A PUMP!

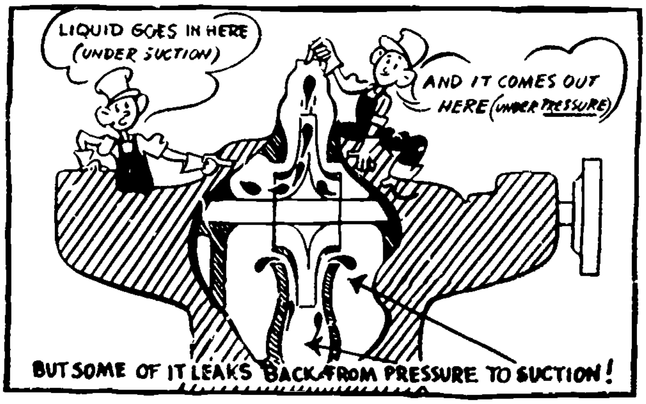
When the original installation is made, all piping should be in place and self-supporting before connection. Openings should meet with no force. Otherwise the casing is apt to be cracked . . . or sprung enough to allow closely-fitted pump parts to rub.

It's good practice to check the piping supports regularly to see that loosening, or settling of the building, hasn't put strains on the casing.

NOW OUR PUMP IS ALMOST COMPLETE, BUT IT WOULD LEAK LIKE A SIEVE . . .

We're far enough along now to trace the flow of water through our pump. It's not easy to show suction piping in the cross-section view above, so imagine it stretching from your eye to the lower center of the pump.

Our pump happens to be a "double suction" pump, which means that water flow is divided inside the pump casing . . . reaching the eye of the impeller from either side

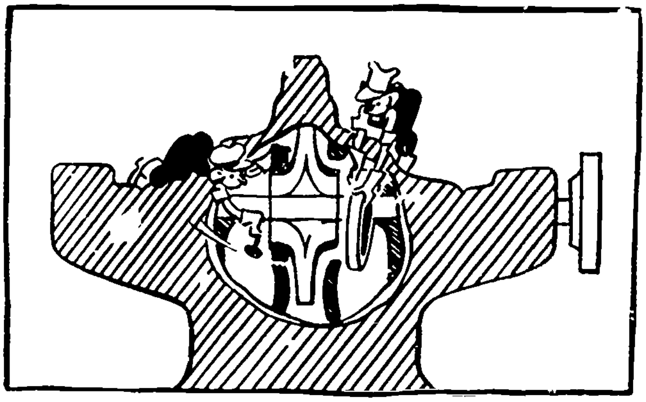


As water is sucked into the spinning impeller, centrifugal force causes it to flow outward . . . building up high pressure at the outside of the pump (which will force water *OUT*) and creating low pressure at the center of the pump (which will suck water *IN*.) This situation is diagrammed in the upper half of the pump, above.

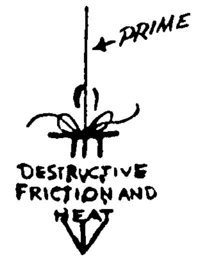
So far so good . . . except that water tends to be sucked back from pressure to suction through the space between impeller and casing — as diagrammed in the lower half of the pump, above — and our next step must be to plug this leak, if our pump is to be very efficient!

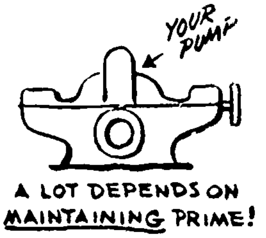
SO WE ADD WEARING RINGS TO PLUG INTERNAL LIQUID LEAKAGE . . .

You might ask why we didn't build our parts closer fitting in the first place — instead of narrowing the gap between them by inserting wearing rings.



The answer is that those rings are removable and *REPLACEABLE* . . . when wear enlarges the tiny gap between them and the impeller. (Sometimes rings are attached to impeller rather than casing — or rings are attached to *BOTH* so they face each other.)





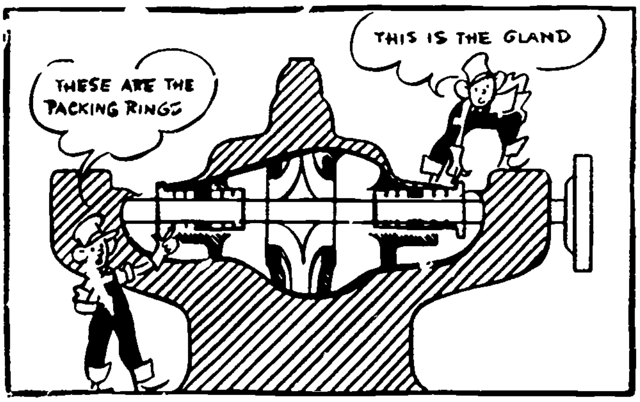
Maintenance Rule No. 7. *NEVER ALLOW A PUMP TO RUN DRY* (either through lack of proper priming when starting or through loss of suction when operating). Water is a *LUBRICANT* between rings and impeller.

Maintenance Rule No. 8. *EXAMINE WEARING RINGS AT REGULAR INTERVALS.* When seriously worn, their replacement will greatly improve pump efficiency.

TO KEEP AIR FROM BEING SUCKED IN, WE USE STUFFING BOXES . . .

We have two good reasons for wanting to keep air out of our pump: 1) we want to pump water, not air; 2) air leakage is apt to cause our pump to lose suction.

Each stuffing box we use consists of a casing, rings of packing and a gland at the outside end.



Maintenance Rule No. 9: *PACKING SHOULD BE REPLACED PERIODICALLY — DEPENDING ON CONDITIONS — USING THE PACKING RECOMMENDED BY YOUR PUMP MANUFACTURER.* Forcing in a ring or two of new packing instead of replacing worn packing is *BAD PRACTICE.* It's apt to displace the seal cage (see next column).

Put each ring of packing in separately, seating it firmly before adding the next. Stagger adjacent rings so the points where their ends meet do not coincide.

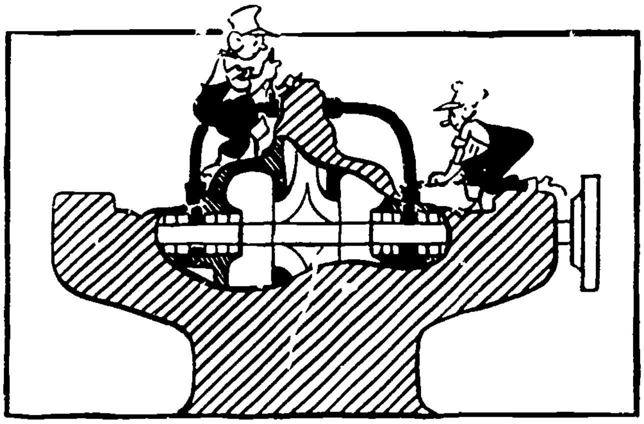
Maintenance Rule No. 10: *NEVER TIGHTEN A GLAND MORE THAN NECESSARY* . . . as excessive pressure will wear shaft sleeves unduly.

Maintenance Rule No. 11: *IF SHAFT SLEEVES ARE BADLY SCORED, REPLACE OR REPAIR THEM IMMEDIATELY* . . . or packing life will be entirely too short.

TO MAKE PACKING MORE AIR-TIGHT, WE ADD WATER SEAL PIPING . . .

In the center of each stuffing box is a "seal cage." By connecting it with piping to a point near the impeller rim, we bring liquid *UNDER PRESSURE* to the stuffing box.

This liquid acts both to block out air intake and to lubricate the packing. It makes both packing and shaft sleeves wear longer . . . *PROVIDING IT'S CLEAN LIQUID!*

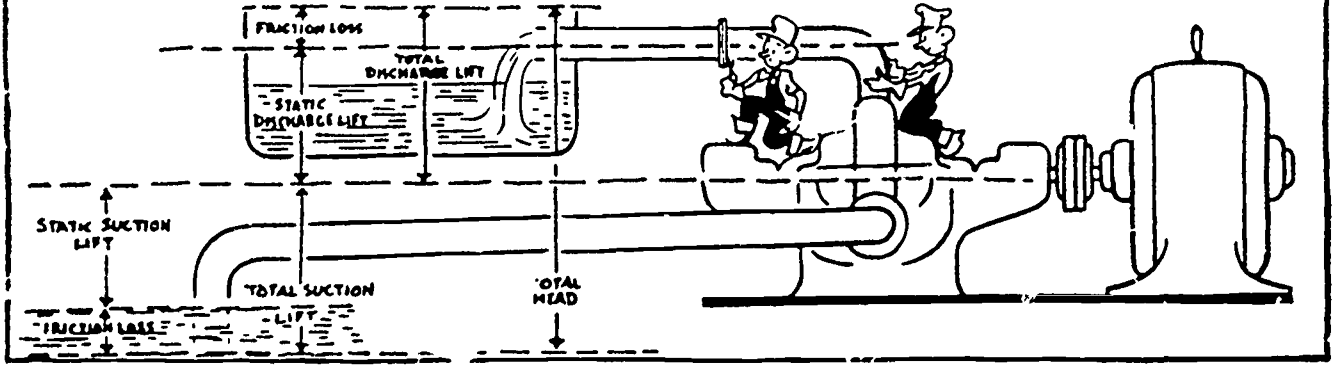


WATER IS A LUBRICANT!

Maintenance Rule No. 12: *IF THE LIQUID BEING PUMPED CONTAINS GRIT, A SEPARATE SOURCE OF SEALING LIQUID SHOULD BE OBTAINED* (e.g., it may be possible to direct some of the pumped liquid into a container and settle the grit out).

To control liquid flow, draw up the gland just tight enough so a *THIN* stream flows from the stuffing box during pump operation.

DISCHARGE PIPING COMPLETES THE PUMP INSTALLATION — AND NOW WE CAN ANALYZE THE VARIOUS FORCES WE'RE DEALING WITH . . .



SUCTION At least 75% of centrifugal pump troubles trace to the suction side. To minimize them . .

1. Total suction lift (distance between center line of pump and liquid level when pumping, plus friction losses) generally should not exceed 15 feet.
2. Piping should be at least a size larger than pump suction nozzle.
3. Friction in piping should be minimized . . use as few and as easy bends as possible . . . avoid scaled or corroded pipe.

DISCHARGE lift, plus suction lift, plus friction in the piping from the point where liquid enters the suction piping to the end of the discharge piping equals total head.

PUMPS SHOULD BE OPERATED NEAR THEIR RATED HEADS.

Otherwise, pump is apt to operate under unsatisfactory and unstable conditions which reduce efficiency and operating life of the unit.

Note the description of "cavitation" below — and directions for figuring the head your pumps are working against.

PUMP CAPACITY generally is measured in gallons per minute A new pump is guaranteed to deliver its rating in capacity and head.

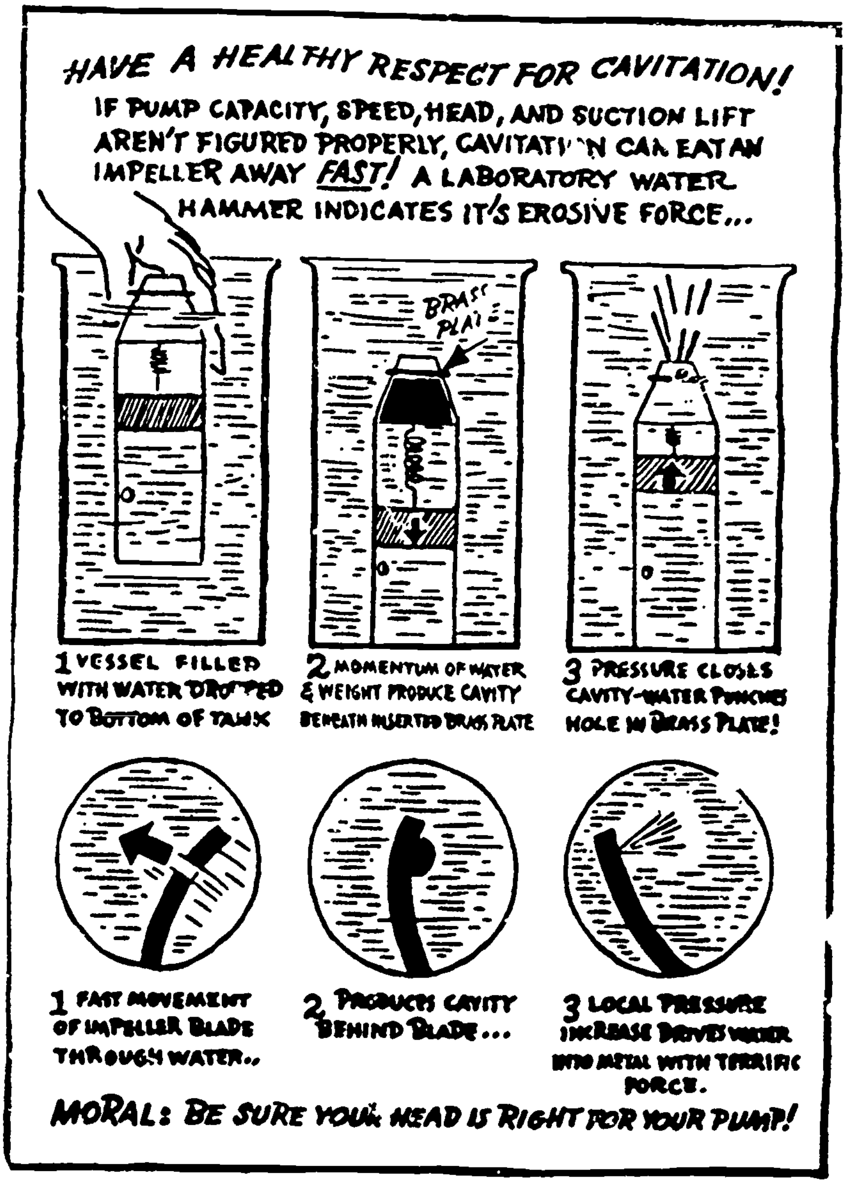
But whether a pump *RETAINS* its actual capacity depends to a great extent on its maintenance.

Wearing rings must be replaced when necessary — to keep internal leakage losses down.

Friction must be minimized in bearings and stuffing boxes by proper lubrication . . . and misalignment must not be allowed to force scraping between closely-fitted pump parts.

POWER of the driving motor, like capacity of the pump, will not remain at constant level without proper maintenance. (If you use electric motors, by all means send for Allis-Chalmers free "Guide to Care of Electric Motors!")

Starting load on motors can be reduced by throttling or closing the pump discharge valve (*NEVER* the suction valve!) . . but the pump must not be operated for long with the discharge valve closed. Power then is converted into friction — overheating the water with serious consequences.



Cavitation is a condition that can cause a drop in pump efficiency, vibration, noise and rapid damage to the impeller of a pump. Cavitation occurs due to unusually low pressures within a pump. These low pressures can develop when pump inlet pressures drop below the design inlet pressures or when the pump is operated at flow rates considerably higher than design flows. When the pressure within the flowing water drops very low, the water starts to boil and vapor bubbles form. These bubbles then collapse with great force which knocks metal particles off the pump impeller. This same action can and does occur on pressure reducing valves and partially closed gate and butterfly valves.

18.212 Horizontal Centrifugal Pumps

Horizontal centrifugal pumps, like the one we just constructed on paper in the last section, are available in a number of configurations. The one we built is best described as a single-stage, horizontal, double-suction, split-case centrifugal pump. The pump is a single-stage pump because it has only one impeller. Some horizontal pumps have two impellers that are working in series to create higher heads than can readily be obtained with only one impeller. Our paper pump was double suction in that water entered the impeller from both sides. The advantage of this design is that the longitudinal thrust from the water entering the impeller is balanced. This greatly reduces the thrust load that the pump's bearings must carry. The split case designation indicates that the pump case is made in two halves. Some centrifugal pumps have a single suction in line with the shaft. These are described as single stage end suction centrifugal pumps.

18.213 Vertical Centrifugal Pumps (Figures 18.16, 18.17 and 18.18)

Another common configuration for centrifugal pumps is the vertical suction cased centrifugal pump. This is an adaptation of the deep well turbine pump for booster pump service. They are very flexible in design as the engineers can specify either single or multi-stage in a wide variety of sizes and characteristics.

Besides the usual lubrication of the electric motor, the only routine maintenance required is to adjust and repair, as needed, the single packing gland.

18.214 Reciprocating or Piston Pumps

The word "reciprocating" means moving back and forth, so a reciprocating pump is one that moves a liquid by a piston that moves back and forth. A simple reciprocating pump is shown in Figure 18.19. If the piston is pulled to the left, Check Valve A will be open and the liquid will enter the pump and fill the casing. When the piston reaches the end of its travel to the left and is pushed back to the right, Check Valve A will close, Check Valve B will open, and the liquid will be forced out the exit line.

A piston pump is a positive-displacement pump. Never operate it against a closed discharge valve or the pump, valve, and/or pipe could be damaged by excessive pressures. Also, the suction valve should be open when the pump is started. Otherwise an excessive suction or vacuum could develop and cause problems.

18.215 Progressive Cavity (Screw-Flow) Pumps (Figure 18.20)

The progressive cavity pump consists of a screw-shaped rotor snugly enclosed in a non-moving stator or housing (Figure 18.21). The threads of the screw-like rotor (commonly manufactured of chromed steel) make contact along the

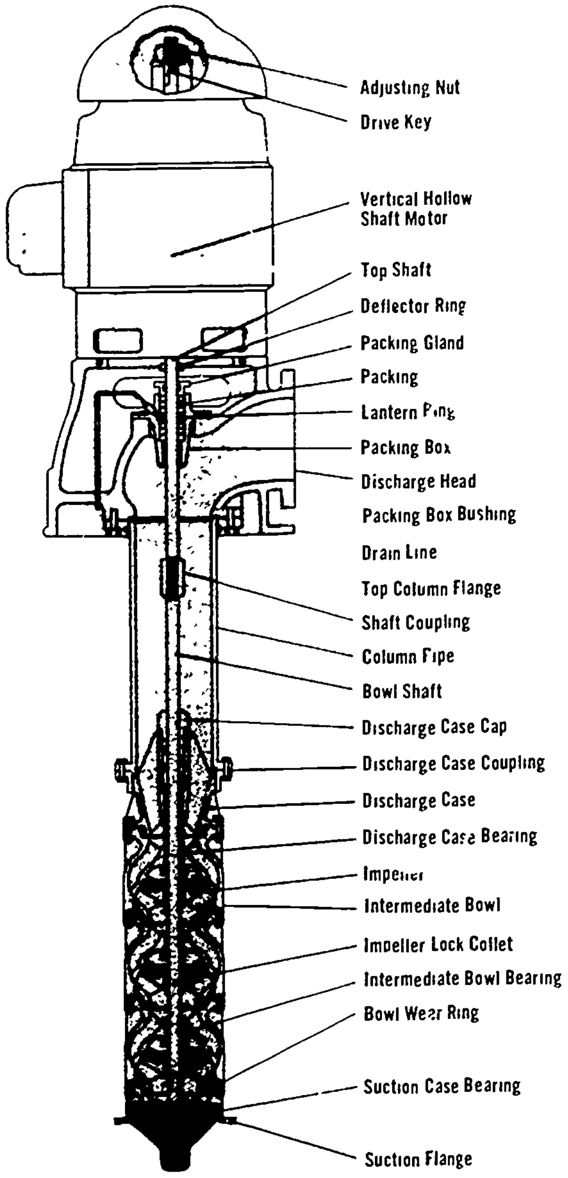


Fig. 18.16 Vertical centrifugal pump (multistage)
(Permission of Aurora Pump Company)

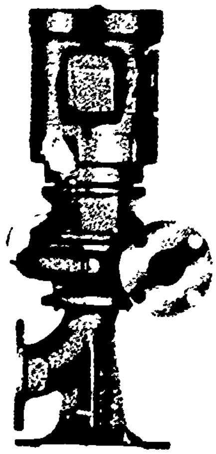


Fig. 18.17 Vertical centrifugal pump (single stage)
(Permission of Aurora Pump Company)

walls of the stator (usually made of synthetic rubber). The gaps between the rotor threads are called "cavities." When water is pumped through an inlet valve, it enters the cavity As the rotor turns, the material is moved along until it leaves the conveyor (rotor) at the discharge end of the pump. The size of the cavities along the rotor determines the capacity of the pump.

All progressive cavity pumps operate on the basic principle described above. To further increase capacity, some models have a shaped inside surface of the stator (housing) with a similarly shaped rotor. In addition, some models use a rotor that moves up and down inside the stator as well as turning on its axis (Figure 18.21). This allows a further increase in the capacity of the pump.

Progressive cavity pumps are recommended for materials which contain higher concentrations of suspended solids. They are commonly used to pump sludges. Progressive cavity pumps should NEVER be operated dry (without liquid in the cavities), nor should they be run against a closed discharge valve.

18.216 Chemical Metering Pumps

Many chemical metering pumps are a type of positive displacement pump For information on chemical metering pumps, see Chapter 13, Fluoridation, Section 13.30, "Chemical Feeders," and Section 18.4, "Chemical Feeders," in this Chapter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18.20A List the pieces of equipment and special tools commonly found in a pump repair shop.

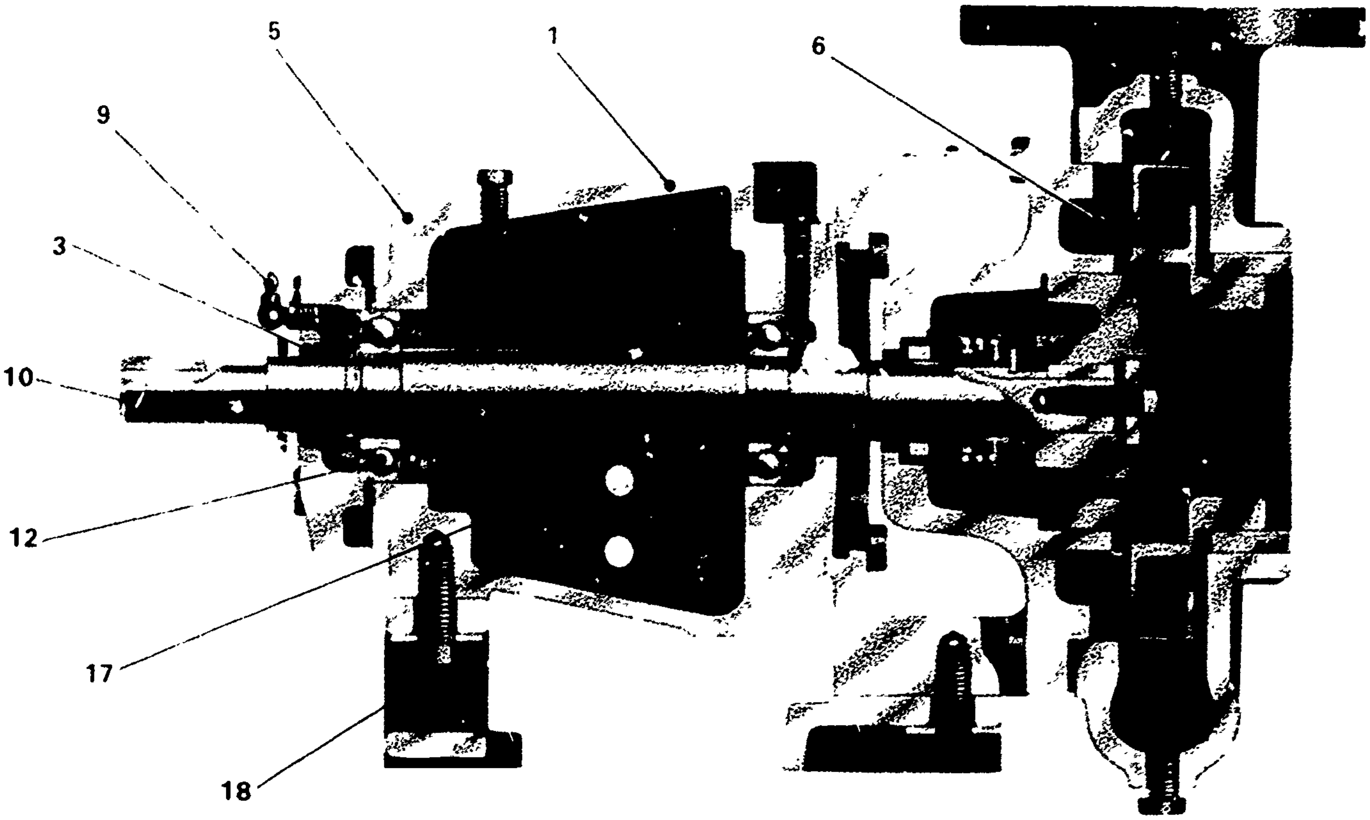
18.21A What is the purpose of a pump impeller?

18.21B Why should the intake end of suction piping have a suitable screen?

18.21C Why must suction piping always be up-sloping?

18.21D What is cavitation?

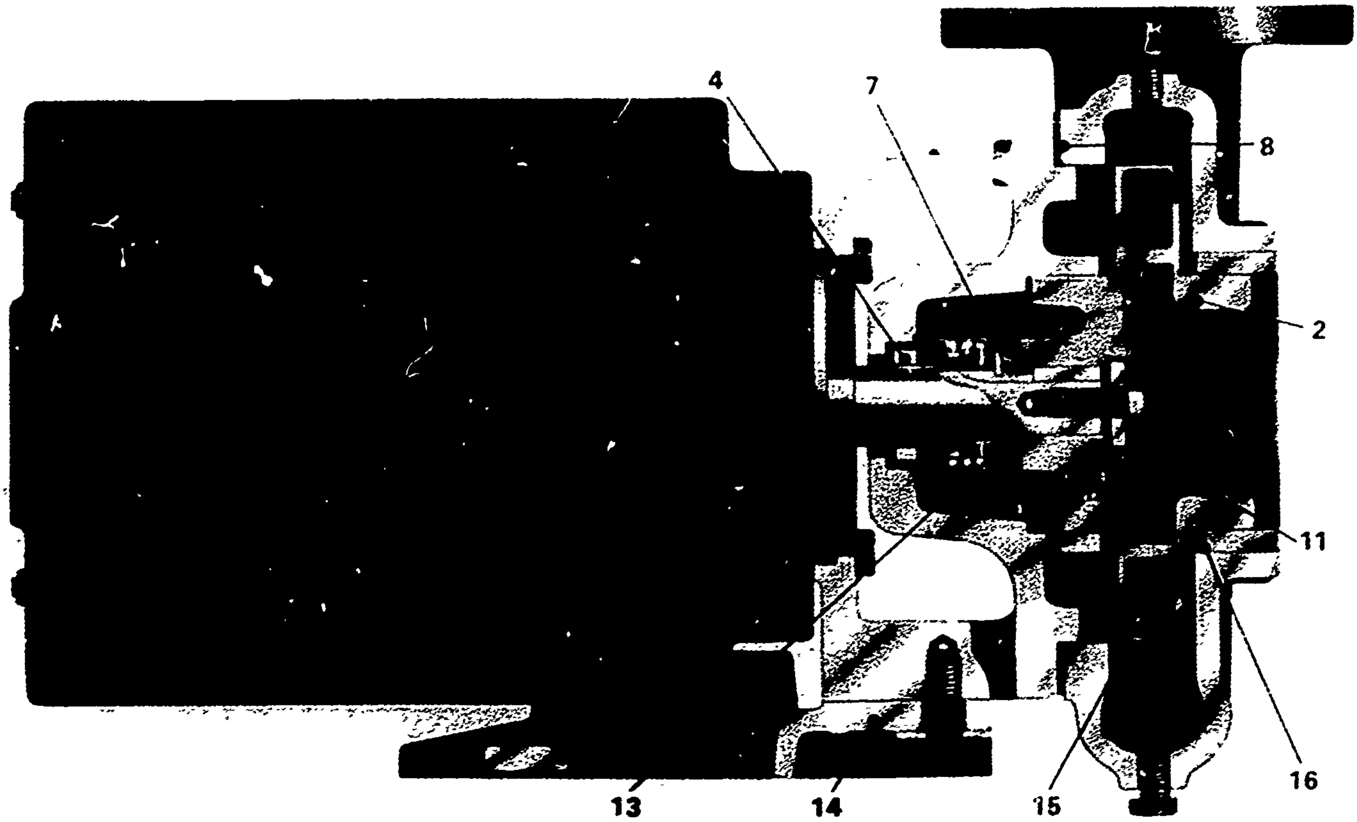
18.21E What is an advantage of having a *DOUBLE-SUCTION* pump over a *SINGLE-SUCTION* pump?



1. Motor frame
2. Impeller
3. Oil seal
4. Mechanical seal
5. Frame
6. Casing
7. Shaft sleeve
8. Back pull-out
9. Lubrication fittings
10. Shaft
11. Impeller
12. Bearings
13. Shaft sleeve
14. Close coupled motor support
15. Impeller
16. Wearing ring
17. Oil reservoir
18. Rear support foot

Fig. 18.18 Centrifugal pump parts

(Permission of Aurora Pump Company)



1. Motor frame
2. Impeller
3. Oil seal
4. Mechanical seal
5. Frame
6. Casing
7. Shaft sleeve
8. Back pull-out
9. Lubrication fittings
10. Shaft
11. Impeller
12. Bearings
13. Shaft sleeve
14. Close coupled motor support
15. Impeller
16. Wearing ring
17. Oil reservoir
18. Rear support foot

Fig. 18.18 Centrifugal pump parts (continued)

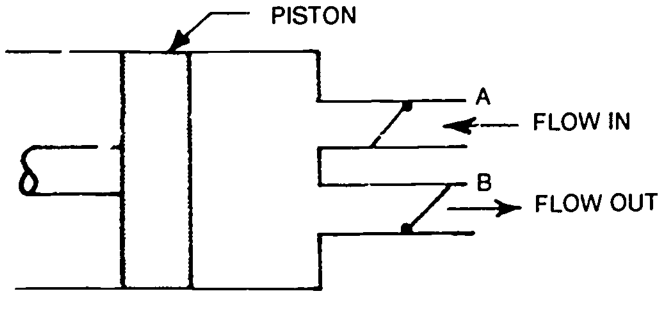


Fig. 18.19 Simple reciprocating pump

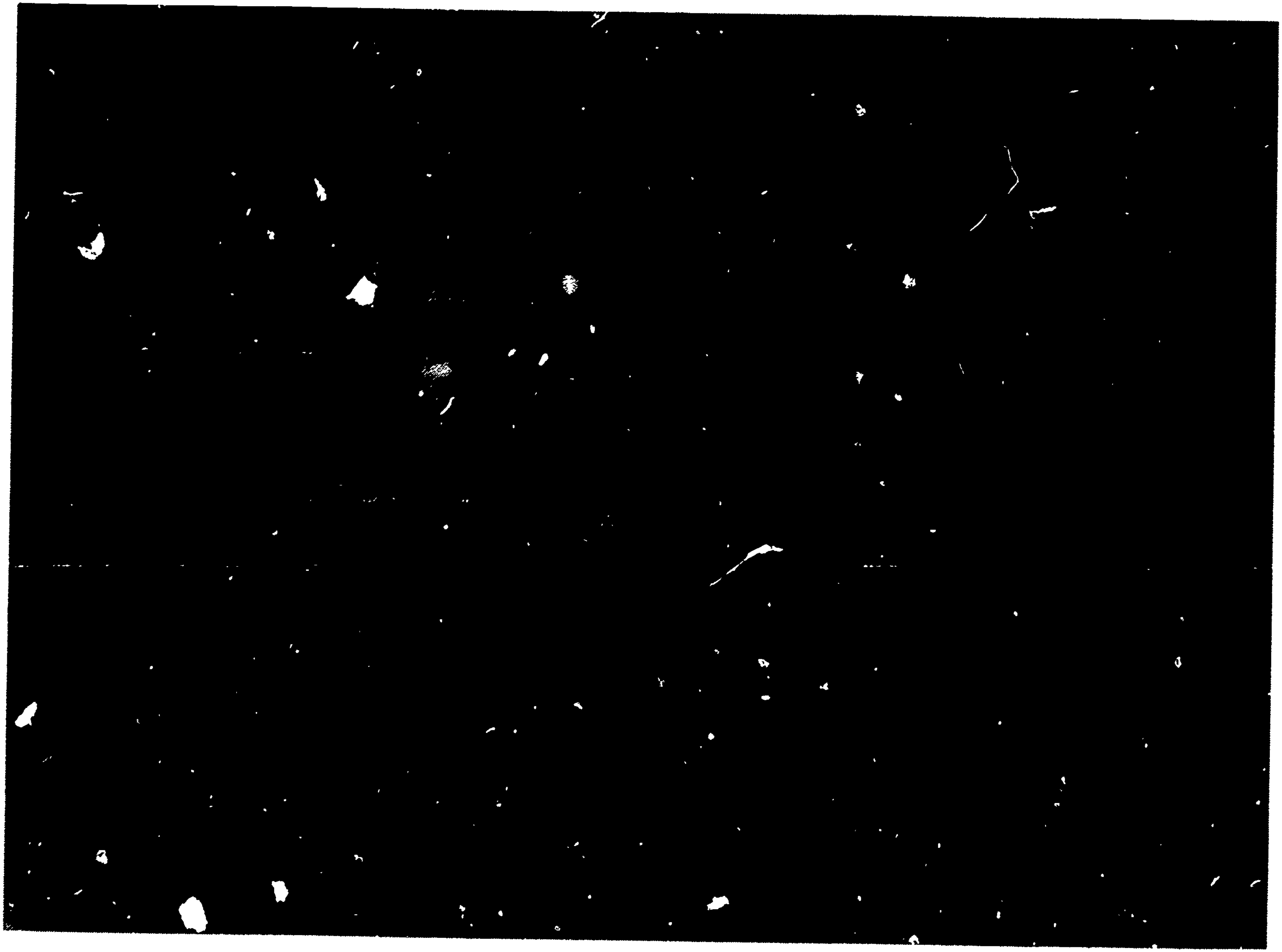


Fig. 18.20 Progressive cavity (screw-flow) pump
(Permission of Moyno Pump Division, Robbins & Meyer, Inc)

Pumping principle

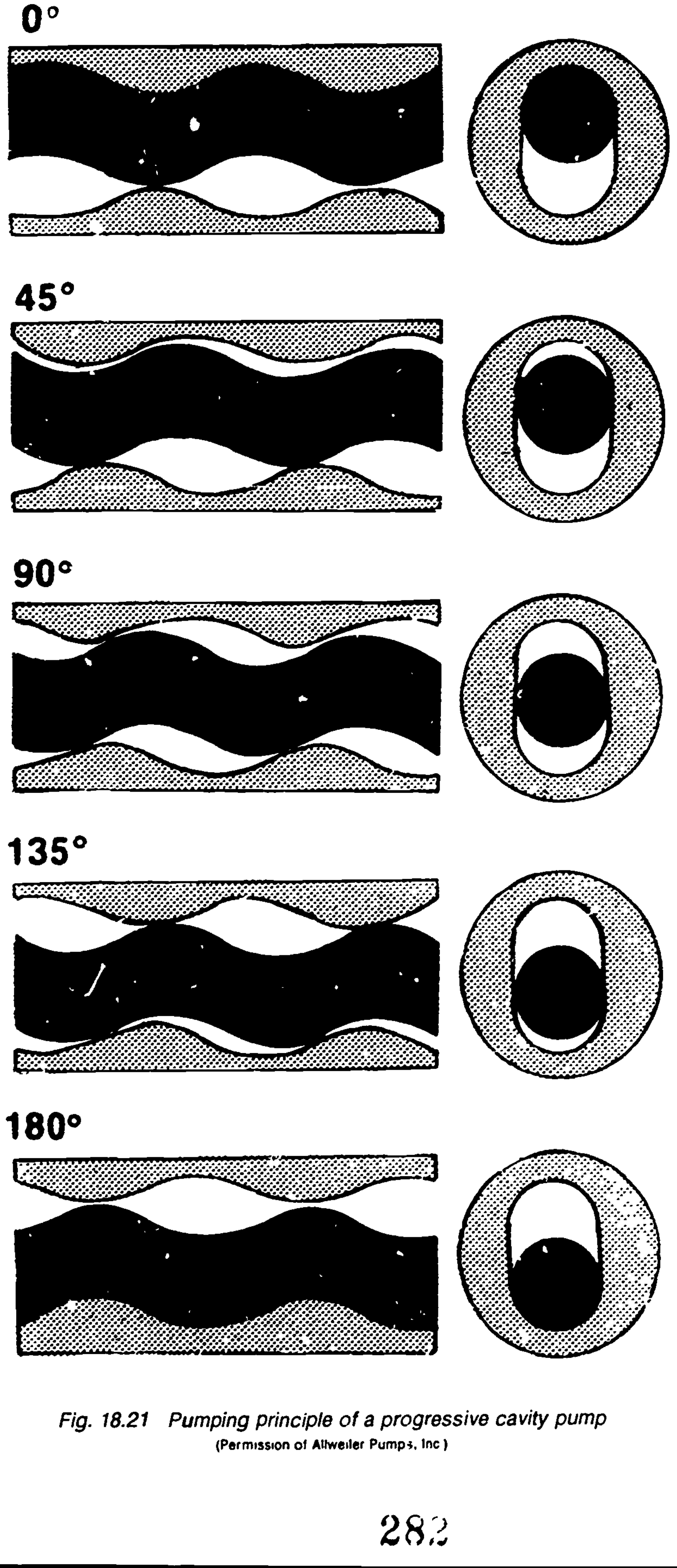


Fig. 18.21 Pumping principle of a progressive cavity pump
(Permission of Allweiler Pumps, Inc.)

18.22 Lubrication

18.220 *Purpose of Lubrication*

Lubrication of equipment is probably one of the most important phases of a maintenance operator's job. Without proper lubrication, the tools and equipment used for operating and maintaining water treatment plants would fail. Proper lubrication of tools and equipment is probably one of the maintenance operator's easiest jobs, but often it is the most neglected.

The purpose of lubrication is to reduce friction between two surfaces. Lubrication also removes heat that is caused by friction. Solid friction of two dry surfaces in contact is changed to a fluid friction of a separating layer of liquid or liquid lubricant. Actually, water is a lubricant, although not a good lubricant.

18.221 *Properties of Lubricants*

A good lubricant must have the following properties:

1. Form a slippery coating on contacting surfaces so they can slide freely past each other, and
2. Exert sufficient pressure to keep the surfaces apart when running.

To be a good lubricant for a particular job, the lubricant used must have the following qualities:

1. Thickness of the lubricant layer must be sufficient to keep the roughness of the metal parts from touching.
2. Lubricity (slipperiness) must be sufficient to allow molecules to slide freely past each other, and
3. Viscosity (resistance to flow) must be sufficient to build up a pressure necessary to keep the surfaces apart. If viscosity alone cannot provide enough pressure, an external pressure must be supplied by a pump.

Viscosity in the United States is the number of seconds it takes 60 cubic centimeters (cc) of an oil to flow through the standard orifice of a Saybolt Universal Viscometer at 100, 130, or 210 degrees Fahrenheit. A 300 - *SSU*[12] @ 130 oil means that it took 300 seconds for 60 cc to flow through a Saybolt Universal Viscometer at 130 degrees Fahrenheit. Viscosity decreases with temperature rise because oil becomes thinner The specific gravity of an oil is measured by comparing the weight of oil with an equal volume of water, both at 60 degrees Fahrenheit.

Some other important information to know about lubricants is their "Pour Point," "Flash Point," and "Fire Point." "Pour Point" is the temperature at which a lubricant refuses to run. This is important in low temperature work. "Flash Point" is the temperature at which oil vaporizes enough to ignite momentarily when near a flame. A low flash point means that oil evaporates more readily in service. "Fire Point" is the temperature at which oil vaporizes enough to keep on burning. Oils in service tend to become acid and may cause corrosion, deposits, sludging and other problems. This condition may not be visible when you look at the oil. Therefore, do not extend the time for an oil change because the oil looks clean.

To detect acid conditions in oils, the neutralization number of an oil is used. The neutralization number is the weight in milligrams of potassium hydroxide required to neutralize one gram of oil. This is used by laboratories which test the oil on large engines, turbines, compressors, and other equipment which have large volume oil reservoirs to determine when oil changes or additives are needed.

Most lubricants in general use are fluid at room temperature. Mostly, these are petroleum base, but others are used. Greases are mixtures of petroleum products with soaps such as lime, soda, aluminum, and metallic. Metallic soaps, forms of calcium, sodium, potassium, and lithium, have good retention in bearings and can withstand high temperatures and pressures. A sodium base grease has sodium as the soap mixed with the petroleum.

Solid materials such as graphite, finely ground mica, and yarn are sometimes used as lubricants. Some recently developed silicon compounds (silicones) work very well under heavy loads and widely varying temperatures.

There are many oil additives on the market today and they are worth investigating. Oil additives are chemical compounds added to an oil to improve certain chemical or physical properties such as stability, lubricity and foaming. They are used to prevent rust or deposits and many other items that could cause problems.

18.222 *Lubrication Schedule*

To have proper lubrication you must first set up a lubrication schedule. This can be a simple check-off sheet or card system or an elaborate computer system. The first thing to do is make a list of everything that needs lubrication down to the smallest item including chains, rollers, and sprockets. After you have listed every item on paper, go through the manufacturer's instruction books to determine the frequency and type of lubrication required. Is the frequency daily, weekly, monthly, semi-annual, or annually? The manufacturer's literature usually lists several different name brands of lubricants which are equal. If you need help determining the type of lubricant or cross-referencing it to your particular brand, contact your supplier. Most oil distributors have a service representative who will come to your facility and go over the individual equipment and specify which lubricants

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[12] *SSU. Standard Saybolt Units.*

you should use. Next, determine the amount of each lubricant required. This is achieved by counting the number of grease fittings Determine the locations of fill plugs, drain plugs, oil levels, sight glasses, dip sticks and other important items. To find these locations, physically inspect each piece of equipment thoroughly and look for all lubrication points. Also the manufacturer's maintenance manual should show the lubrication points for each piece of equipment.

When you have gathered all this information, transfer it to the equipment history cards for future reference. From this information you can make up a lubrication chart or form.

As stated earlier, use whatever type of lubrication form you prepare, but follow it. Always record each lubrication job when completed and have the operator who did the job initial the record card. Always keep your lubrication schedules up to date. If there are failures due to the wrong or insufficient lubricant, change or increase the lubrication frequency on the schedule. Also, new equipment must be added and discarded equipment removed from the schedule. Someone must be assigned to take care of the lubrication and records. Assign more than one operator or rotate this job so if an individual is off work or leaves the crew, there is a continuity in the lubrication schedule.

18.223 Precautions

When handling or storing oils and greases, some special precautions must be followed. Make sure the storage area does not create a fire hazard. Most all lubricants are highly flammable and shouldn't be stored where there is an open flame. "NO SMOKING" signs must be posted outside the building. Be sure to keep any spills wiped up and make sure that all the lids are tight on their containers.

Keep materials and containers clean. Sand, grit, and other substances can contaminate lube supplies and create an equipment failure that lubrication maintenance is intended to prevent. Another good idea is to direct the first shot of grease from a gun into a waste can.

18.224 Pump Lubrication

Pumps, motors, and drives should be oiled and greased in strict accordance with the recommendations of the manufacturer. Cheap lubricants may often be the most expensive in the end. Oil should not be put in the housing while the pump shaft is rotating because the rotary action of the ball bearings will pick up and retain a considerable amount of oil When the unit comes to rest, an overflow of oil around the shaft or out of the oil cup will result.

Greased bearings should be lubricated as follows:

1. Shut off the unit if moving parts that might be a safety hazard are close to the grease fitting or drain plugs.
2. Remove the drain plug from the bearing housing.
3. Remove the grease fitting protective cap and wipe off the grease fitting. Be sure that you do not force dirt into the bearing housing along with the clean grease.
4. Pump in clean grease until the grease coming out of the drain hole is clean. Don't pump grease into a bearing with the drain plug in place. This could easily build up enough pressure to blow out the seals.
5. Put the protective cap back on the grease fitting.
6. With the drain plug still removed, put the unit back in service. As the bearing warms up, excess grease will be expelled from the drain hole. After the unit has been running for a few hours, the drain plug may be put back in place. Special drain plugs with spring loaded check valves are recommended because they will protect against further buildup.
7. Unless you intend to be very careful, we recommend that bearing grease be purchased in cartridge form to minimize the chance of getting dirt into the lubricant.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18.22A What is the purpose of lubrication?

18.22B What happens to oils in service?

18.22C What should be done to insure proper lubrication of equipment?

18.225 Equipment Lubrication

Different authorities may make conflicting lube recommendations for essentially the same item; however, general reference material is available to help select the correct lubricant for a specific application.

Grease is graded on a number scale, or viscosity index, by the National Lubricating Grease Institute. For example, No. 0 is very soft.; No. 6 is quite stiff. A typical grease for most treatment plant applications might be a No. 2 lithium or sodium compound grease, which is used for operating temperatures up to 250°F (120°C).

Generally, the time between flushing and repacking for greased bearings should be divided by 2 for every 25°F (15°C) above 150°F (65°C) operating temperature. Also, generally, the time between lubrications should not be allowed to exceed 48 months, since lube component separation and oxidation can become significant after this period of time, regardless of amount of use.

Another point worth noting is that grease is normally not suitable for moving elements with speeds exceeding 12 000 in./min (5 m/s). Usually, oil-lubricating systems are used for higher speeds. Lighter viscosity oils are recommended for high speeds, and, within the same speed and temperature range, a roller bearing will normally require one grade heavier viscosity than a ball bearing.

A good rule of thumb is to change and flush oil completely at the end of 600 hours of operation or 3 months, whichever occurs first. More specific procedures for flushing and changing lubricants are outlined by most equipment manufacturers.

Every operator should be aware of the dangers of overfilling with either grease or oil. Overfilling can result in high pressures and temperatures, and ruined seals or other components. It has been observed that more antifriction bearings are ruined by over-greasing than by neglect.

A thermometer can tell a great deal about the condition of a bearing. Ball bearings are generally in trouble above 180°F (80°C). Grease-packed bearings typically run 10 to 50 degrees above ambient.

For clarifier drive units, which are almost always located outdoors, condensation presents a dangerous problem for the lubrication system. Most units of current design have a condensate bailing system to remove water from the gear housing by displacement. These units should be checked often for proper operation, particularly during seasons of wide air temperature fluctuation.

Pumps incorporate many types of seals and gaskets constructed of combinations of elastomers and metals. As for lubricants, conflicting advice can be obtained. A file containing data on general properties of materials used can help in the choice of lubricant.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 324.

18.22D Does a soft grease have a high or low viscosity index as compared with a hard grease?

18.22E Is oil or grease used with higher speeds?

18.22F What problems can result from overfilling with oil or grease?

End of Lesson 2 of 5 Lessons on MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 3.

DISCUSSION AND REVIEW QUESTIONS

Chapter 18. MAINTENANCE

(Lesson 2 of 5 Lessons)

Write your answers to these questions in your notebook before continuing. The question numbering continues from Lesson 1.

13. What is the purpose of a pump shaft?
14. What is the purpose of pump sleeves?
15. Why should a pump never be allowed to run dry?
16. How would you develop a lubrication schedule for a pump?
17. Why is cleanliness important in the storing and use of lubricants?

CHAPTER 18. MAINTENANCE

(Lesson 3 of 5 Lessons)

18.23 Pump Maintenance

18.230 Section Format

The format of this section differs from the other chapters. This format was designed specifically to assist you in planning an effective preventive maintenance program. The paragraphs are numbered for easy reference when you use the Equipment Service Cards and Service Record Cards mentioned in Section 18.00, page 219, and shown in Figure 18.1.

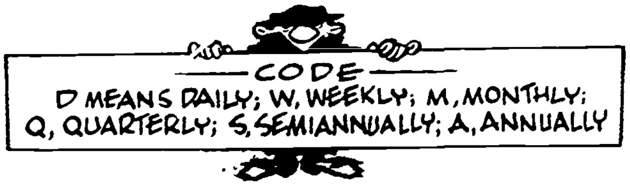
An entire book could be written on the topics covered in this section. Step-by-step details for maintaining equipment are not provided because manufacturers are continually improving their products and these details could soon be out of date. You are assumed to have some familiarity with the equipment being discussed. *FOR DETAILS CONCERNING A PARTICULAR PIECE OF EQUIPMENT, YOU SHOULD CONTACT THE MANUFACTURER.* This section indicates to you the kinds of maintenance you should include in your program and how you could schedule your work. Carefully read the manufacturer's instructions and be sure you clearly understand the material before attempting to maintain and repair equipment. If you have any questions or need any help, do not hesitate to contact the manufacturer or your local representative.

A glossary is not provided in this section because of the large number of technical words that require familiarization with the equipment being discussed. The best way to learn the meaning of these new words is from manufacturers' literature or from their representatives. Some new words are described in the lessons where necessary.

18.231 Preventive Maintenance

The following paragraphs list some general preventive maintenance services and indicate frequency of performance. There are many makes and types of equipment and the wide variation of functions cannot be included; therefore, you will have to use some judgment as to whether the services and frequencies will apply to your equipment. If something goes wrong or breaks in your plant, you may have to disregard your maintenance schedule and fix the problem now.

NOTE: If you need to shut a unit down, make sure it is also locked out and tagged properly. (Figure 18.22)



CODE

D MEANS DAILY; W, WEEKLY; M, MONTHLY; Q, QUARTERLY; S, SEMIANNUALLY; A, ANNUALLY

Paragraph 1: Pumps, General

This paragraph lists some general preventive maintenance services and indicates frequency of performance. Typical centrifugal pump sections are shown in Figure 18.18.

Frequency of Service	
D	1. CHECK WATER-SEAL PACKING GLANDS FOR LEAKAGE. See that the packing box is protected with a clear-water supply from an outside source, make sure that water seal pressure is at least 5 psi (35 kPa or 0.35 kg/sq cm) greater than maximum pump suction pressure. See that there are no *CROSS-CONNECTIONS.*[13] Check packing glands for leakage during operation. Allow a slight seal leakage when pumps are running to keep packing cool and in good condition. The proper amount of leakage depends on equipment and operating conditions. Sixty drops of water per minute is a good rule-of-thumb. If excessive leakage is found, HAND TIGHTEN glands' nuts evenly, but not too tight. After adjusting packing glands, be sure shaft turns freely by hand. If serious leakage continues, renew packing, shaft, or shaft sleeve.
D	2. CHECK GREASE-SEALED PACKING GLANDS. When grease is used as a packing gland seal, maintain constant grease pressure on packing during operation. When a spring-loaded grease cup is used, keep it loaded with grease. Force grease through packing at a rate of about one ounce (30 gm) per day. When water is used, adjust seal pressure to 5 psi (35 kPa or 0.35 kg/sq cm) above maximum pump suction pressure. Never allow the seal to run dry.
W	3. OPERATE PUMPS ALTERNATELY. If two or more pumps of the same size are installed, alternate their use to equalize wear, keep motor windings dry, and distribute lubricant in bearings.

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[13] *Cross-Connection. A connection between a drinking (potable) water system and an unapproved water supply For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.*

DANGER

MAN
WORKING
ON LINE

DO NOT CLOSE THIS
SWITCH WHILE THIS
TAG IS DISPLAYED

SIGNATURE ______________________________

This is the ONLY person authorized to remove this tag

NOTE: Tag also should include: TIME OFF ____________
DATE ____________

Fig. 18.22 Typical warning tag

(Source: Industrial Indemnity/Industrial Underwriters/Insurance Cos.)

Frequency of Service	
W	4. INSPECT PUMP CONTROL. Inspect the pump controls to see that the pump responds properly to changes in the controlling variable. This variable may be either a pressure or a water level. This check could be done physically or by analyzing recording gage records.
D	5. CHECK MOTOR CONDITION. See Paragraph 6: Electric Motors.
W	6. CHECK PACKING GLAND ASSEMBLY. Check packing gland, the unit's most abused and troublesome part. If stuffing box leaks excessively when gland is pulled up with mild pressure, remove packing and examine shaft sleeve carefully. Replace or repair grooved or scored shaft sleeve because packing cannot be held in stuffing box with roughened shaft or shaft sleeve. Replace the packing a strip at a time, tamping each strip thoroughly and staggering joints. (See Fig. 18.23.) Position lantern ring (water-seal ring) properly. If grease sealing is used, completely fill lantern ring with grease before putting remaining rings of packing in place. The type of packing used (Fig. 18.24) is less important than the manner in which packing is placed. Never use a continuous strip of packing. This type of packing wraps around and scores the shaft sleeve or is thrown out against outer wall of stuffing box, allowing water to leak through and score the shaft. The proper size of packing should be available in your plant's equipment files. See Fig. 18.25 for illustrated steps on how to pack a pump.

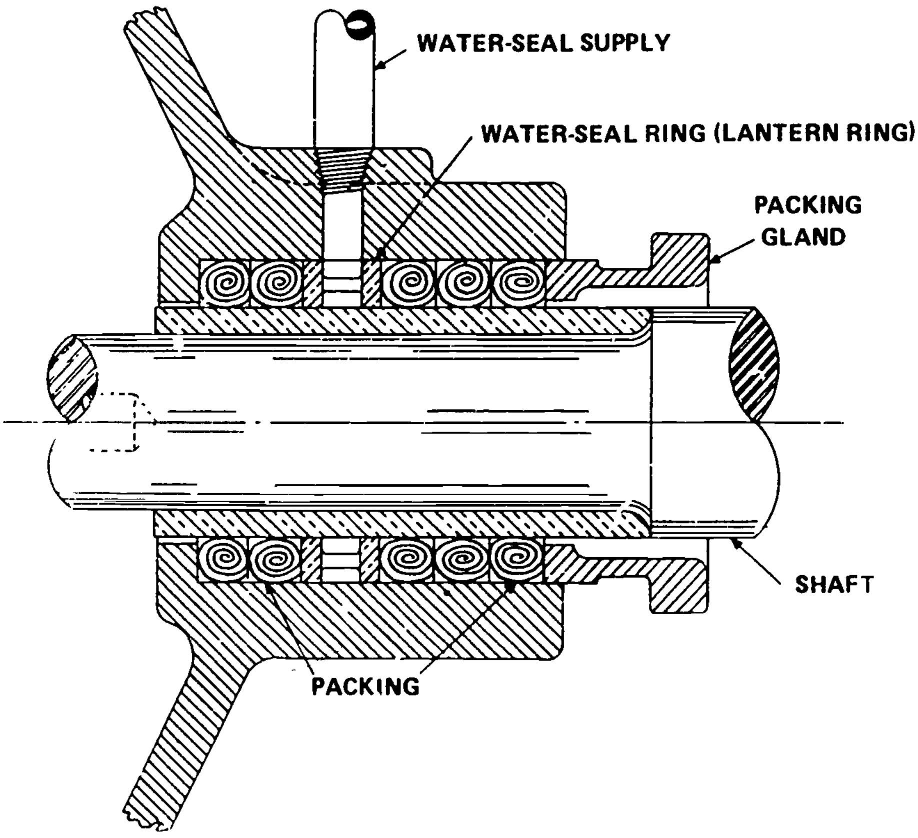
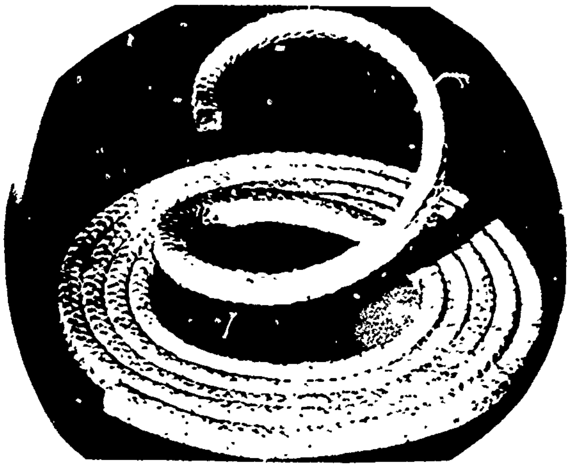
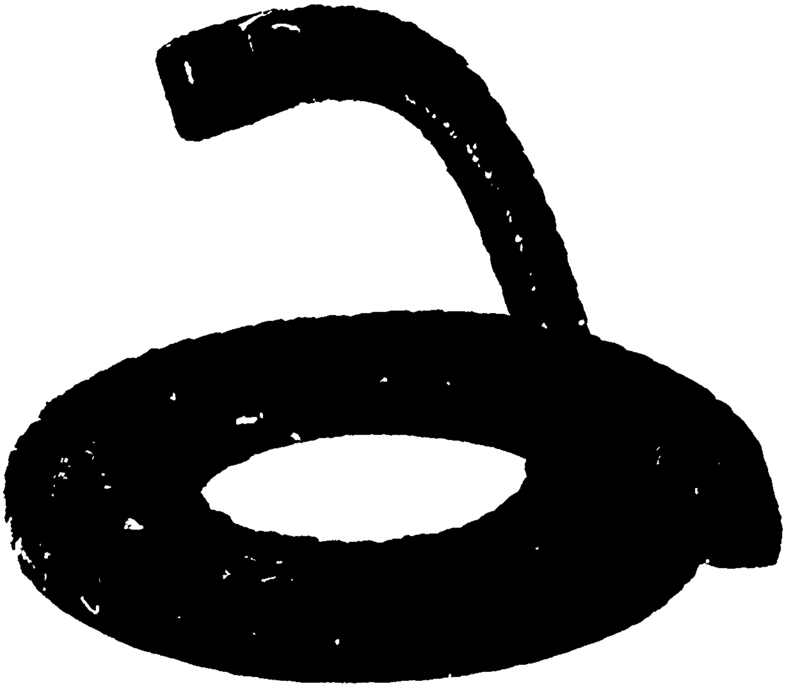


Fig. 18.23 Method of packing shaft
(Source War Department Technical Manual TM5-666)

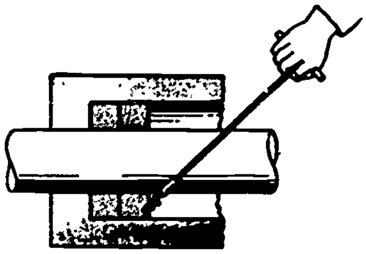


Teflon Packing

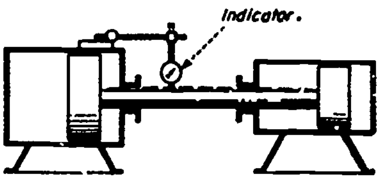


Graphite Packing

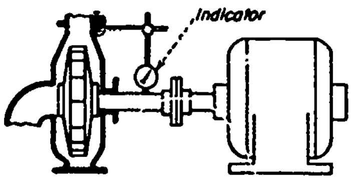
Fig. 18.24 Packing
(Courtesy A W Chesteron Co)



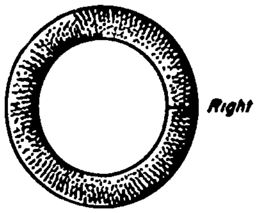
1 Remove *all* old packing. Aim packing hook at bore of the box to keep from scratching the shaft. Clean box thoroughly so the new packing won't hang up



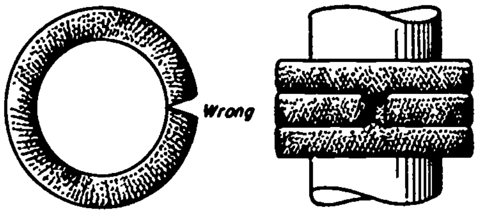
2 Check for bent rod, grooves or shoulders. If the neck bushing clearance in bottom of box is great, use stiffer bottom ring or replace the neck bushing



3 Revolve rotary shaft. If the indicator runs out over 0.003-in., straighten shaft, or check bearings, or balance rotor. Gyrating shaft beats out packing



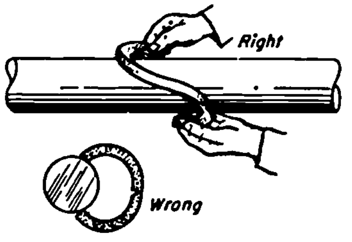
6 Cutting off rings while packing is wrapped around shaft will give you rings with parallel ends. This is very important if packing is to do job



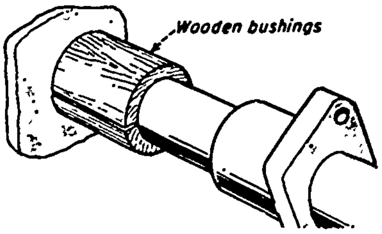
7 If you cut packing while stretched out straight, the ends will be at an angle. With gap at angle, packing on either side squeezes into top of gap and ring, cannot close. This brings up the question about gap for expansion. Most packings need none. Channel-type packing with lead core may need slight gap for expansion

HOW TO PACK A PUMP

(*Editor's Note:* This step-by-step illustration of a basic maintenance duty was brought to our attention by Anthony J. Zigment, Director, Municipal Training Division, Department of Community Affairs.)



11 Open ring joint sidewise, especially lead-filled and metallic types. This prevents distorting molded circumference—breaking the ring opposite gap



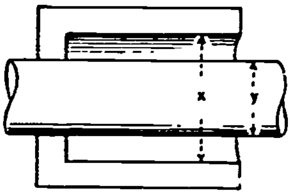
12 Use split wooden bushing. Install first turn of packing, then force into bottom of box by tightening gland against bushing. Seat each turn this way

Cross expansion | Sectional | Diagonal

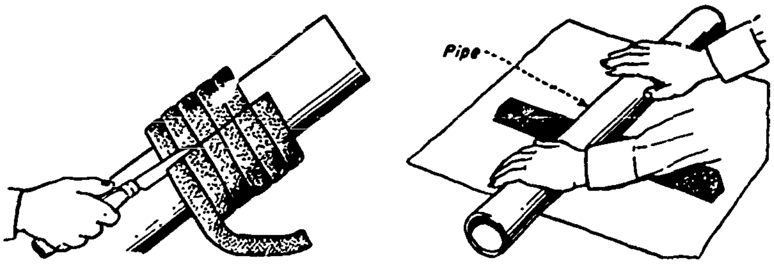
15 Always install cross-expansion packing so plies slope toward the fluid pressure from housing. Place sectional rings so slope between inside and outside ring is toward the pressure. Diagonal rings must also have slope toward the fluid pressure. Watch these details for best results when installing new packing in a box

Fig. 18.25 How to pack a pump

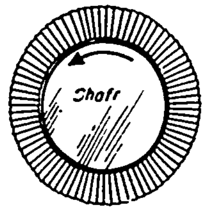
(Source Water Pollution Control Association of Pennsylvania Magazine, January-February, 1976)



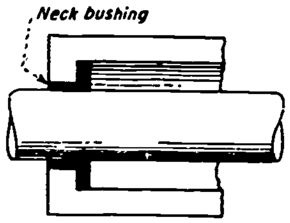
4 To find the right size of packing to install, measure stuffing-box bore and subtract rod diameter, divide by 2. Packing is too critical for guesswork.



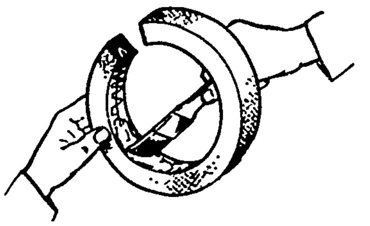
5 Wind packing, needed for filling stuffing box, snugly around rod (for same size shaft held in vise) and cut through each turn while coiled, as shown. If the packing is slightly too large, never flatten with a hammer. Place each turn on a clean newspaper and then roll out with pipe as you would with a rolling pin



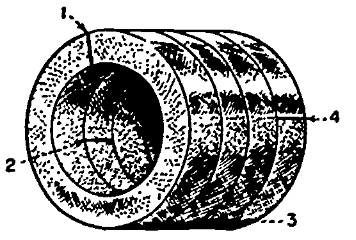
8 Install foil-wrapped packing so edges on inside will face direction of shaft rotation. This is a must; otherwise, thin edges flake off, reduce packing life



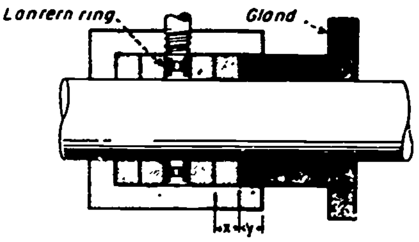
9 Neck bushing slides into stuffing box. Quick way to make it is to pour soft bearing metal into tin can, turn and bore for sliding fit into place



10 Swabbing new metallic packings with lubricant supplied by packing maker is OK. These include foil types, lead-core, etc. If the rod is oily, don't swab it



13 Stagger joints 180 degrees if only two rings are in stuffing box. Space at 120 degrees for three rings, or 90 degrees if four rings or more are in set



14 Install packing so lantern ring lines up with cooling-liquid opening. Also, remember that this ring moves back into box as packing is compressed. Leave space for gland to enter as shown. Tighten gland with wrench—back off finger-tight. Allow the packing to leak until it seats itself, then allow a slight operating leakage

Hydraulic-packing pointers

First, clean stuffing box, examine ram or rod. Next, measure stuffing-box depth and packing set—find difference. Place ⅛-in. washers over gland studs as shown. Lubricate ram and packing set (if for water). If you can use them, endless rings give about 17% more wear than cut rings. Place male adapter in bottom, then carefully slide each packing turn home—don't harm lips. Stagger joints for cut rings. Measure from top of packing to top of washers, then compare with gland. Never tighten down new packing set until all air has chance to work out. As packing wears, remove one set of washers, after more wear, remove other washer.

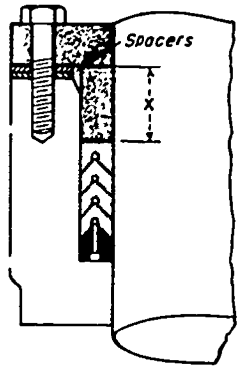


Fig. 18.25 How to pack a pump (continued)

Frequency of Service

If a bronze shaft sleeve is not too badly scored, the shaft sleeve can be restored to service. The repair procedure consists of turning the sleeve down to a uniform diameter with a rough cut. Then spray the sleeve with stainless steel to a slightly oversized outside diameter followed by machining and polishing to bring the sleeve back to its original diameter. You will probably find that these reworked sleeves will outlast the originals.

W 7. CHECK MECHANICAL SEALS. Mechanical seals usually consist of two sub-assemblies: (1) a rotating ring assembly, and (2) a stationary assembly.

Inspect seal for leakage and excessive heat. If any part of the seal needs replacing, replace the entire seal (both sub-assemblies) with a new seal that has been provided by the manufacturer. Before installing a new seal, be sure that there are no chips or cracks on the carbide sealing surface. Keep a new mechanical seal clean at all times

Always be sure that a mechanical seal is surrounded with water before starting and running the pump.

Q 8. INSPECT AND LUBRICATE BEARINGS. Unless otherwise specifically directed for a particular pump model, lubricate according to the procedures covered in Section 18.224, page 263. Check sleeve bearings to see that oil rings turn freely with the shaft. Repair or replace if defective.

Measure sleeve bearings and replace those worn excessively. Generally, allow clearance of 0.002 inch plus 0.001 inch for each inch or fraction of inch of shaft-journal diameter.

Q 9. CHECK OPERATING TEMPERATURE OF BEARINGS. Check bearing temperature with thermometer, not by hand. If antifriction bearings are running hot, check for over-lubrication and relieve if necessary If sleeve bearings run too hot, check for lack of lubricant. If proper lubrication does not correct condition, disassemble and inspect bearing. Check alignment of pump and motor if high temperatures continue.

S 10. CHECK ALIGNMENT OF PUMP AND MOTOR. For method of aligning pump and motor, see Paragraph 10: Couplings. If misalignment recurs frequently, inspect entire piping system. Unbolt piping at suction and discharge nozzles to see if it springs away, indicating strain on casing. Check all piping supports for soundness and effective support of load.

Vertical pumps usually have flexible shafting which permits slight angular misalignment; however, if solid shafting is used, align exactly. If beams carrying intermediate bearings are too light or are subject to contraction or expansion, replace beams and realign intermediate bearings carefully.

S 11 INSPECT AND SERVICE PUMPS.

a Remove rotating element of pump and inspect thoroughly for wear. Order replacement parts where necessary. Check impeller clearance between volute

b. Remove any deposit or scaling. Clean out water-seal piping.

c. Determine pump capacity by pumping into empty tank of known size or by timing the draining of pit or sump.

$$\text{Pump Capacity, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

or

$$\text{Pump Capacity, } \frac{\text{liters}}{\text{sec}} = \frac{\text{Volume, liters}}{\text{Time, seconds}}$$

See EXAMPLE 1 for procedures on how to calculate pump capacity.

d. Test pump efficiency. Refer to pump manufacturer's instructions on how to collect data and perform calculations. Also see pages 147 and 148 in *SMALL WATER SYSTEM OPERATION AND MAINTENANCE* of this series of manuals.

e. Measure total dynamic suction head or lift and discharge head to test pump and pipe condition. Record figures for comparison with later tests.

f. Inspect foot and check valves, paying particular attention to check valves, which can cause water hammer when pump stops. (See Paragraph 13: Check Valves also.) Foot valves are a type of check valve which are used when pumping raw water.

g. Examine wearing rings. Replace seriously worn wearing rings to improve efficiency. Check wearing ring clearances which generally should be no more than 0.003 inch per inch of wearing diameter.

CAUTION: To protect rings and castings, never allow pump to run dry through lack of proper priming when starting or loss of suction when operating.

A 12. DRAIN PUMP FOR LONG-TERM SHUTDOWN. When shutting down pump for a long period, open motor disconnect switch; and if so equipped, turn on the electric motor winding heaters. Shut all valves on suction, discharge, water-seal, and priming lines; drain pump completely by removing vent and drain plugs. This procedure protects pump against corrosion, sedimentation, and freezing. Inspect pump and bearings thoroughly and perform all necessary

Frequency of Service

servicing. Drain bearing housings and replenish with fresh oil, purge old grease and replace. When a pump is out of service, run it monthly to warm it up and to distribute lubrication so the packing will not "freeze" to the shaft. Resume periodic checks after pump is put back in service.

FORMULAS

To find the volumes of a rectangle in cubic feet, multiple the length times width times depth.

Volume, cu ft = (Length, ft) (Width, ft) (Depth, ft)

To find the volume of a cylinder in cubic feet, multiply 0.785 times the diameter squared times the depth.

Volume, cu ft = (0.785) (Diameter, ft)^2 (Depth, ft)

To convert a volume from cubic feet to gallons, multiply the volume in cubic feet times 7.48 gallons per cubic foot.

Volume, gal = (Volume, cu ft) (7.48 gal/cu ft)

To calculate the output or capacity of a pump in gallons per minute, divide the volume pumped in gallons by the pumping time in minutes.

$$\text{Pump Capacity, GPM} = \frac{\text{Volume Pumped, gallons}}{\text{Pumping Time, minutes}}$$

EXAMPLE 1

A pump's capacity is measured by recording the time in minutes for water to rise 3 feet in an 8-foot diameter tank. What is the pumping rate or capacity in gallons per minute when the pumping time is 9 minutes?

Known	Unknown
Diameter, ft = 8 ft	Pump Capacity, GPM
Depth, ft = 3 ft	
Time, min = 9 min	

Calculate the tank volume in cubic feet.

$$\begin{aligned}\text{Volume, cu ft} &= (0.785)\ (\text{Diameter, ft})^2\ (\text{Depth, ft})\\ &= (0.785)\ (8\ \text{ft})^2\ (3\ \text{ft})\\ &= 151\ \text{cu ft}\end{aligned}$$

Convert the tank volume from cubic feet to gallons.

$$\begin{aligned}\text{Volume, gal} &= (\text{Volume, cu ft})\ (7.48\ \text{gal/cu ft})\\ &= (151\ \text{cu ft})\ (7.48\ \text{gal/cu ft})\\ &= 1129\ \text{gallons}\end{aligned}$$

Calculate the pump capacity in gallons per minute.

$$\begin{aligned}\text{Pump Capacity, GPM} &= \frac{\text{Volume Pumped, gal}}{\text{Pumping Time, min}}\\ &= \frac{1129\ \text{gallons}}{9\ \text{min}}\\ &= 125\ \text{GPM}\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.23A What is a cross-connection?

18.23B Is a slight water-seal leakage desirable when a pump is running? If so, why?

18.23C How would you measure the capacity of a pump?

18.23D Estimate the capacity of a pump (in GPM) if it lowers the water in a 10-foot wide by 15-foot long wet well 1.7 feet in five minutes.

18.23E What should be done to a pump before it is shut down for a long time, and why?

Paragraph 2: Reciprocating Pumps, General

The general procedures in this paragraph apply to all reciprocating pumps described in this section.

Frequency of Service

W 1. CHECK SHEAR PIN ADJUSTMENT. Set eccentric by placing shear pin through proper hole in eccentric flanges to give required stroke. Tighten the two ⅝- or ⅞-inch hexagonal nuts on connecting rods just enough to take spring out of lock washers. (See Paragraph 11: Shear Pins). When a shear pin fails, eccentric moves toward neutral position, preventing damage to the pump. Remove cause of obstruction and insert new shear pin. Shear pins fail because of one of three common causes:

(1) Solid object lodged under piston,

(2) Clogged discharge line, and

(3) Stuck or wedged valve.

D 2. CHECK PACKING ADJUSTMENT. Give special attention to packing adjustment. If packing is too tight, it reduces efficiency and scores piston walls. Keep packing just tight enough to keep sludge from leaking through gland. Before pump is installed or after it has been idle for a time, loosen all nuts on packing gland. Run pump with sludge suction line closed and valve covers open for a few minutes to break in the packing. Turn down gland nuts no more than necessary to prevent sludge from getting past packing. Tighten all packing nuts uniformly.

When packing gland bolts cannot be taken up farther, remove packing. Remove old packing and thoroughly clean cylinder and piston walls. Place new packing into cylinder, staggering packing-ring joints, and tamp each ring into place. Break in and adjust packing as explained above. When chevron type packing is used, tighten gland nuts only finger tight because excessive pressure ruins packing and scores plunger.

Q 3. CHECK BALL VALVES. When valve balls are so worn that diameter is ⅝ inch (1.5 cm) smaller than original size, they may jam into

Frequency of Service

guides in valve chamber. Check size of valve balls and replace if badly worn.

Q 4. CHECK VALVE-CHAMBER GASKETS. Valve-chamber gaskets on most pumps serve as a safety device and blow out under excessive pressure. Check gaskets and replace if necessary. Keep additional gaskets on hand for replacement.

A 5. CHECK ECCENTRIC ADJUSTMENT. To take up babbitt bearing, remove brass shims provided on connecting rod. After removing shims, operate pump for at least one hour and check to see that eccentric does not run hot.

D 6. NOTE UNUSUAL NOISES. Check for noticeable water hammer when pump is operating. This noise is most pronounced when pumping water or very thin sludge; it decreases or disappears when pumping heavy sludge. Eliminate noise by opening the ¼-inch (0.6 cm) petcock on pump body slightly; this draws in a small amount of air, keeping discharge air chamber full at all times.

D 7. CHECK CONTROL VALVE POSITIONS. Because any plunger pump may be damaged if operated against closed valves in the pipeline, especially the discharge line, make all valve setting changes with pump shut down; otherwise pumps which are installed to pump from two sources or to deliver to separate tanks at different times may be broken if all discharge line valves are closed simultaneously for a few seconds or discharge valve directly above pump is closed.

W 8. GEAR REDUCER. Check oil level by removing plug on the side of the gear case Unit should not be in operation.

Q 9. CHANGE OIL AND CLEAN MAGNETIC DRAIN PLUG.

W 10. CONNECTING RODS. Set oilers to disperse two drops per minute.

W 11. PLUNGER CROSSHEAD. Fill plunger as required to half cover the wrist pin with oil.

D 12. PLUNGER TROUGH. Keep small quantity of oil in trough to lubricate the plunger.

M 13 MAIN SHAFT BEARING. Grease bearings monthly. Pump should be in operation when lubricating to avoid excessive pressure on seals.

14. CHECK ELECTRIC MOTOR. See Paragraph 5: Electric Motors.

Paragraph 3: Propeller Pumps, General

D 1. CHECK MOTOR CONDITION. See Paragraphs 6.1 and 6.2.

D 2. CHECK PACKING GLAND ASSEMBLY. See Paragraph 1.6.

W 3. INSPECT PUMP ASSEMBLY. See Paragraph 1.4.

W 4. LUBE LINE SHAFT AND DISCHARGE BOWL BEARING. Maintain oil in oiler at all times. Adjust feed rate to approximately four drops per minute.

W 5. LUBE SUCTION BOWL BEARING. Lube through pressure fitting. Usually three or four strokes of gun are enough.

W 6. OPERATE PUMPS ALTERNATELY. See Paragraph 1.3.

A 7. LUBE MOTOR BEARINGS. See Paragraph 6.3.

Paragraph 4: Progressive Cavity Pumps, General

(Fig. 18.20, page 260).

D 1 CHECK MOTOR CONDITION. See Paragraphs 6.1 and 6.2.

D 2. CHECK PACKING GLAND ASSEMBLY. See Paragraph 1.6.

D 3. CHECK DISCHARGE PRESSURE. A higher than normal discharge pressure may indicate a line blockage or a closed valve downstream. An abnormally low discharge pressure can mean reduced rate of discharge.

S 4. INSPECT AND LUBRICATE BEARINGS — GREASE. If possible, remove bearing cover and visually inspect grease. When greasing, remove relief plug and cautiously add 5 or 6 strokes of the grease gun. Afterwards, check bearing temperature with thermometer. If over 220°F (104°C), remove some grease.

S 5. LUBEFLUSH MOTOR BEARINGS. See Paragraph 6.3.

S 6. CHECK PUMP OUTPUT Check how long it takes to fill a vessel of known volume or quantity; or check performance against a meter, if available. See Paragraph 1.11.c.

A 7. SCOPE MOTOR BEARINGS. See Paragraph 6.4.

A 8. SCOPE PUMP BEARINGS. See Paragraph 6.4.

Paragraph 5: Pump Controls

To ensure the best operation of the pump, a systematic inspection of the controls should be made at least once a week.

W 1. CHECK CONTROLS. Controls respond to the control variable.

W 2. STARTUP. The unit starts when the control system makes contact, and the pump stops at the prescribed control setting.

W 3. MOTOR SPEED. The motor comes up to speed quickly and is maintained.

W 4. SPARKING. A brush-type motor does not spark profusely in starting or running.

Frequency of Service

W 5. INTERFERENCE WITH CONTROLS. Grease and dirt are not interfering with controls.

W 6. ADJUSTMENTS. Any necessary adjustments are properly completed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.23F What are some of the common causes of shear pin failure in reciprocating pumps?

18.23G What may happen when water or a thin sludge is being pumped by a reciprocating pump?

18.23H What could be the causes of a higher than normal discharge pressure in a progressive cavity pump?

Paragraph 6: Electric Motors (Fig. 18.26)

In order to ensure the proper and continuous function of electric motors, the items listed in this paragraph must be performed at the designated intervals. If operational checks indicate a motor is not functioning properly, these items will have to be checked to locate the problem.

D 1. CHECK MOTOR CONDITIONS.

- a. Keep motors free from dirt, dust and moisture.
- b. Keep operating space free from articles which may obstruct air circulation.
- c. Check for excessive grease leakage from bearings.

D 2. NOTE ALL UNUSUAL CONDITIONS.

- a. Unusual noises in operation.
- b. Motor failing to start or come to speed normally, sluggish operation.
- c. Motor or bearings which feel or smell hot.
- d. Continuous or excessive sparking commutator or brushes. Blackened commutator.
- e. Intermittent sparking at brushes.
- f. Fine dust under coupling having rubber buffers or pins.
- g. Smoke, charred insulation, or solder whiskers extending from armature.
- h. Excessive humming.
- i. Regular clicking.
- j. Rapid knocking.

Frequency of Service

- k. Brush chatter.
- l. Vibration.
- m. Hot commutator.

A 3 LUBRICATE BEARINGS (Fig. 18.27). Check grease in ball bearing and relubricate when necessary.

Follow instructions in Section 18.224, Pump Lubrication, when lubricating greased bearings.

A 4. USING A *STETHOSCOPE,*[14] CHECK BOTH BEARINGS. Listen for whines, gratings, or uneven noises. Listen all around the bearing and as near as possible to the bearing. Listen while the motor is being started and shut off. If unusual noises are heard, pinpoint the location.

5. IF YOU THINK THE MOTOR is running unusually hot, check with a thermometer. Place the thermometer on the casing near the bearing, holding it there with putty or clay. Check the current on each leg to determine if the currents are balanced and within the motor name plate limits.

A 6. *DATEOMETER.*[15] If there is a dateometer on the motor, after changing the oil in the motor, loosen the dateometer screw and set to the corresponding year.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.23I What are the major items you would include when checking an electric motor?

18.23J What is the purpose of a stethoscope?

Paragraph 7: Belt Drives

Frequency of Service

1. GENERAL. Maintaining a proper tension and alignment of belt drives ensures long life of belts and sheaves. Incorrect alignment causes poor operation and excessive belt wear. Inadequate tension reduces the belt grip, causes high belt loads, snapping, and unusual wear.

   a. Cleaning belts. Keep belts and sheaves clean and free of oil, which causes belts to deteriorate. To remove oil, take belts off sheaves and wipe belts and sheaves with a rag moistened in a non-oil base solvent. Carbon tetrachloride is *NOT* rec-

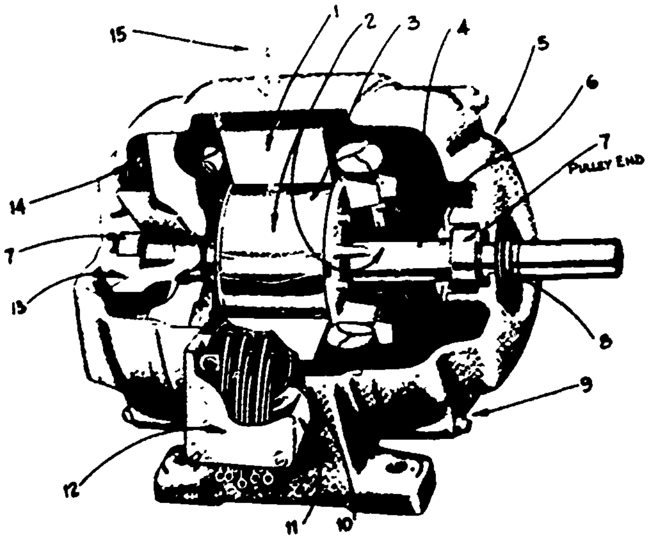
---

[14] *Stethoscope. An instrument used to magnify sounds and convey them to the ear.*

[15] *Dateometer (day-TOM-ut-ter). A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.*

DRIP PROOF

ITEM NO.	PART NAME
1	Wound Stator w/ Frame
2	Rotor Assembly
3	Rotor Core
4	Shaft
5	Bracket
6	Bearing Cap
7	Bearings
8	Seal, Labyrinth
9	Thru Bolts/Caps
10	Seal, Lead Wire
11	Terminal Box
12	Terminal Box Cover
13	Fan
14	Deflector
15	Lifting Lug



TOTALLY ENCLOSED FAN COOLED

ITEM NO.	PART NAME
1	Wound Stator w/ Frame
2	Rotor Assembly
3	Rotor Core
4	Shaft
5	Brackets
6	Bearings
7	Seal, Labyrinth
8	Thru Bolts/Caps
9	Seal, Lead Wire
10	Terminal Box
11	Terminal Box Cover
12	Fan, Inside
13	Fan, Outside
14	Fan Grill
15	Fan Cover
16	Fan Cover Bolts
17	Lifting Lug

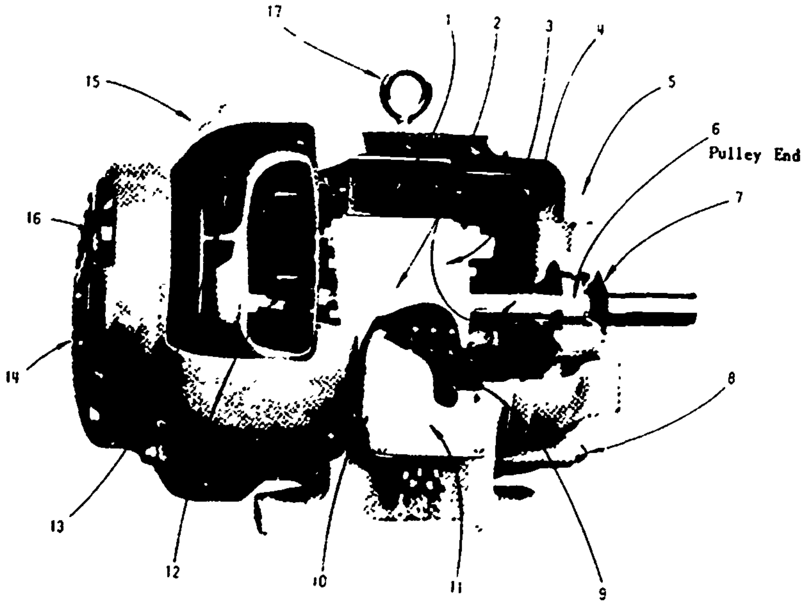
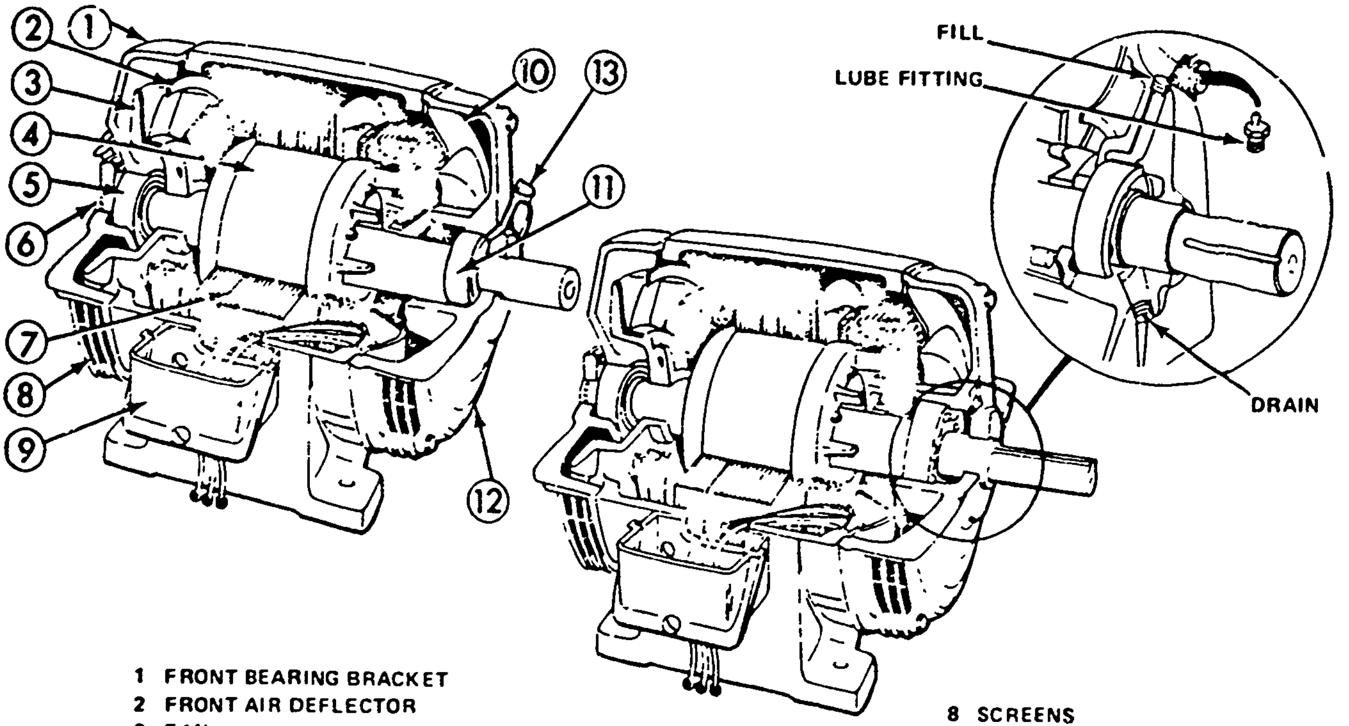


Fig. 18.26 Typical motors
(Courtesy of Sterling Power Systems, Inc.)

ELECTRIC MOTOR

MOTOR LUBRICATION



1 FRONT BEARING BRACKET
2 FRONT AIR DEFLECTOR
3 FAN
4 ROTOR
5 FRONT BEARING
6 END COVER
7 STATOR

8 SCREENS
9 CONDUIT BOX
10 BACK AIR DEFLECTOR
11 BACK BEARING
12 BACK BEARING BRACKET
13 OIL LUBRICATION CAP

Fig. 18.27 Electric motor lubrication

Frequency of Service

ommended because exposure to its fumes has many toxic effects on humans. Carbon tetrachloride also is absorbed into the skin on contact and its effects become stronger with each contact.

b. Installing belts. Before installing belts, replace worn or damaged sheaves, then slack off on adjustments. Do not try to force belts into position. Never use a screwdriver or similar lever to get belts onto sheaves. After belts are installed, adjust tension; recheck tension after eight hours of operation. (See Table 18.3).

c. Replacing belts. Replace belts as soon as they become frayed, worn, or cracked. NEVER REPLACE ONLY ONE V-BELT ON A MULTIPLE DRIVE. Replace the complete set with a set of matched belts, which can be obtained from any supplier. All belts in a matched set are machine-checked to insure equal size and tension.

d. Storing spare belts. Store spare belts in a cool, dark place. Tag all belts in storage to identify them with the equipment on which they can be used.

2. V-BELTS. A properly adjusted V-belt has a slight bow in the slack side when running; when idle it has an alive springiness when thumped with the hand. An improperly tightened belt feels dead when thumped.

If the slack side of the drive is less than 45° from the horizontal, vertical sag at the center of the span may be adjusted in accordance with Table 18.3 below:

TABLE 18.3 HORIZONTAL BELT TENSION

Span (inches)		10	20	50	100	150	200
Vertical Sag (inches)	From	01	03	20	80	1 80	3 30
	To	03	09	58	2 30	4 90	8 60
Span (millimeters)		250	500	1250	2500	3750	5000
Vertical Sag (millimeters)	From	0 25	0 75	5 00	20 0	45 0	82 5
	To	0 75	2 25	14 50	57 5	122 5	215 0

M a. Check tension. If tightening belt to proper tension does not correct slipping, check for overload, oil on belts, or other possible causes. Never use belt dressing to stop belt slippage. Rubber wearings near the drive are a sign of improper tension, incorrect alignment, or damaged sheaves.

M b. Check sheave (pulley) alignment. Lay a long straight edge or string across outside faces of pulley, and allow for differences in dimensions from center lines of grooves to outside faces of the pulleys being aligned. Be especially careful in aligning drives with more than one V-belt on a sheave, as misalignment can cause unequal tension

Paragraph 8: Chain Drives

1. GENERAL. Chain drives may be designated for slow, medium, or high speeds.

a. Slow-speed drives. Because slow-speed drives are usually enclosed, adequate lubrication is difficult. Heavy oil applied to the outside of the chain seldom reaches the working parts; in addition, the oil catches dirt and grit and becomes abrasive. For lubricating and cleaning methods, see 5 and 6 below.

b. Medium- and high-speed drives. Medium-speed drives should be continuously lubricated with a device similar to a sight-feed oiler. Highspeed drives should be completely enclosed in an oil-tight case and the oil maintained at proper level.

D 2. CHECK OPERATION. Check general operating condition during regular tours of duty.

Q 3. CHECK CHAIN SLACK. The correct amount of slack is essential to proper operation of chain drives. Unlike other belts, chain belts should not be tight around the sprocket; when chains are tight, working parts carry a much heavier load than necessary. Too much slack is also harmful; on long centers particularly, too much slack causes vibrations and chain whip, reducing life of both chain and sprocket. A properly installed chain has a slight sag or looseness on the return run.

S 4. CHECK ALIGNMENT. If sprockets are not in line or if shafts are not parallel, excessive sprocket and chain wear and early chain failure result. Wear on inside of chain, side walls, and sides of sprocket teeth are signs of misalignment. To check alignment, remove chain and place a straight edge against sides of sprocket teeth.

S 5. CLEAN. On enclosed types, flush chain and enclosure with a petroleum solvent (kerosene). On exposed types, remove chain and soak and wash it in solvent. Clean sprockets, install chain, and adjust tension.

S 6. CHECK LUBRICATION. Soak exposed-type chains in oil to restore lubricating film. Remove excess lubricant by hanging chains up to drain.

Do not lubricate underwater chains which operate in contact with considerable grit. If water is clean, lubricate by applying waterproof grease with brush while chain is running.

Do not lubricate chains on elevators or on conveyors of feeders which handle dirty or gritty materials. Dust and grit combine with lubricants to form a cutting compound which reduces chain life.

Frequency of Service

S 7. CHANGE OIL. On enclosed types only, drain oil and refill case to proper level.

S 8. INSPECT. Note and correct abnormal conditions before serious damage results. Do not put a new chain on worn sprockets. Always replace worn sprockets when replacing a chain because out-of-pitch sprockets cause as much chain wear in a few hours as years of normal operation.

9. TROUBLESHOOTING. Some common symptoms of improper chain-drive operation and their remedies follow:

a. Excessive noise. Correct alignment, if misaligned. Adjust centers for proper chain slack. Lubricate in accordance with aforementioned methods. Be sure all bolts are tight. If chain or sprockets are worn, reverse or renew if necessary.

b. Wear on chain, side walls, and sides of teeth. Remove chain and correct alignment.

c. Chain climbs sprockets. Check for poorly fitting sprockets and replace if necessary. Make sure tightener is installed on drive chain.

d. Broken pins and rollers. Check for chain speed which may be too high for the pitch, and substitute chain and sprockets with shorter pitch if necessary. Breakage also may be caused by shock loads.

e. Chain clings to sprockets Check for incorrect or worn sprockets or heavy, tacky lubricants. Replace sprockets or lubricants if necessary.

f. Chain whip. Check for too-long centers or high, pulsating loads and correct cause.

g. Chains get stiff. Check for misalignment, improper lubrication, or excessive overloads. Make necessary corrections or adjustments.

Paragraph 9: Variable Speed Belt Drives (See Fig 18.28)

D 1. CLEAN DISCS. Remove grease, acid, and water from disc faces.

D 2. CHECK SPEED-CHANGE MECHANISM. Shift drive through entire speed range to make sure shafts and bearings are lubricated and discs move freely in lateral direction on shafts.

W 3. CHECK V-BELT. Make sure it runs level and true. If one side rides high, a disc is sticking on shaft because of insufficient lubrication or wrong lubricant. In this case, stop the drive at once, remove V-belt, and clean disc hub and shaft thoroughly with petroleum solvent until disc moves freely. Relubricate with soft ball-bearing grease and replace V-belt in opposite direction from that in which it formerly ran.

Frequency of Service

M If drive is not operated for 30 days or more, shift unit to minimum speed position, placing spring on variable-speed shaft at minimum tension and relieving belt of excessive pressure.

4 LUBRICATE DRIVE. Make sure to apply lubricant at all the six force-feed lubrication fittings (Fig. 18.28: A, B, D, E, G and H) and the one cup type fitting (C).

NOTE: If the drive is used with a reducer, fitting E is not provided.

W a. Once every ten days to two weeks, use two or three strokes of a grease gun through fittings A and B at ends of shifting screw and variable-speed shaft, respectively, to lubricate bearings of movable discs. Then, with unit running, shift drive from one extreme speed position to the other to ensure thorough distribution of lubricant over disc-hub bearings.

Q b. Add two or three shots of grease through fittings D and E to lubricate frame bearing on variable-speed shaft.

Q c Every 90 days, add two or three cupfulls of grease to Cup C which lubricates thrust bearing on constant-speed shaft.

Q d. Every 90 days, use two or three strokes of grease gun through fittings G and H to lubricate motorframe bearings.

CAUTION: Be sure to follow manufacturer's recommendation on type of grease. After lubricating, wipe excessive grease from sheaves and belt.

QUESTIONS

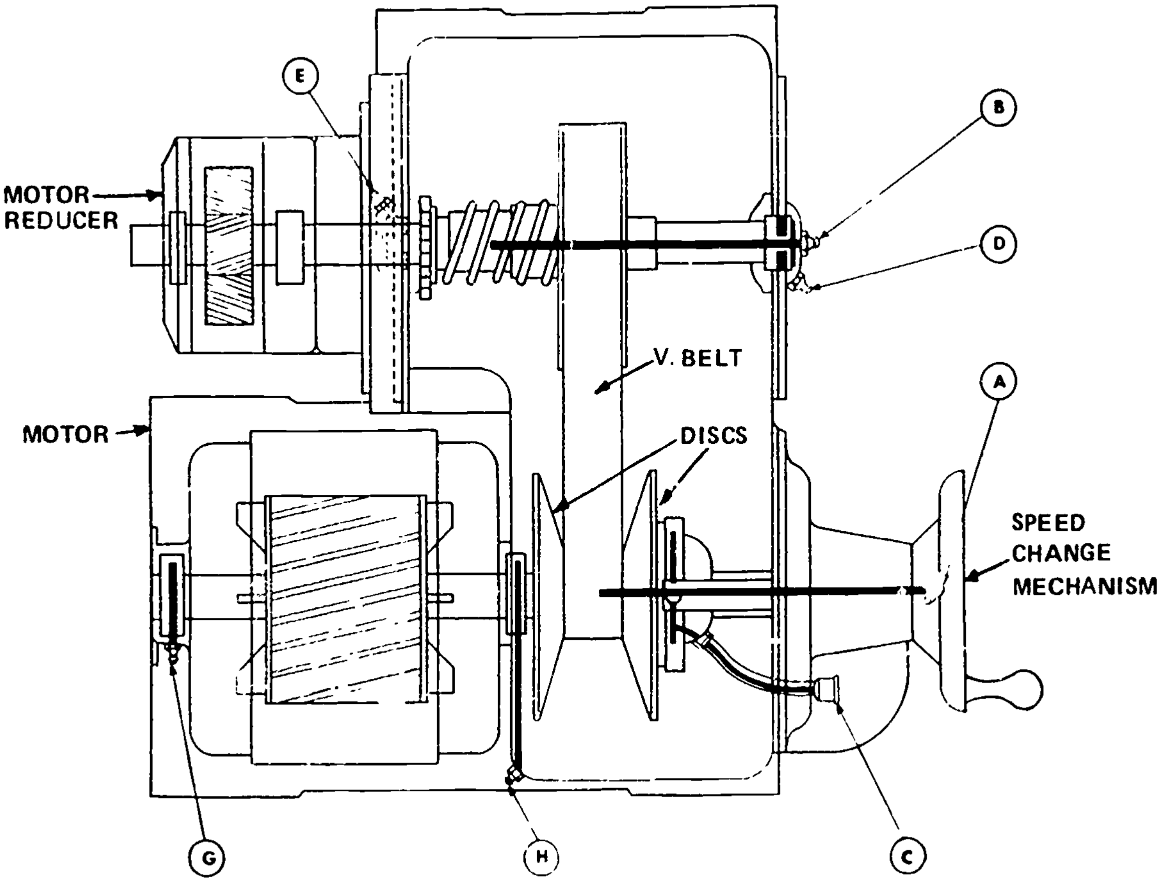
Write your answers in a notebook and then compare your answers with those on page 325.

18 23K How can you tell if a belt on belt-drive equipment has proper tension and alignment?

18 23L Why should sprockets be replaced when replacing a chain in a chain-drive unit?

Paragraph 10: Couplings

1 GENERAL. Unless couplings between the driving and driven elements of a pump or any other piece of equipment are kept in proper alignment, breaking and excessive wear results in either or both the driven machinery and the driver. Burned-out bearings, sprung or broken shaft, and excessively worn or ruined gears are some of the damages caused by misalignment. To prevent outages and the expense of installing replacement parts, check the alignment of all equipment before damage occurs.



NOTE A, B, D, E, G and H are force-feed lubrication fittings.
C is a cup type lubrication fitting

Fig 18.28 Reeves Varidrive
(Source War Department Technical Manual TM5-666)

Frequency of Service

a. Improper original installation of the equipment may not necessarily be the cause of the trouble. Settling of foundations, heavy floor loadings, warping of bases, excessive bearing wear, and many other factors cause misalignment. A rigid base is not always security against misalignment. The base may have been mounted off level, which could cause it to warp.

b. Flexible couplings permit easy assembly of equipment, but they must be aligned as exactly as flanged couplings if maintenance and repair are to be kept to a minimum. Rubber-bushed types cannot function properly if the bolts cannot move in their bushings.

S 2. CHECK COUPLING ALIGNMENT (straight edge method). Excessive bearing and motor temperatures caused by overload, noticeable vibration, or unusual noises may all be warnings of misalignment. Realign when necessary (Fig 18 29) using a straight edge and thickness gage or wedge. To ensure satisfactory operation, level up to within 0.005 inch (0.13 mm) as follows:

a. Remove coupling pins.

b. Rigidly tighten driven equipment; slightly tighten bolts holding drive.

c To correct horizontal and vertical misalignment, shift or shim drive to bring coupling halves into position so no light can be seen under a straight edge laid across them. Place straight edge in four positions, holding a light in back of straight edge to help ensure accuracy.

d. Check for angular misalignment with a thickness or feeler gage inserted at four places to make certain space between coupling halves is equal.

e. If proper alignment has been secured, coupling pins can be put in place easily using only finger pressure. Never hammer pins into place.

f. If equipment is still out of alignment, repeat the procedure.

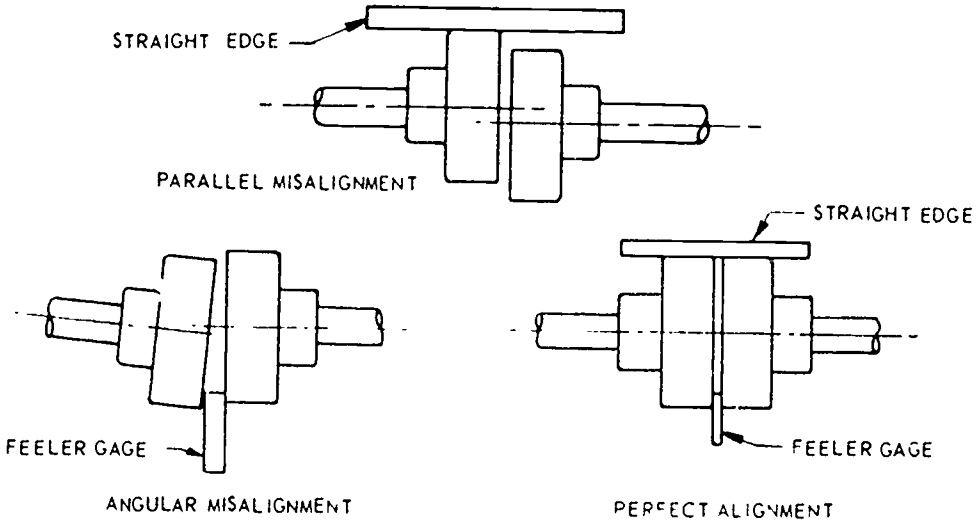


Fig. 18.29 Testing alignment, straight edge
(Source Unknown)

Frequency of Service

S 3. CHECK COUPLING ALIGNMENT (dial indicator method). Dial indicators also are used to measure coupling alignment. This method produces better results than the straight edge method. The dial indicates very small movements or distances which are measured in mils (one mil equals 1/1000 of an inch). The indicator consists of a dial with a graduated face (with "plus" and "minus" readings, a pedestal, and a rigid indicator bar (or "fixture") as shown in Figure 18.30).

The dial indicator is attached to one coupling via the fixture and adjusted to the zero position or reading. When the shaft of the machine is rotated, misalignment will cause the pedestal to compress (a "plus" reading), or extend (a "minus" reading). Literature provided by the manufacturer of machinery usually will indicate maximum allowable tolerances or movement.

Carefully study the manufacturer's literature provided with your dial indicator before attempting to use the device.

A 4. CHANGE OIL IN FAST COUPLINGS. Drain out old oil and add oil to proper level. Correct quantity is given on instruction card supplied with each coupling.

Paragraph 11: Shear Pins

Some water treatment units use shear pins as protective devices to prevent damage in case of sudden overloads. To serve this purpose, these devices must be in operational condition at all times. Under some operating conditions, shearing surfaces of a shear pin device may freeze together so solidly that an overload fails to break them.

Manufacturers' drawings for particular installations usually specify shear pin material and size. If this information is not available, obtain the information from the manufacturer, giving the model, serial number, and load conditions of unit. When necessary to determine shear pin size, select the lowest strength which does not break under the unit's usual loads. When proper size is determined, never use a pin of greater strength, such as a bolt or a nail.

If necked pins are used, be sure the necked-down portion is properly positioned with respect to shearing surfaces. When a shear pin breaks, determine and remedy the cause of failure before inserting new pin and starting drive in operation.

Frequency of Service

M 1. GREASE SHEARING SURFACES

Q 2. REMOVE SHEAR PIN. Operate motor for a short time to smooth out any corroded spots.

A 3. CHECK SPARE INVENTORY. Make sure an adequate supply is on hand, properly identified and with record of proper pin size, necked diameter, and longitudinal dimensions.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.23M What factors could cause couplings to become out of alignment?

18.23N What is the purpose of shear pins?

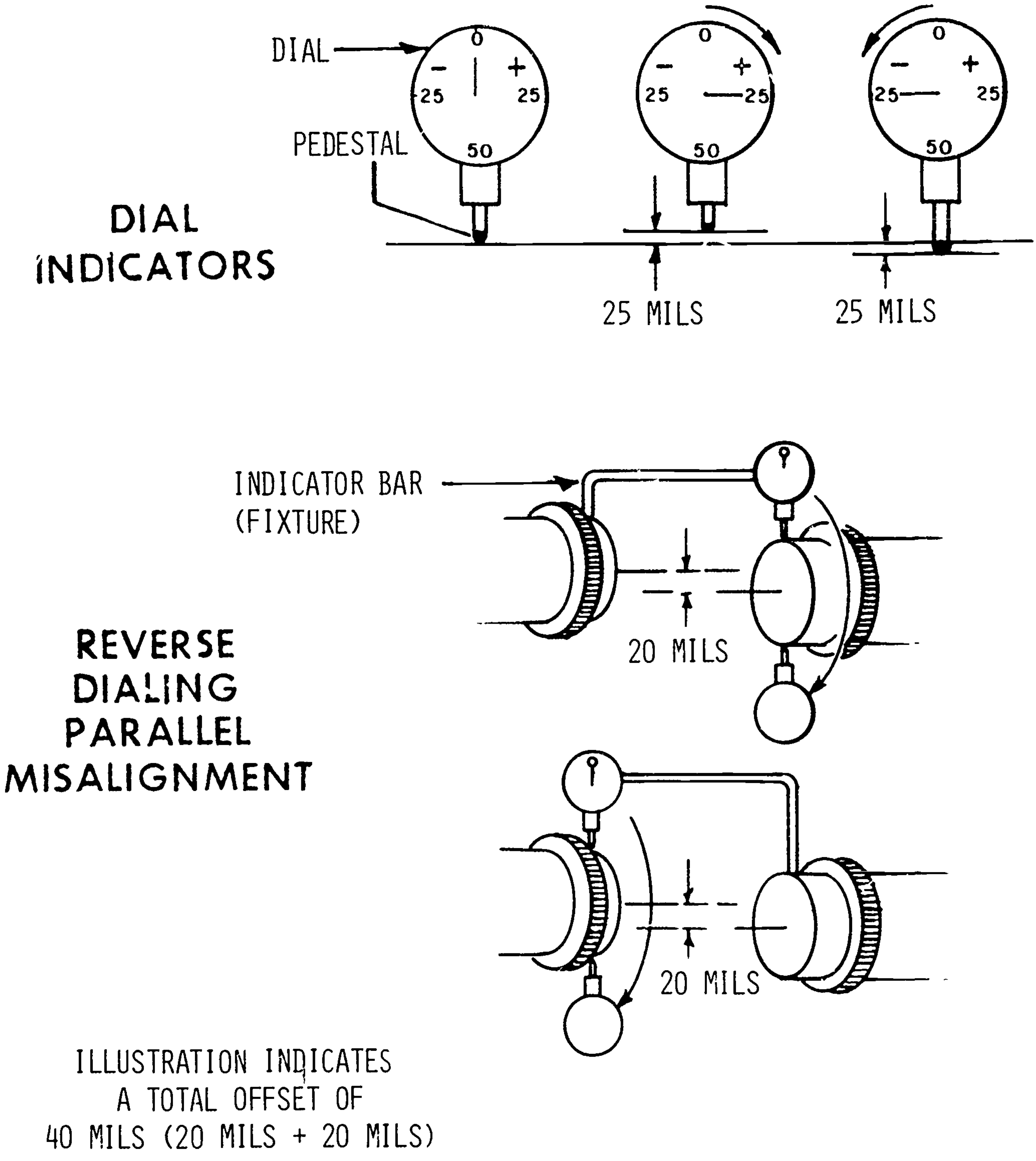


Fig. 18.30 Use of a dial indicator
(Permission of DYMAC, a Division of Spectral Dynamics Corporation)

18.24 Pump Operation

18.240 Starting a New Pump

The initial startup work described in this paragraph should be done by a competent and trained person, such as a manufacturer's representative, consulting engineer, or an experienced operator. The operator can learn a lot about pumps and motors by accompanying and helping a competent person put new equipment into operation.

Before starting a pump, lubricate it according to the lubrication instructions. Turn the shaft by hand to see that it rotates freely. Then check to see that the shafts of the pump and motor are aligned and the flexible coupling adjusted. (Refer to Paragraph 10: Couplings, page 278; also see Section 18.23, "Pump Maintenance," page 265.) If the unit is belt driven, sheave (pulley) alignment and belt adjustment should be checked. (Refer to Paragraph 7: Belt Drives.) Check the electric voltage with the motor characteristics and inspect the wiring See that thermal overload units in the starter are set properly Turn on the motor just long enough to see that it turns the pump in the direction indicated by the rotational arrows marked on the pump. If separate water seal units or vacuum primer systems are used, these should be started. Finally, make sure lines are open Sometimes there is an exception (see following paragraph) in the case of the discharge valve.

A pump should not be run without first having been primed To prime a pump, the pump must be completely filled with water In some cases, automatic primers are provided. If they are not, it is necessary to vent the casing. Most pumps are provided with a valve to accomplish this. Allow the trapped air to escape until water flows from the vent; then replace the vent cap. In the case of suction-lift applications, the pump must be filled with water unless a self-primer is provided. In nearly every case, you may start a pump with the discharge valve open. Exceptions to this, however, are where water hammer or pressure surges might result, or where the motor does not have sufficient margin of safety or power. Sometimes there are no check valves in the discharge line. In this case (with the exception of positive displacement pumps) it is necessary to start the pump and then open the discharge lines. Where there are common discharge headers, it is essential to start the pump and then open the discharge valve A positive displacement pump (reciprocating or piston types) should never be operated against a closed discharge line.

After starting the pump, again check to see that the direction of rotation is correct. Packing-gland boxes (stuffing boxes) should be observed for slight leakage (approximately 60 drops per minute) as described in Paragraph 1: Pumps, General Check to see that the bearings do not overheat from over- or under-lubrication. The flexible coupling should not be noisy, if it is, the noise may be caused by misalignment or improper clearance or adjustment. Check to be sure pump anchorage is tight Compare delivered pump flows and pressures with pump performance curves. If pump delivery falls below performance curves, look for obstructions in the pipelines and inspect piping for leaks

18.241 Pump Shutdown

When shutting down a pump for a long period, the motor disconnect switch should be opened, locked out, and tagged with reason for tag noted. If the electric motor is equipped with winding heaters, check to be sure they are turned on. This helps to prevent condensation from forming which can weaken the insulation on the windings. All valves on the suction, discharge, and water-seal lines should be shut tightly. Completely drain the pump by removing the vent and drain plugs.

Inspect the pump and bearings thoroughly so that all necessary servicing may be done during the inactive period. Drain the bearing housing and then add fresh lubricant. Follow any additional manufacturer's recommendations.

18.242 Pump-Driving Equipment

Driving equipment used to operate pumps includes electric motors and internal combustion engines. In rare instances, pumps are driven with steam turbines, steam engines, air and hydraulic motors.

In all except the large installations, electric motors are used almost exclusively, with synchronous and induction types being the most commonly used. Synchronous motors operate at constant speeds and are used chiefly in large sizes. Three-phase, squirrel-cage induction motors are most often used in treatment plants. These motors require little attention and, under average operating conditions, the factory lubrication of the bearing will last approximately one year. (Check with the manufacturer for average number of operating hours for bearings.) When lubricating motors, remember that too much grease may cause bearing trouble or damage the winding.

Clean and dry all electrical contacts. Inspect for loose electrical contacts. Make sure that hold-down bolts on motors are secure. Check voltage while the motor is starting and running. Examine bearings and couplings

18.243 Electrical Controls

A variety of electrical equipment is used to control the operation of pumps or to protect electric motors. If starters, disconnect switches, and cutouts are used, they should be installed in accordance with the local regulations (city and/or county codes) regarding this equipment. In the case of larger motors, the power company often requires starters which do not overload the power lines.

The electrode-type, bubbler-type, and diaphragm-type water level control systems are all similar in effect to the float-switch system. Scum is a problem with most water-level controls that operate pumps and must be removed on a regular basis.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.24A Where would you find out how to lubricate a pump?

18 24B What problems can develop if too much grease is used in lubricating a motor?

18.244 Operating Troubles

The following list of operating troubles includes most of the causes of failure or reduced operating efficiency. The remedy or cure is either obvious or may be identified from the description of the cause.

SYMPTOM A — PUMP WILL NOT START

CAUSES:

1. Blown fuses or tripped circuit breakers due to:
   - A. Rating of fuses or circuit breakers not correct,
   - B. Switch (breakers) contacts corroded or shorted,
   - C. Terminal connections loose or broken somewhere in the circuit,
   - D. Automatic control mechanism not functioning properly,
   - E. Motor shorted or burned out,
   - F. Wiring hookup or service not correct,
   - G. Switches not set for operation,
   - H. Contacts of the control relays dirty and arcing,
   - I. Fuses or thermal units too warm,
   - J. Wiring short-circuited, and
   - K. Shaft binding or sticking due to rubbing impeller, tight packing glands, or clogging of pump.
2. Loose connections, fuse, or thermal unit

SYMPTOM B — REDUCED RATE OF DISCHARGE

CAUSES:

1 Pump not primed
2. Air in the water
3. Speed of motor too low
4. Improper wiring
5. Defective motor
6. Discharge head too high
7. Suction lift greater than anticipated
8. Impeller clogged
9. Discharge line clogged
10. Pump rotating in wrong direction
11. Air leaks in suction line or packing box
12. Inlet to suction line too high, permitting air to enter
13. Valves partially or entirely closed
14 Check valves stuck or clogged
15 Incorrect impeller adjustment
16 Impeller damaged or worn
17. Packing worn or defective
18 Impeller turning on shaft because of broken key
19 Flexible coupling broken
20 Loss of suction during pumping may be caused by leaky suction line, ineffective water or grease seal
21 Belts slipping
22 Worn wearing ring

SYMPTOM C — HIGH POWER REQUIREMENTS

CAUSES:

1 Speed of rotation too high
2. Operating heads lower than rating for which pump was designed, resulting in excess pumping rates
3. Sheaves on belt drive misaligned or maladjusted
4. Pump shaft bent
5 Rotating elements binding
6. Packing too tight
7. Wearing rings worn or binding
8. Impeller rubbing

SYMPTOM D — NOISY PUMP

CAUSES

1 Pump not completely primed
2 Inlet clogged
3. Inlet not submerged
4 Pump not lubricated properly
5. Worn impellers
6. Strain on pumps caused by unsupported piping fastened to the pump
7 Foundation insecure
8. Mechanical defects in pump
9 Misalignment of motor and pump where connected by flexible shaft
10 Rocks in the impeller
11 Cavitation

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18 24C What items would you check if a pump will not start?

18.24D How would you attempt to increase the discharge from a pump if the flow rate is lower than expected?

18.245 Starting and Stopping Pumps

The operator must determine what treatment processes will be affected by either starting or stopping a pump. The pump discharge point must be known and valves either opened or closed to direct flows as desired by the operator when a pump is started or stopped

18.2450 Centrifugal Pumps. Basic rules for the operation of centrifugal pumps include the following items

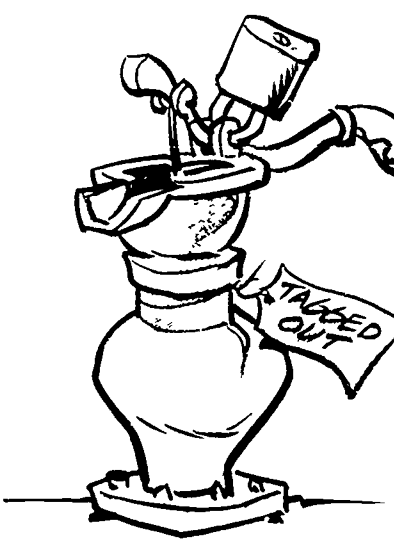
1. Do not operate the pump when safety guards are not installed over or around moving parts.
2. Do not start a pump that has been locked or tagged out for maintenance or repairs
3. Never run a centrifugal pump when the impeller is dry. Always be sure the pump is primed.
4. Never attempt to start a centrifugal pump whose impeller or shaft is spinning backwards.
5. Do not operate a centrifugal pump that is vibrating excessively after startup. Shut unit down and isolate pump from system by closing the pump suction and discharge valves Look for a blockage in the suction line and the pump impeller

There are several situations in which it may be necessary to start a CENTRIFUGAL pump against a CLOSED discharge valve. Once the pump is primed, running and indicating a discharge pressure, slowly open the pump discharge valve until the pump is fully on line. This procedure is used with treatment processes or piping systems with vacuums or pressures that cannot be dropped or allowed to fluctuate greatly while an alternate pump is put on the line.

Most centrifugal pumps used in water treatment plants are designed so that they can be easily started even if they haven't been primed. This is accomplished with a positive static suction head or a low suction lift. On most of these arrangements, the pump will not require priming as long as the pump and the piping system do not leak. Leaks would allow the water to drain out of the pump volute. When pumps in water systems lose their prime, the cause is often a faulty check valve on the pump discharge line. When the pump stops, the discharge check valve will not seal (close) properly. Water previously pumped then flows back through the check valve and through the pump. The pump is drained and has lost its prime.

About ninety-five percent of the time, the centrifugal pumps in water treatment plants are ready to operate with suction and discharge valves open and seal water turned on. When the automatic start or stop command is received by the pump from the controller, the pump is ready to respond properly.

When the pumping equipment must be serviced, take it off the line by locking and tagging out the pump controls until all service work is completed.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.24E Why should a pump that has been locked or tagged out for maintenance or repairs not be started?

18.24F Under what conditions might a centrifugal pump be started against a closed discharge valve?

STOPPING PROCEDURES

This section contains a typical sequence of procedures to follow to stop a centrifugal pump. Exact stopping procedures for any pumping system depend upon the condition of the discharge system. The sudden stoppage of a pump could cause severe *WATER HAMMER*[16] problems in the piping system.

1 Inspect process system affected by pump, start alternate pump if required, and notify supervisor or log action.
2 Before stopping and operating pump, check its operation. This will give an indication of any developing problems, required adjustments, or problem conditions of the unit. This procedure only requires a few minutes Items to be inspected include:
   a Pump packing gland.
      1) Seal water pressure
      2) Seal leakage (too much, sufficient or too little leakage)
      3) Seal leakage drain flowing clear
      4) Mechanical seal leakage (if equipped)
   b. Pump operating pressures.
      1) Pump suction (Pressure Vacuum)

         A higher vacuum than normal may indicate a partially plugged or restricted suction line. A lower vacuum may indicate a higher suction water level or a worn pump impeller or wearing rings.

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[16] *Water Hammer The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.*

2) Pump discharge pressure

System pressure is indicated by the pump discharge pressure. Lower than normal discharge pressures can be caused by:

a) Worn impeller or wearing rings in the pump;

b) A different point of discharge can change discharge pressure conditions;

c) A broken discharge pipe can change the discharge head.

NOTE. To determine the maximum head a centrifugal pump can develop, slowly close the discharge valve at the pump. Read the pressure gage between the pump and the discharge valve when the valve is fully closed. This is the maximum pressure the pump is capable of developing. Do not operate the pump longer than a few minutes with the discharge valve closed completely because the energy from the pump is converted to heat and water in the pump can become hot enough to damage the pump.

c. Motor temperature and pump bearing temperature.

If motor or bearings are too hot to touch, further checking is necessary to determine if a problem has developed or if the temperature is normal. High temperatures may be measured with a thermometer.

d Unusual noises, vibrations, or conditions about the equipment.

If any of the above items indicate a change from the pump's previous operating condition, additional service or maintenance may be required during shutdown.

3. Actuate stop switch for pump motor and lock out switch. If possible use switch next to equipment so that you may observe the equipment stop. Observe the following items:

a. Check valve closes and seats.

Valve should not slam shut, or discharge piping will jump or move in their supports. There should not be any leakage around the check valve shaft. If check valve is operated automatically, it should close smoothly and firmly to the fully closed position.

NOTE If the pump is not equipped with a check valve, close discharge valve before stopping pump.

b Motor and pump should wind down slowly and not make sudden stops or noises during shutdown.

c After equipment has completely stopped, pump shaft and motor should not start back-spinning. If back-spinning is observed in a pump with a check valve or foot valve, close the pump discharge valve *SLOWLY!* Be extra careful if there is a plug valve on a line with a high head because when the discharge valve is part way closed, the plug valve could slam closed and damage the pump or piping.

4. Go to power control panel containing the pump motor starters just shut down and *OPEN* motor breaker switch, lock out, and tag.

5. Return to pump and close:

   a. Discharge valve,

   b Suction valve,

   c. Seal water supply valve, and

   d Pump volute bleed line (if so equipped).

6. If required, close and open appropriate valves along piping system through which pump was discharging.

Starting Procedures

This section contains a typical sequence of procedures to follow to start a centrifugal pump.

1 Check motor control panel for lock and tags. Examine tags to be sure that *NO* item is preventing startup of equipment.

2. Inspect equipment

   a. Be sure stop switch is locked out at equipment location.

   b. Guards over moving parts must be in place.

   c. Clean-out on pump volute and drain plugs should be installed and secure.

   d. Valves should be in closed position.

   e. Pump shaft must rotate freely.

   f Pump motor should be clean and air vents clear.

   g Pump, motor, and auxiliary equipment lubricant level must be at proper elevations.

   h. Determine if any special considerations or precautions are to be taken during startup.

3. Follow pump discharge piping route. Be sure all valves are in the proper position and that the pump flow will discharge where intended.

4. Return to motor control panel.

   a. Remove tag.

   b. Remove padlock.

   c. Close motor main breaker.

   d. Place selector switch to manual (if you have automatic equipment).

5. Return to pump equipment
   a. Open seal water supply line to packing gland. Be sure seal water supply pressure is adequate
   b. Open pump suction valve slowly.
   c Bleed air out of top of pump volute in order to prime pump Some pumps are equipped with air relief valves or bleed lines back to the wet well for this purpose.
   d. When pump is primed, slowly open pump discharge valve and recheck prime of pump Be sure no air is escaping from volute.
   e. Unlock stop switch and actuate start switch. Pump should start
6. Inspect equipment.
   a. Motor should come up to speed promptly. If ammeter is available, test for excessive draw of power (amps) during startup and normal operation. Most three-phase induction motors used in water treatment plants will draw 5 to 7 times their normal running current during the brief period when they are coming up to speed.
   b No unusal noise or vibrations should be observed during startup
   c. Check valve should be open and no chatter or pulsation should be observed.
   d. Pump suction and discharge pressure readings should be within normal operating range for this pump.
   e Packing gland leakage should be normal.
   f. If a flow meter is on the pump discharge, record pump output
7 If the unit is operating properly, return to the motor control panel and place the motor mode of operation selector in the proper operating position (manual-auto-off).
8. The pump and auxiliary equipment should be inspected routinely after the pump has been placed back into service.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 325.

18.24G What should be done before stopping an operating pump?

18.24H What could cause a pump shaft or motor to spin backwards?

18.24I Why should the position (open or closed) of all valves be checked before starting a pump?

18.2451 Positive Displacement Pumps. Steps for starting and stopping positive displacement pumps are outlined in this section. There are two basic differences in the operation of positive displacement pumps as compared with centrifugal pumps. Centrifugal pumps (due to their design) will permit an operator error, but a positive displacement pump will not and someone will have to pay for correcting the damages.

Important rules for operating positive displacement pumps include

1. NEVER, NEVER OPERATE A POSITIVE DISPLACEMENT PUMP AGAINST A CLOSED VALVE, ESPECIALLY A DISCHARGE VALVE.

1 Excessive pressure could rupture the equipment and possibly seriously injure or kill someone nearby.

2 Positive displacement pumps are used to pump solids (sludge) and meter chemicals. Certain precautions must be taken to prevent injury or damage. If the valves on both ends of a sludge line are closed tightly, the line becomes a closed vessel Gas from decomposition of the sludge can build up and rupture pipes or valves.

3. Positive displacement pumps also are used to meter and pump chemicals. Care must be exercised to avoid venting chemicals to the atmosphere.

4. Never operate a positive displacement pump when it is dry or empty, especially the progressive-cavity types that use rubber stators. A small amount of liquid is needed for lubrication in the pump cavity between the rotor and the stator.

In addition to *NEVER* closing a discharge valve on an operating positive displacement pump, the only other difference (when compared with a centrifugal pump) may be that the positive displacement pump system may or may not have a check valve in the discharge piping after the pump Installation of a check valve depends upon the designer and the material being pumped.

Other than the specific differences mentioned in this section, the starting and stopping procedures for positive displacement pumps are similar to the procedures for centrifugal pumps.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326.

18 24J What is the most important rule regarding the operation of positive displacement pumps?

18 24K What could happen if a positive displacement pump is started against a closed discharge valve?

18 24L Why should both ends of a sludge line never be closed tight?

End of Lesson 3 of 5 Lessons on MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 4.

DISCUSSION AND REVIEW QUESTIONS

Chapter 18. MAINTENANCE

(Lesson 3 of 5 Lessons)

Write your answers to these questions in your notebook before continuing. The question numbering continues from Lesson 2

18 When two or more pumps of the same size are installed, why should they be operated alternately?

19 What should be checked if pump bearings are running hot?

20. What happens when the packing is too tight on a reciprocating pump?

21 Why should adjustments in control valves for reciprocating pumps be made when the pump is shut down?

22. Why would you use a stethoscope to check an electric motor?

23. How would you determine if a motor is running unusually hot?

24 How would you clean belts on a belt drive?

25. Why should you never replace only one belt on a multiple-drive unit?

26. What do rubber wearings near a belt drive indicate?

27. How can you determine if a chain in a chain-drive unit has the proper slack?

28. What happens when couplings are not in proper alignment?

29 How can you determine if a new pump will turn in the direction intended?

30. When shutting down a pump for a long period, what precautions should be taken with the motor disconnect switch?

31 How can you determine if a new pump is delivering design flows and pressures?

CHAPTER 18. MAINTENANCE

(Lesson 4 of 5 Lessons)

18.25 Compressors

Compressors (Fig 18.31) are commonly used in the operation and maintenance of water treatment plants They are used to activate and control pump control systems (bubblers), valve operators, and water pressure systems They are also used to operate portable pneumatic tools, such as jack hammers, compactors, air drills, sand blasters, tapping machines, and air pumps.

A compressor is a device used to increase the pressure of air or gas. They can be of a very simple diaphragm or bellows type such as are found in aquarium pumps, or extremely complex rotary, piston, or sliding vane type compressors. A compressor usually has a suction pipe with a filter and a discharge pipe which goes to an air receiver or storage tank. The compressed air or gas is then used from the air receiver.

Due to the complexity of compressors, the water treatment plant operator usually will not be repairing them. You will, however, be required to maintain these compressors. With proper maintenance a compressor should give years of trouble-free service.

The first step for compressor maintenance, and this pertains to any mechanical equipment, is to get the manufacturer's instruction book and read it completely. Each compressor is different and the particular manufacturer will provide its recommended maintenance schedules and procedures. Some of the maintenance procedures are discussed in the following paragraphs.

1. Inspect the suction filter of the compressor regularly. The frequency of cleaning depends upon the use of the compressor and the atmosphere around it. Under normal operations the filter should be inspected at least

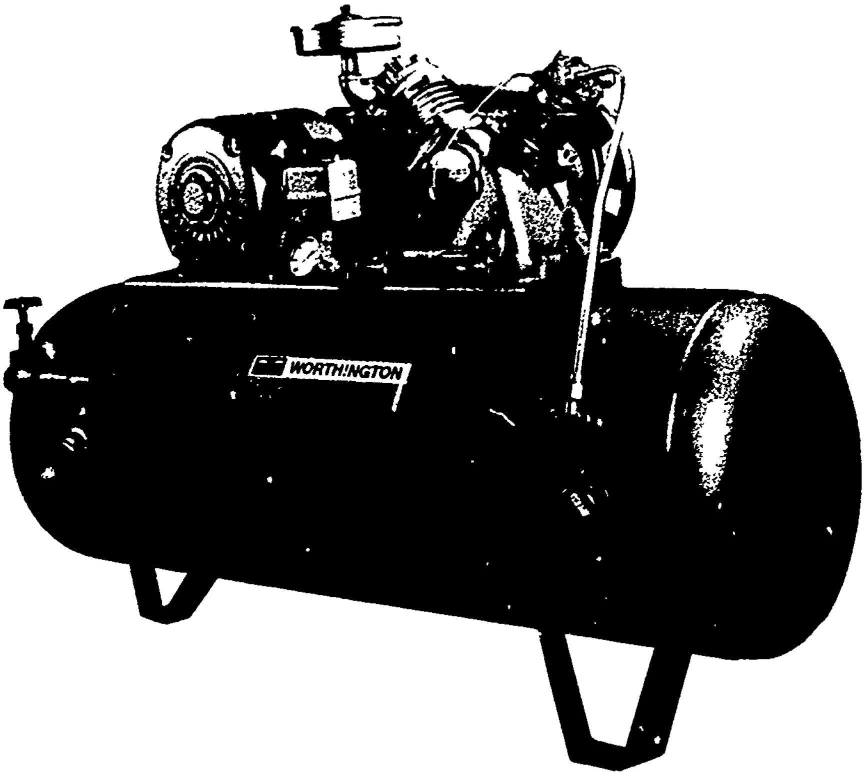

Fig. 18.31 *Two-stage piston compressor*
(Courtesy Worthington Corporation)

monthly and cleaned or replaced every three to six months Inspect and replace the filter more frequently in areas with excavation and dust. When breaking up concrete, inspect the filters daily.

There are several types of filters, such as paper, cloth, wire screen, oil bath, and others. The impregnated paper filters must be replaced when dirty. The cloth-type filters can be washed with soap and water, dried and reinstalled. If a cloth-type filter is used, it is recommended that a spare be kept so one can be cleaned while the other is being used. The wire mesh and oil-bath type filters can be cleaned with a standard solvent, reoiled or oil bath filled and used again. Never operate a compressor without the suction filter because dirt and foreign materials will collect on the rotors, pistons, or blades and cause excessive wear.

2. Lubrication. Improper or lack of lubrication is probably the biggest cause of compressor failures. Most compressors require oiling of the bearings. They can have crank case reservoirs, oil cups, grease fittings, a pressure system or separate pump Whatever type, it must be inspected daily. Examine the reservoir dip stick or sight glass. Make sure that drip-feed oilers are dripping at the proper rate, force fed oilers have the proper pressure, and grease fittings are greased at the proper interval. Compressors use a certain amount of oil in their operation and special attention is needed to keep the reservoirs full. Care also must be used to not overfill the crankcase. On some compressors it is possible for the oil to get into the compression side and lock up the compressor, or damage it. Remember!

A LIQUID CANNOT BE COMPRESSED.

When air or gas are compressed, they give off heat and the compressor becomes very hot. This tends to break down oil faster, so most compressor manufacturers have special oils recommended for their particular compressor. Also, due to the heat and contamination, it is necessary to change oil quite frequently. Compressor oil should be changed at least every three months, unless manufacturer states differently. If there are filters in the oil system, these also should be changed.

3. Cylinder or casing fins should be cleaned weekly with compressed air or vacuumed off. The fins must be clean to insure proper cooling of the compressor.

4. Unloader. Many compressors have unloaders that allow the compressor to start under a no-load condition. These can be inspected by observing the compressor. When the compressor starts, it should come up to speed and the unloader will change, starting the compression cycle. This can usually be heard by a change in sound. When it stops, you can hear a small pop and hear the air bleed off the cylinders. If the unloader is not working properly, the compressor will stall when starting, not start, or if belt-driven, burn off the belts.

5 Test the safety valves weekly The pop off or safety valves are located on the air receiver or storage tank. They prevent the pressure from building up above a specified pressure by opening and venting to the atmosphere. In gas compressors, they vent to the suction side of the compressor. Some compressors have high pressure cut-off switches, low oil pressure switches, and high temperature cut-off switches. These switches have pre-set cut-off settings and must not be changed without proper authorization If for any reason any of the safety switches are not functioning properly, the problem must be corrected before starting the compressor again The safety switch settings should be recorded and the results kept in the equipment file

6. Drain the condensate (condensed water) from the air receiver daily. Due to temperature changes, the air receiver will fill with condensate. Each day the condensate should be drained from the bottom of the tank There is usually a small valve at the bottom of the air receiver for this purpose. Some air receivers are equipped with automatic drain valves These must be inspected periodically to insure they are operating satisfactorily

7 Inspect belt tension on compressors Usually you should be able to press the belt down with hand pressure approximately three-fourths of an inch. This is done at the center between the two pulleys MAKE SURE COMPRESSOR IS LOCKED OFF BEFORE MAKING THIS TEST. Do not over-tighten belts because it will cause overheating and excessive wear on bearings and motor overloading

8 Examine operating controls Make sure the compressor is starting and stopping at the proper settings If it is a dual installation, make sure they are alternating if so designed, inspect gage for accuracy Compare readings with recorded startup values or other known, accurate readings

9. Many portable compressors are equipped with tool oilers on the receivers. These are used for mixing a small quantity of oil with the compressed air for lubrication of the tools being used These are located on the discharge side of the air receiver. They have a reservoir which must be filled with rock drill oil.

10 All compressors should be thoroughly cleaned at least monthly Dirt, oil, grease, and other material must be thoroughly cleaned off the compressor and surrounding area Compressors have a tendency to lose oil around piping, fittings and shafts; thus constant cleaning is required by the maintenance operator to insure proper and safe operation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326.

18 25A List some of the uses of a compressor in connection with operation and maintenance of a water treatment plant.

18.25B How often should the suction filter of a compressor be cleaned?

18.25C How often should compressor oil be changed?

18 25D How often should the condensate from the air receiver be drained?

18 25E What must be done before testing belt tension on compressors with your hands?

18.26 Valves[17]

18.260 Use of Valves

Valves are the controlling devices placed in piping systems to stop, regulate, check, divert, or otherwise modify the flow of liquids or gases There are specific valves that are more suitable for certain jobs than others. The five most common valves that you will find in a water treatment facility are discussed in this section

18.261 Gate Valves (Figures 18.32 and 18 33)

The basic parts of a gate valve are: the operator (handle), the shaft packing assembly, the bonnet, the valve body with seats, the stem, and the disc Gate valves come in a large number of sizes, but the principle of operation is quite similar for all sizes. One could associate the action of a gate valve to that of a guillotine having a screw shaft instead of the rope The valve disc is raised or lowered by a threaded shaft and is guided on each side to ensure that it will not hang up in the operation. The disc is screwed down until it wedges itself between two machined valve seats This makes a leak-proof seat on both sides of the disc The discs are replaceable Some gate valves have discs with wedges inside As more force is applied to the screwed stem, the wedges force the discs into tighter contact with the valve seats

Gate valves are either of the rising (Figure 18 32) or non-rising stem (Figure 18.33) type The rising stem has companion threads in the valve bonnet. As the valve is opened, the stem is threaded out, lifting the wedged disc In the non-rising type, the stem is held in place in the bonnet by a collar. The stem is threaded with companion threads in the wedged disc As the valve opens, the disc rises on the stem Consequently, the hand wheel stays on the same plane.

Gate valves are not commonly used to control flows With the valve partially open, the water velocity is increased through the valve and minute particles transported in the water can cause undue seat wear. However, the vee-ported gate valve can be used in controlling flows. As the valve is opened, the vee is widened to allow more flow Because of the valve design, little damage is done to the valve seats in the vee-ported type of gate valve.

Suggested operation and maintenance procedures are listed below:

1 Open valve fully. When at stop, reverse and close valve one-half turn.

2 Operate all large valves at least yearly to insure proper operation

3. Inspect valve stem packing for leaks Tighten as needed

4. If the valve has a rising stem, keep stem threads clean and lubricated

5. Close valves slowly in pressure lines to prevent water hammer

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[17] *For additional information on valves, see WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE, Chapter 3, Distribution System Facilities, Section 3.670, "Valves," in this series of manuals.*

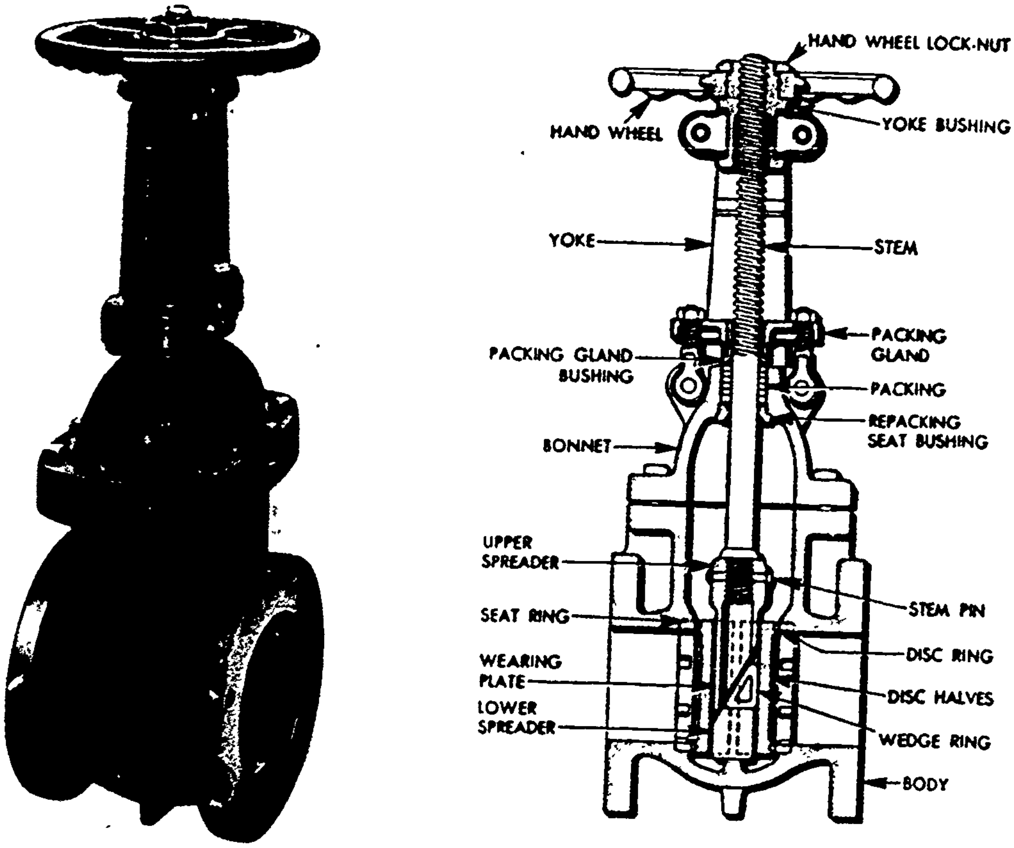

Fig. 18.32 Rising stem gate valve
(Permission of Stockham Valves & Fittings, Copyright, 1976)

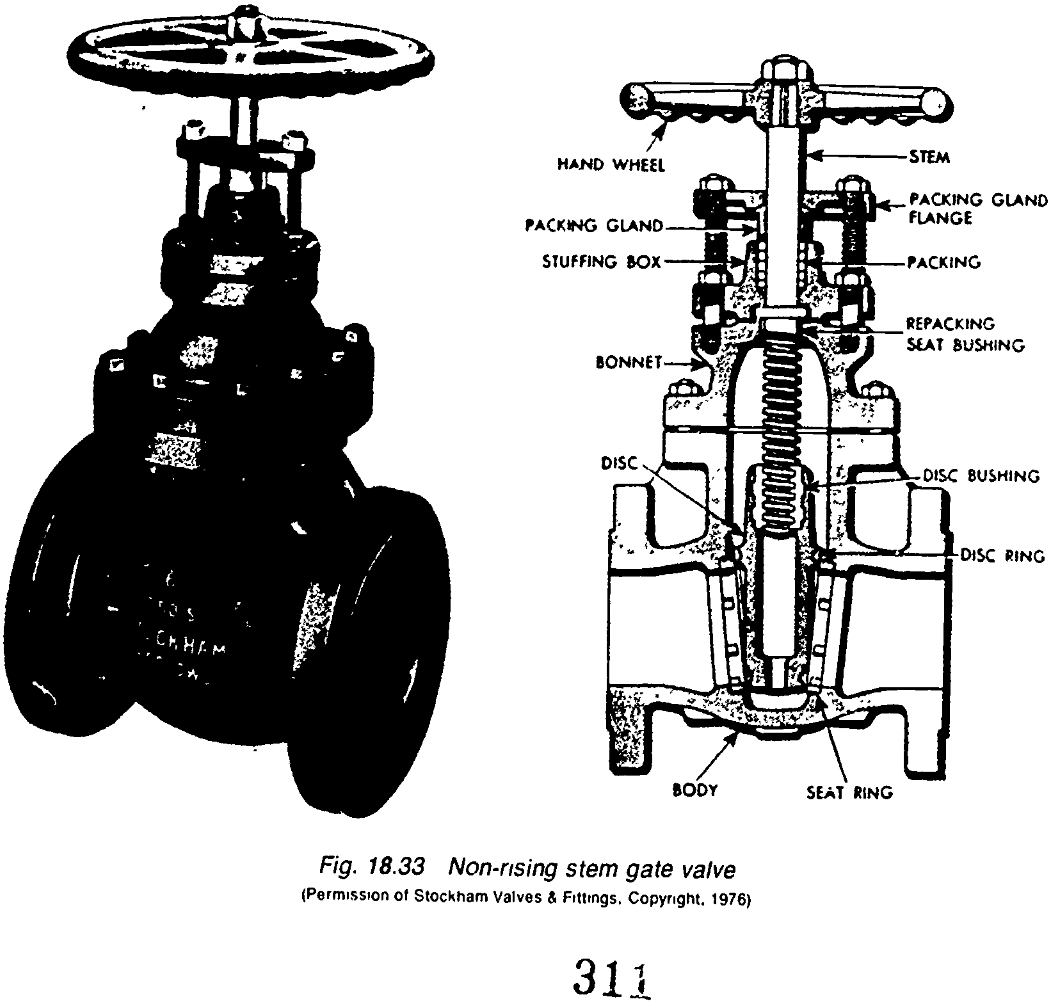

Fig. 18.33 Non-rising stem gate valve
(Permission of Stockham Valves & Fittings, Copyright, 1976)

6. If a valve will not close by using the normal operator, check for the cause. Using a "cheater" (bar-pipe wrench) will only aggravate your problem.

18.262 Maintenance of Gate Valves

Paragraph 12: Gate Valves

The most common maintenance required by gate valves is oiling, tightening, or replacing the stem stuffing box packing.

Frequency of Service

A 1. REPLACE PACKING. Modern gate valves can be repacked without removing them from service. Before repacking, open valve wide. This prevents excessive leakage when the packing or the entire stuffing box is removed. It draws the stem collar tightly against the bonnet on a non-rising stem valve, and tightly against the bonnet bushing on a rising stem valve.

- a. Stuffing box. Remove all old packing from stuffing box with a packing hook or a rattail file with bent end. Clean valve stem of all adhering particles and polish it with fine emery cloth. After polishing remove the fine grit with a clean cloth to which a few drops of oil have been added.
- b. Insert packing Insert new split-ring packing in stuffing box and tamp it into place with packing gland. Stagger ring splits. After stuffing box is filled, place a few drops of oil on stem, assemble gland, and tighten it down on packing

S 2 OPERATE VALVE. Operate inactive gate valves to prevent sticking.

A 3 LUBRICATE GEARING. Lubricate gate valves as recommended by manufacturer. Lubricate thoroughly any gearing in large gate valves. Wash open gears with solvent and lubricate with grease.

S 4 LUBRICATE RISING-STEM THREADS. Clean threads on rising-stem gate valves and lubricate with grease

A 5 LUBRICATE BURIED VALVES. If a buried valve works hard, lubricate it by pouring oil down through a pipe which is bent at the end to permit oiling the packing follower below the valve nut

A 6 REFACE LEAKY GATE VALVE SEATS If gate valve seats leak, reface them immediately, using the method discussed below. A solid wedge disc valve is used for illustration, but the general method also applies to other types of reparable gate valves. Proceed as follows:

- a Remove bonnet and clean and examine disc and body thoroughly. Carefully determine extent of damage to body rings and disc If corrosion has caused excessive pitting or eating away of metal, as in guide ribs in body, repairs may be impractical.
- b Check and service all parts of valve completely. Remove stem from bonnet and examine it for scoring and pitting where packing makes contact. Polish lightly with fine emery cloth to put stem in good condition. Use soft jaws if stem is put in vise
- c. Remove all old packing and clean out stuffing box Clean all dirt, scale, and corrosion from inside of valve bonnet and other parts.
- d Do not salvage an old gasket. Remove it completely and replace with one of proper quality and size.
- e. After cleaning and examining all parts, determine whether valve can be repaired by removing cuts from disc and body seat faces or by replacement of body seats. If repair can be made, set disc in vise with face leveled, wrap fine emery cloth around a flat tool, and rub or lap off entire bearing surface on both sides to a smooth, even finish. Remove as little metal as possible.
- f Repair cuts and scratches on body rings, lapping with an emery block small enough to permit convenient rubbing all around rings. Work carefully to avoid removing so much metal that disc will seat too low. When seating surfaces of disc and seat rings are properly lapped in, coat faces of disc with *PRUSSIAN BLUE*[18] and drop disc in body to check contact. When good, continuous contact is obtained, the valve is tight and ready for assembly. Insert stem in bonnet, install new packing, assemble other parts, attach disc to stem, and place assembly in body Raise stem to prevent contact with seats so bonnet can be properly seated on body before tightening the joint.
- g. Test repaired valve before putting it back in line to ensure that repairs have been properly made.
- h. If leaky gate valve seats cannot be refaced, remove and replace seat rings with a power lathe Chuck up body with rings vertical to lathe and use a strong steel bar across ring lugs to unscrew them. They can be removed by hand with a diamond point chisel if care is taken to avoid damaging threads. Drive new rings home tightly. Use a wrench on a steel bar across lugs when putting in rings by hand. Always coat threads with a good lubricant before putting threads into the valve body. This helps to make the

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[18] *Prussian Blue. A blue paste or liquid (often on a paper like carbon paper) used to show contact area Used to determine if gate valve seats fit properly.*

Frequency
of
Service

threads easier to remove the next time the seats have to be replaced Lap in rings to fit disc perfectly.

18.263 *Globe Valves* (Fig. 18.34)

The globe valve seating configuration is quite different from the gate valve Globe valves use a circular disc to make a flat surface contact with a ground-fitted valve seat. This is similar to placing your thumb over the end of a tube. The parts of the valve are similar in name and function to the gate valve. They can be of the rising or non-rising stem type

What is unique about the globe valve is its internal design (Figure 18.34). This design enables the valve to be used in a controlling mode The valve seats are not subject to excessive wear when partially opened like the gate valve. After extended use, the valve may not have a positive shutoff but it will still be effective in throttling flows. Procedures for operating and maintaining globe valves are similar to the procedures outlined for gate valves in Section 18.262

18.264 *Eccentric Valves* (Figs 18.35 and 18.36)

The eccentric valve has many desirable features These features include allowance for high flow capacity, quarter turn operation, no lubrication, excellent resistance to wear, and good throttling characteristics. The eccentric valve uses a cam shaped plug to match an eccentric valve seat. As the valve is closed, the plug throttles the flow yet maintains a smooth flow rate The plug does not come into contact with the valve seat until it is in the closed position.

Because the plug has a resilient coating, it insures a leak-tight seal at the valve seats The Buna-N, neoprene, or viton plug coating is a very wear resistant compound and can function well under a wide temperature range. This valve is excellent for controlling the flows of slurries and sludges found in water treatment facilities

18.265 *Butterfly Valves* (Fig. 18.37)

The butterfly valve is used primarily as a control valve. The flow characteristics allow the water to move in straight lines with little turbulence in the area of the valve disc (butterfly). Complete flow shutoff can be accomplished but the PSI rating is relatively low in comparison to eccentric or gate valves

The butterfly valve uses a machined disc that can be opened to 90 degrees to allow full flow through the valve. Quarter turn operation moves the valve from the 'closed' to 'open' position The disc is mounted on a shaft eccentric that allows the disc to come into its seat with minimum seating torque and scuffing of the rubber seat There is no contact between the disc and the seat until the last few degrees of valve closure

A resilient rubber is used as the seat and is of a continuous form that is not interrupted by a shaft connection. Wear resistance characteristics are good when used in slurry and sludge applications.

When the valve is closed, the disc is forced against the rubber seat Wedges with jacking screws compress the rubber seat via a jack ring. The rubber seat then conforms to the entire disc circumference. The rubber can be readily replaced when necessary without complete valve dismantling Large valves do not need to be removed from the line for seat replacement.

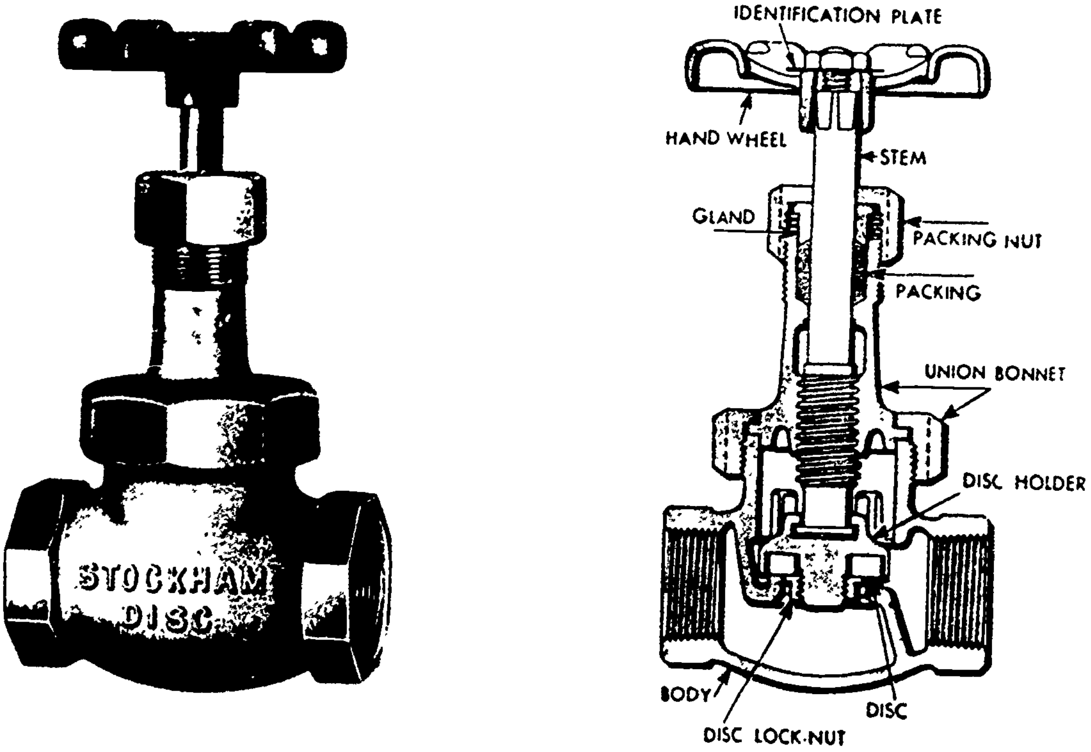
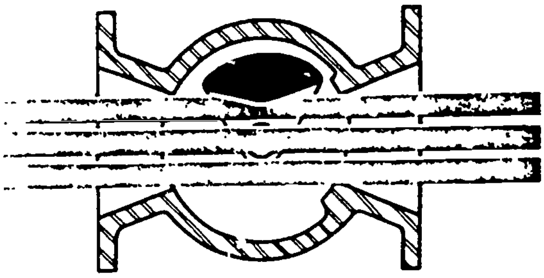


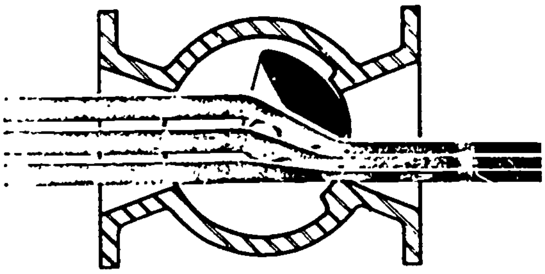
Fig. 18.34 Globe valve
(Permission of Stockham Valves and Fittings)

ECCENTRIC ACTION

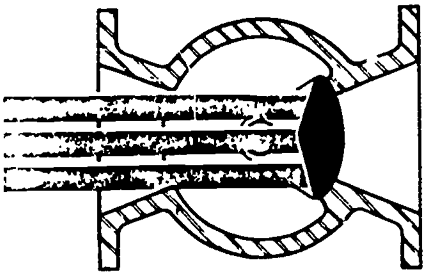
The DeZurik design matches a single-faced eccentric or cam-shaped plug with an eccentric raised body seat. With rotary motion only, the plug advances against the seat as it closes. Here's how it works:



OPEN—The plug is out of the flow path. There is no bonnet or other cavity to fill with slurry material. Flow is straight-through with minimum pressure drop.



CLOSING—At any position between open and closed, the eccentric plug still has not touched the seat. There is no friction to cause wear or binding. Flow is still smooth and straight. Throttling action is excellent on all types of services from slurries to gas.



CLOSED—The eccentric plug makes contact with the eccentric seat only in the fully closed position. Action is easy, without binding or scraping. There is no continual seat wear. The plug is moved firmly into the seat to provide a positive, drip-tight, long-lasting seal.

Fig. 18.35 How eccentric valves work
(Permission of DeZurik Corporation, Sartell, Minnesota)

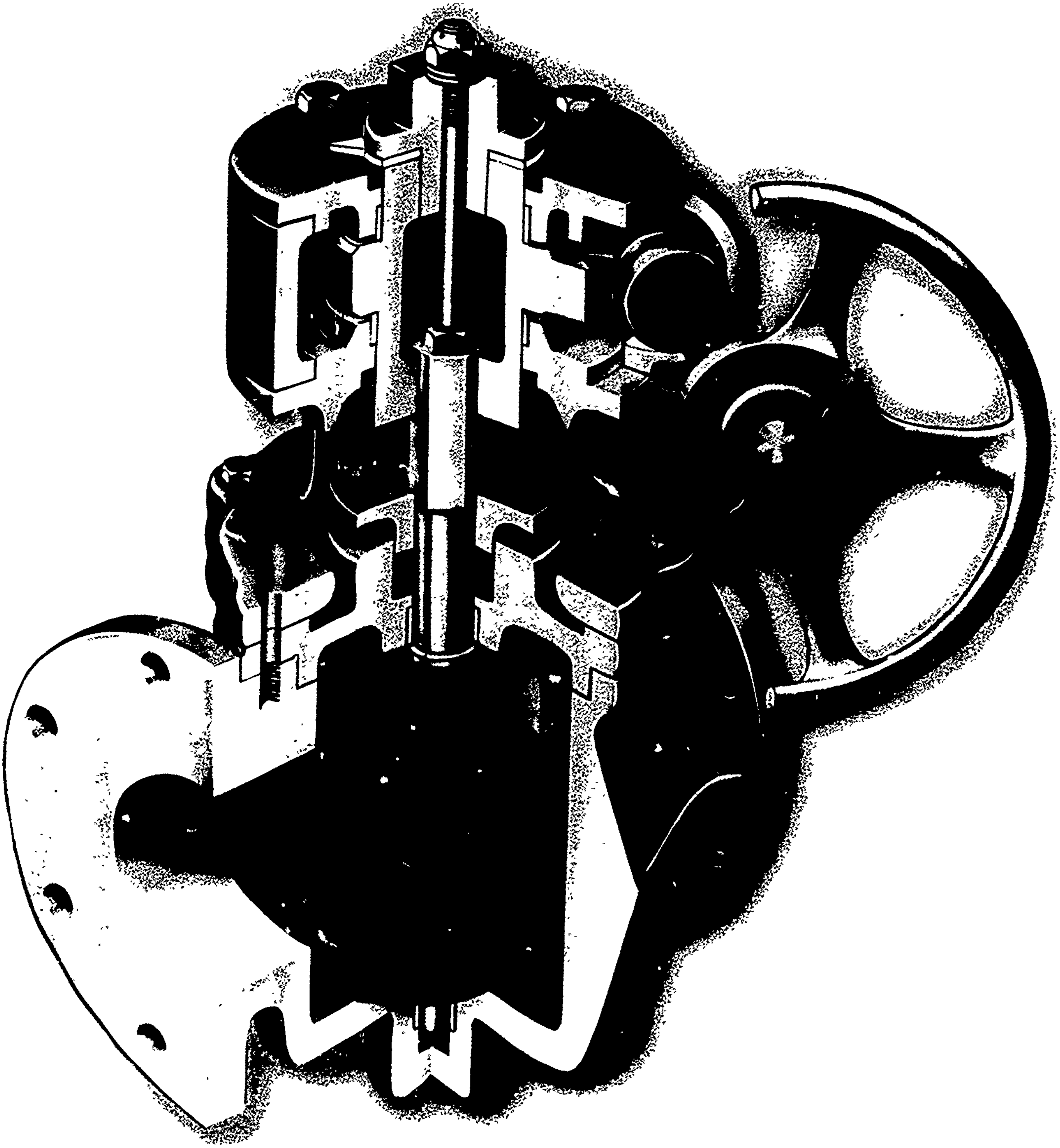


Fig. 18.36 Eccentric valve

(Permission of DeZurik Corporation, Sartell, Minnesota)

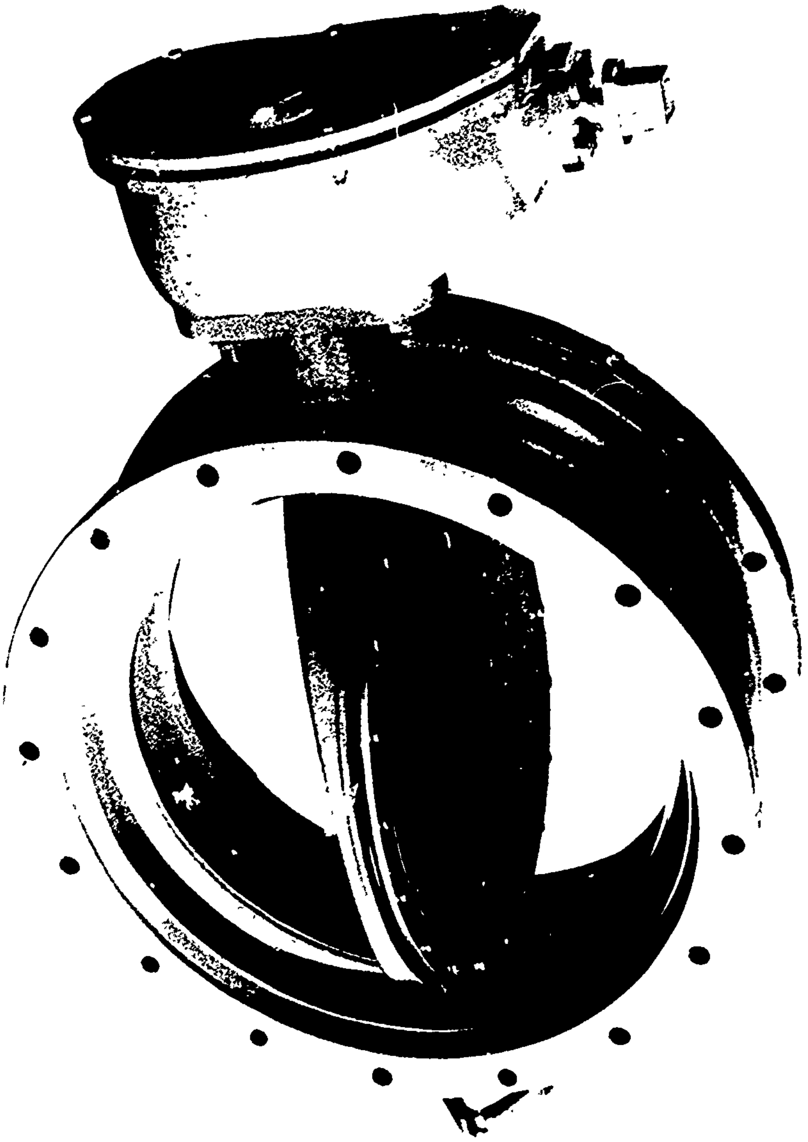


Fig. 18.37 Butterfly valve

(Permission of American-Darling Valve, Birmingham, Alabama)

18.266 Check Valves (Fig. 18.38)

The term 'check valve' describes its function. A check valve allows water to flow in one direction only. If the water attempts to flow in the opposite direction, an internal mechanism closes the valve and "checks" the flow. Three types of check mechanisms may be used — the swing check, the water check, or the lift check. In the swing check, a moveable disc rests at a right angle to the flow and seats against a ground seat. The moveable disc is called the clapper. The clapper can be one of three types: gravity operated, lever and weight operated, or lever and spring operated. In many installations the water being pumped must be delivered at a desired flow rate and pressure. A clapper with an external means of adjusting the opening in the check valve may be necessary to produce desired flows and pressures. By positioning the weight on the lever or adjusting the spring tension, a check valve can be made to operate either partially or fully open at various pressures and flows. The spring or counter weight also ensures that the check valve closes at "no flow." This is very helpful if the valve is not in a position that will enable gravity alone to operate the clapper. The gravity-operated clapper does not have an external adjustment and relies on the weight of the clapper to close the valve at "no flow" conditions.

Most swing check valves provide for full opening, that is, the clapper can move up into the bonnet and thus be completely out of the flow. Head loss in swing check valves may be relatively high and this factor must be considered in selecting the device for a particular application. This type of check valve is quite common in pump installations and often has a dampening feature to cushion the closing of the clapper.

The wafer check has a circular disc that hinges in the center (diameter) of the disc. Water passing through collapses the disc and the stoppage of flow allows the disc to return to its circular form. Because the valve has a tendency to be fouled up by stringy material, it is not commonly used in handling raw water. Wafer check valves are very effective when used with clean water.

The lift check uses a vertical lift disc or ball. When there is flow, the disc or ball is lifted from its ground seat and fluid passes through the valve. As flow stops, the check realigns itself with its seat and checks or prevents water backflow. The moveable portion can be a spring or gravity return.

The foot valves used in pump suctions are nearly always of the vertical lift disc design. A check valve of this type is usually applied to handle clean water.

Backflow prevention by check valves is essential in many applications to:

1. Prevent pumps from reversing when power is removed,
2. Protect water systems from being cross-connected,
3. Aid in pump operation as a dampener, and
4. Ensure "full pipe" operation (pipe is full of water).

Table 18.4 provides a comparison of various types of check valves with features of these valves. Figures 18.39 through 18.45 provide drawings and photographs of the different types of check valves listed in Table 18.4.

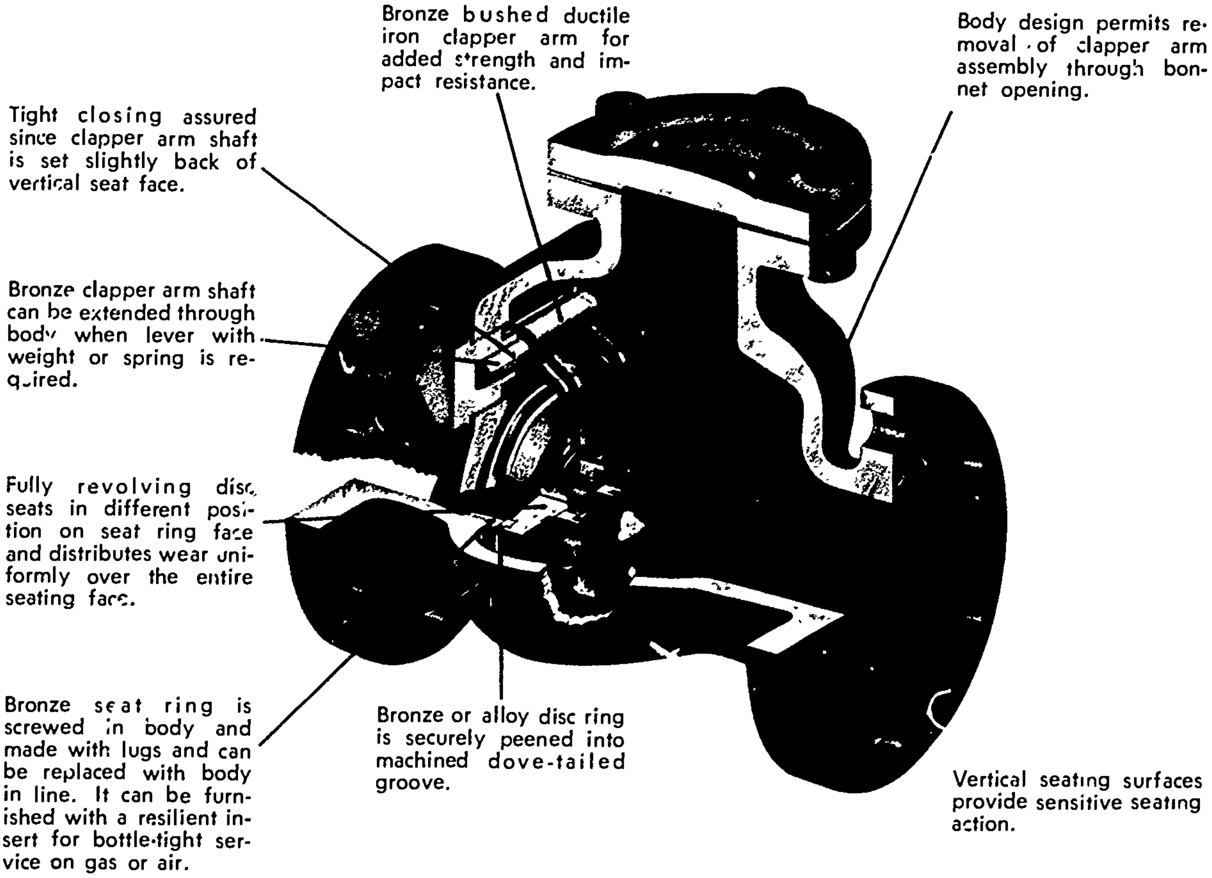


Fig. 18.38 Check valve

(Permission of American-Darling Valve, Birmingham, Alabama)

TABLE 18.4 COMPARISON OF FEATURES OF DIFFERENT TYPES OF CHECK VALVES[a]

WAFER SILENT CHECK VALVE	RUBBER FLAPPER CHECK VALVE	SLANTING DISC CHECK VALVE	
			1. Lowest initital cost
			2. Shortest laying length
X			3. Highest head loss (see head loss curves)
X			4. Resilient seat (optional)
	X		5. For waste and raw sewage
X		X	6. Clean water only
	X	X	7. Cushion closing
X			8. Silent closing (positively silent)
	X	X	9. Free open – Free close
		X	10. Control open or close or both (optional)
X			11. Vertical installation flow up or down
	X		12. Can be rubber lined
		X	13. Disc position indicator
	X		14. Buried service
			15. Outside lever
		X	16. Surge pressure control
	X		17. Reverse flow
X		X	18. Up to 600# class
X			19. Up to 1500# class
		X	20. Lowest head loss (see head loss curves)
			21. Up to 2500# class
			22. Control open and close standard
			23. Shut off valve
			24. Throttling valve
	X	X	25. Vertical installation flow up only
			26. Electric motor operated
			27. Remote control
			28. Control closure upon power failure
	X		29. Resilient seat standard
		X	30. Velocities in excess of 15 FPS
			31. Velocities up to 5 FPS
X	X		32. Velocities up to 10 FPS

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[a] Permission of APCO/Valve and Primer Corporation.

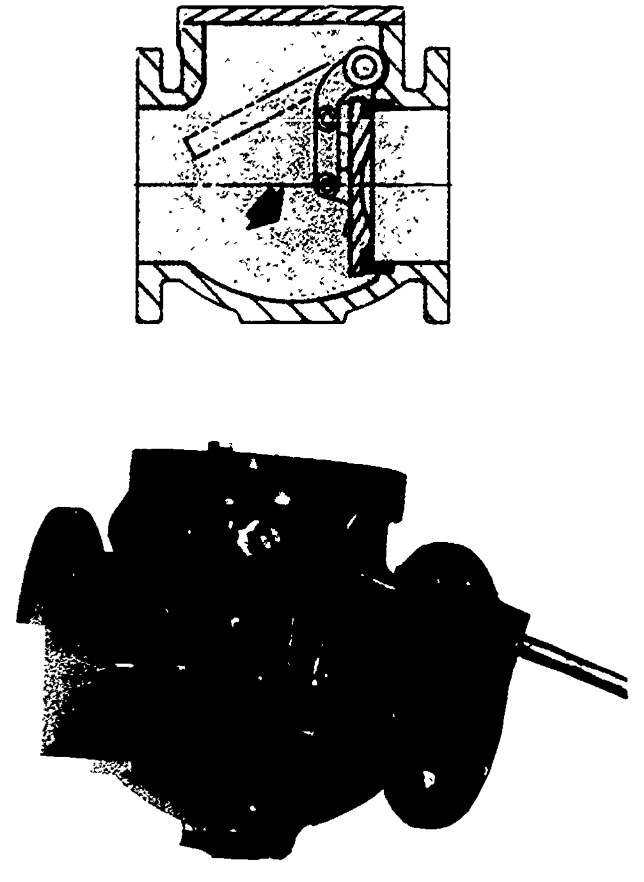


Fig. 18.39 Swing check valves (single disc)

(Permission of APCO/Valve and Primer Corporation)

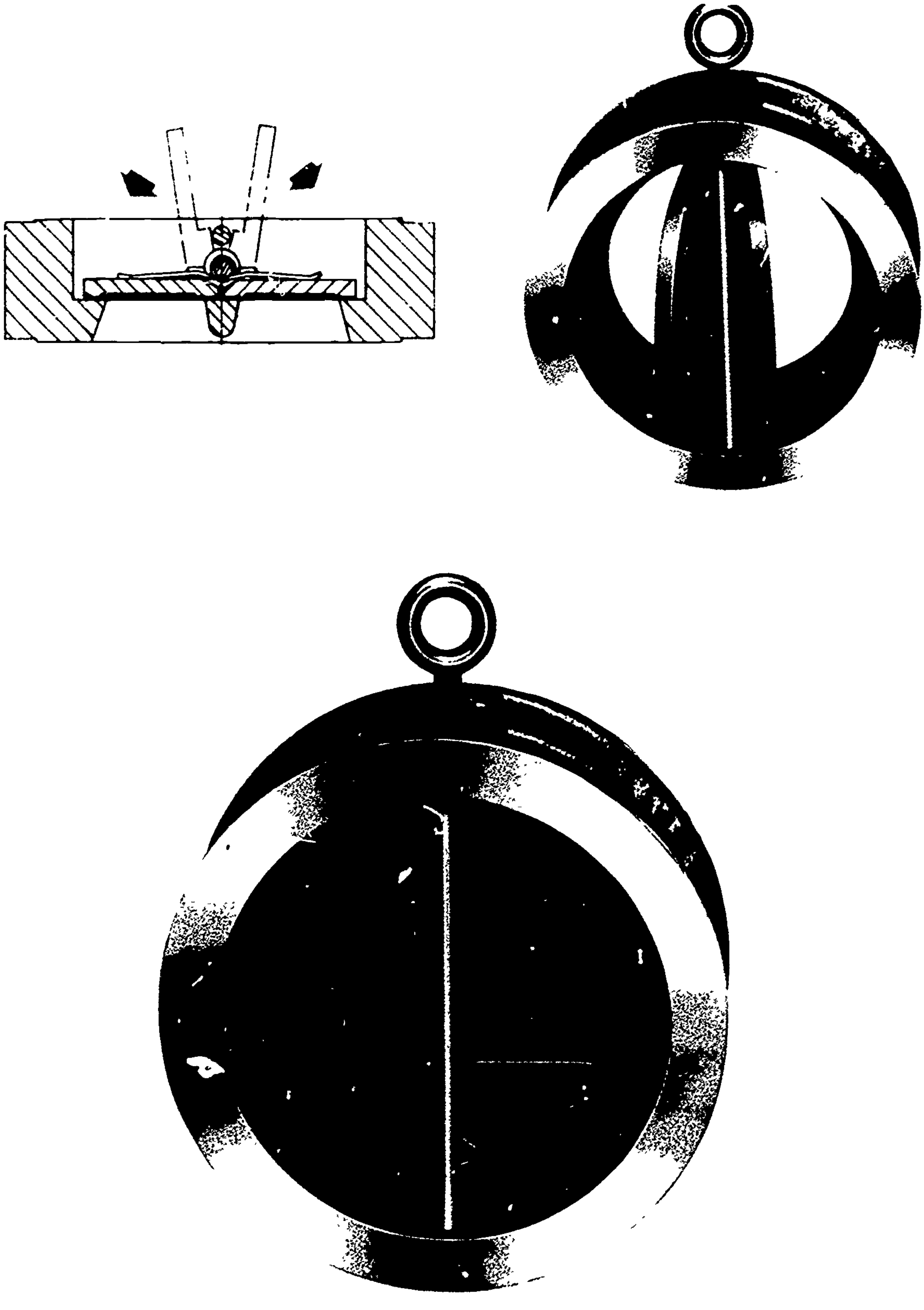


Fig. 18.40 Double disc swing check valves (split swing discs)

(Permission of APCO/Valve and Primer Corporation)

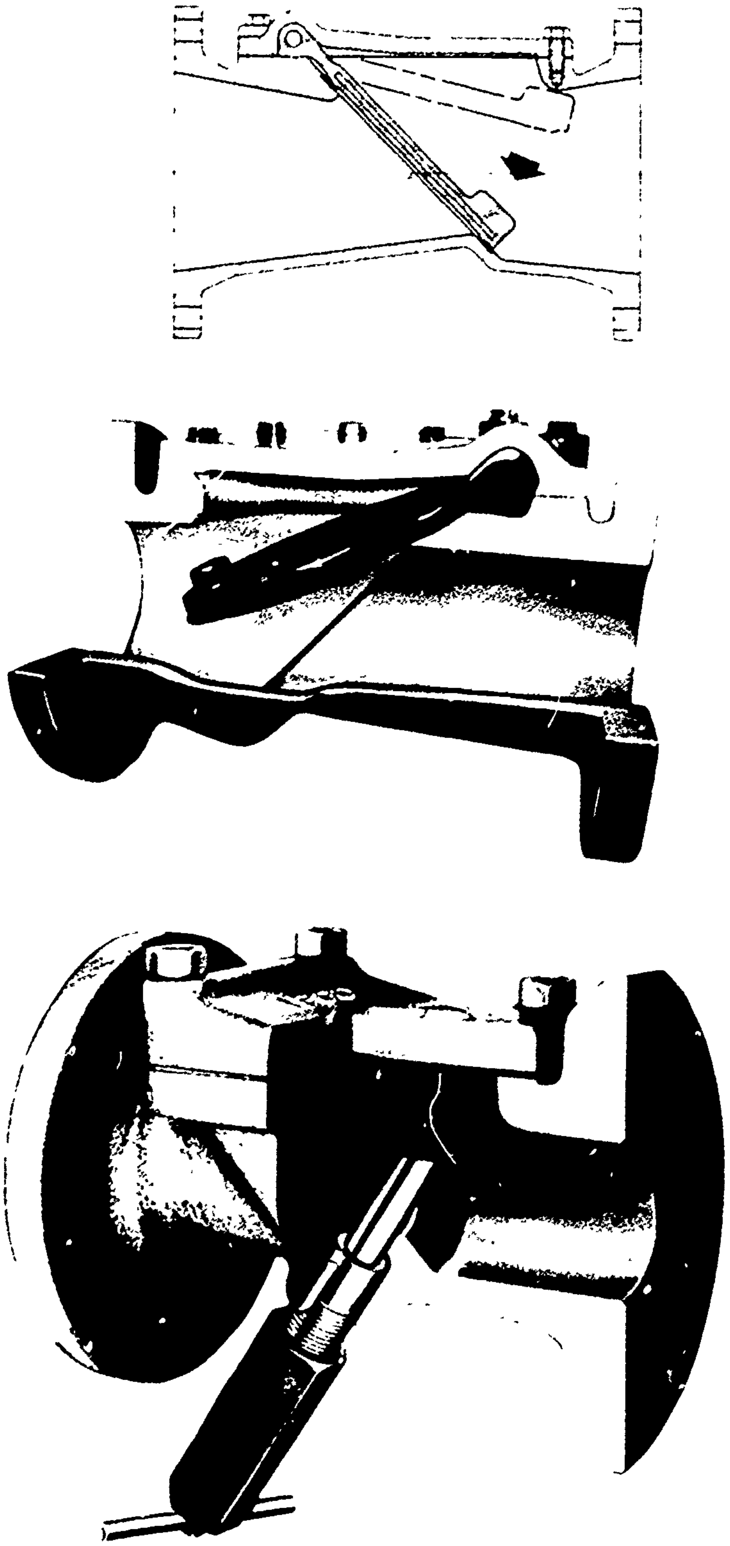


Fig. 18.41 Rubber flapper check valves (angle seating)
(Permission of APCO/Valve and Primer Corporation)

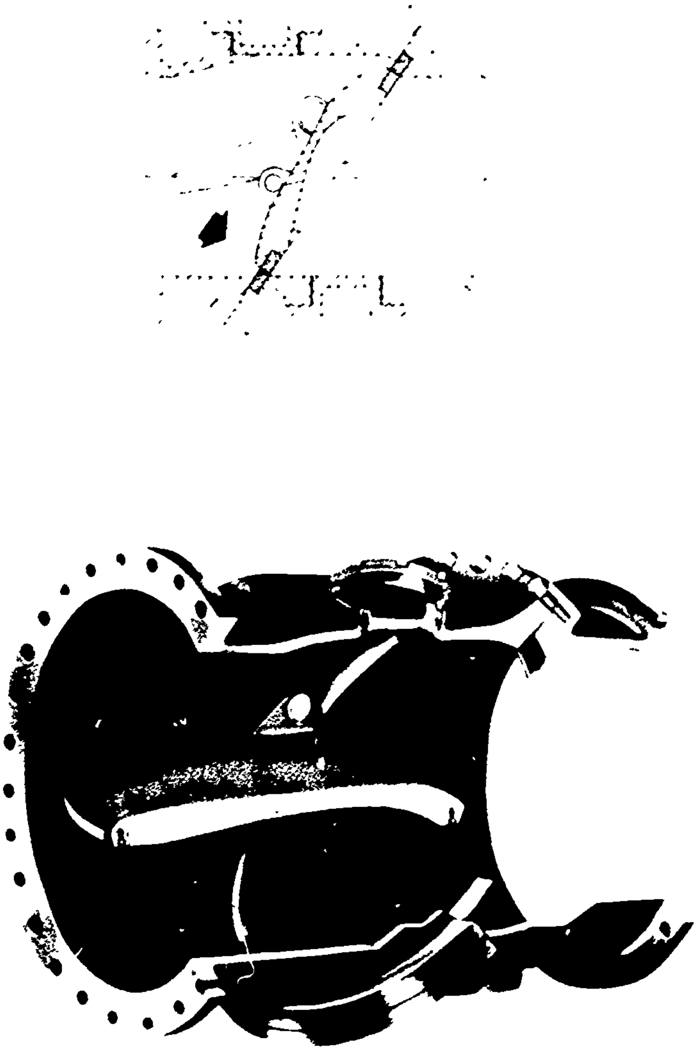


Fig. 18.42 Slanting disc check valves (pivot off center)
(Permission of APCO/Valve and Primer Corporation)

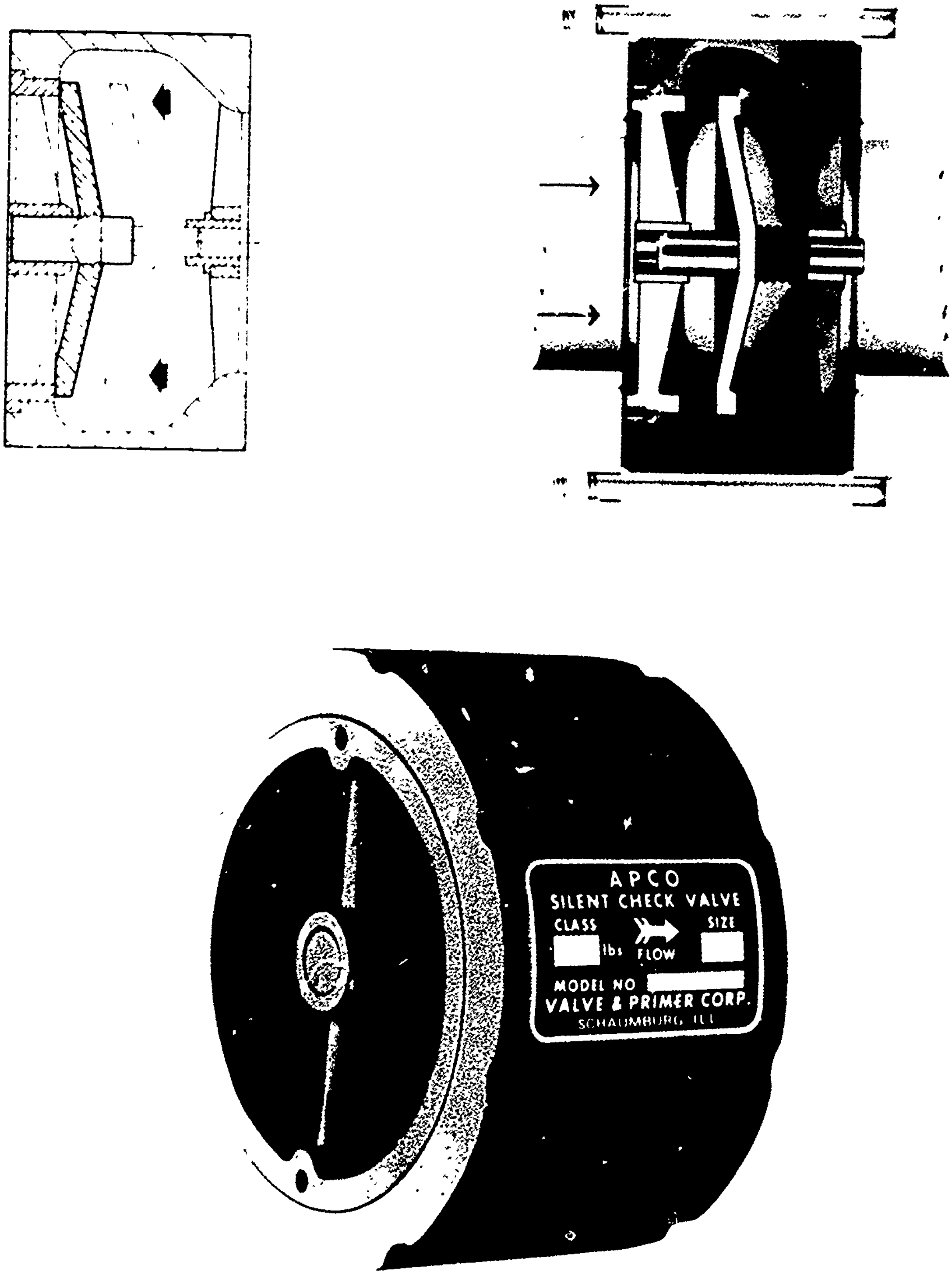


Fig. 18.43 Silent check valves (wafer)
(Permission of APCO/Valve and Primer Corporation)

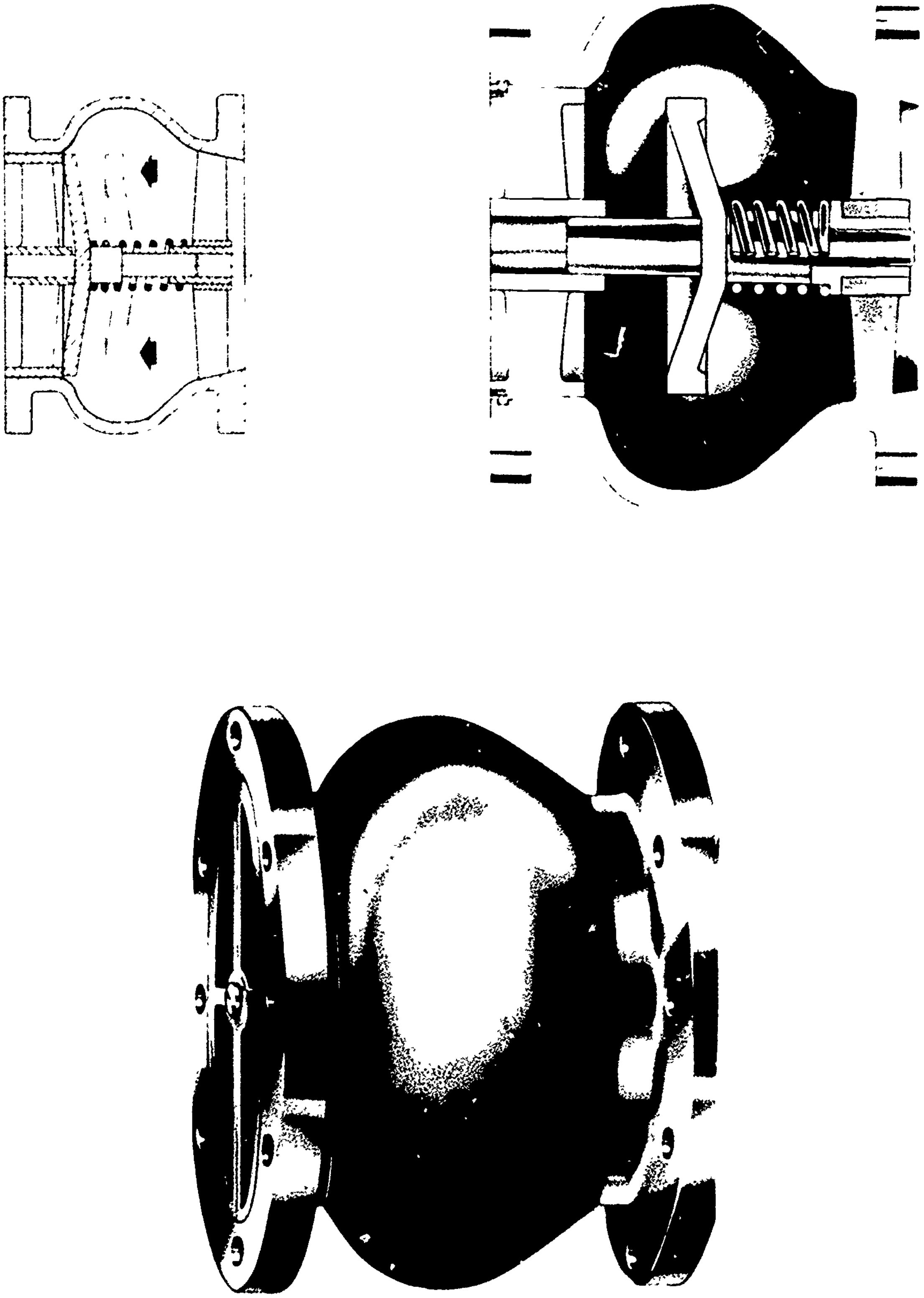


Fig. 18.44 Silent check valves (globe)
(Permission of APCO/Valve and Primer Corporation)

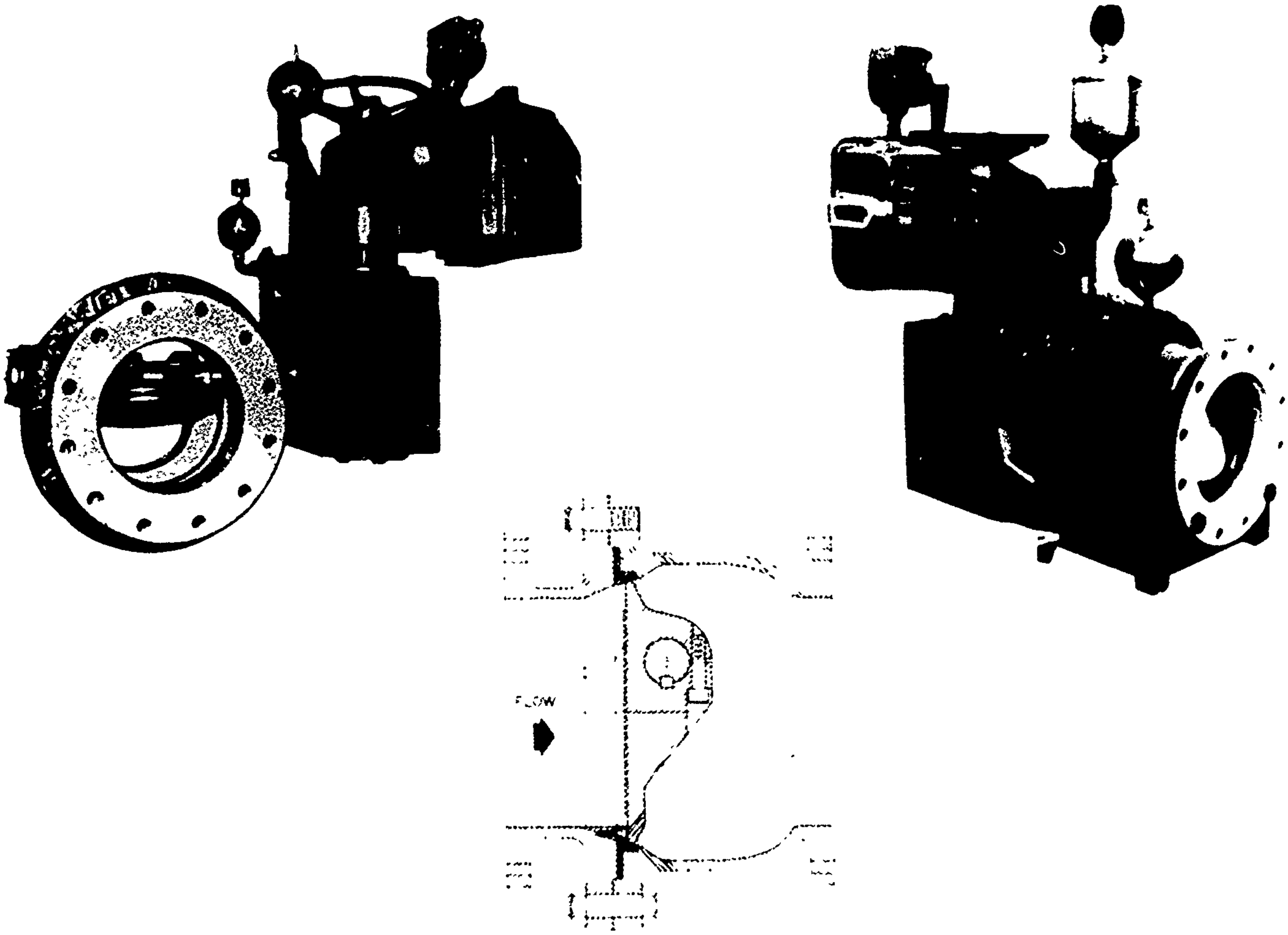


Fig. 18.45 Automatic control check valves
(Permission of APCO/Valve and Primer Corporation)

18.267 Maintenance of Check Valves

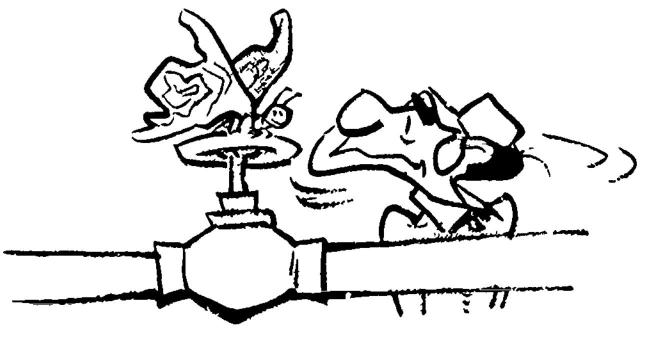
Paragraph 13: Check Valves

Frequency of Service	
A	1 INSPECT DISC FACING Open valves to observe condition of facing on swing check valves equipped with leather or rubber seats on disc. If metal seat ring is scarred, dress it with a fine file and lap with fine emery paper wrapped around a flat tool.
A	2. CHECK PIN WEAR. Check pin wear on balanced disc check valve, since disc must be accurately positioned in seat to prevent leakage

18.268 Automatic Valves

Water treatment plants usually have a number of automatically operated valves. The simplest type is either open or closed and is not required to operate in an intermediate position. Frequently these valves are similar to gate valves that have had their threaded stems and handwheels replaced by a smooth shaft and hydraulic piston. Maintenance on these valves is essentially the same as for gate valves.

Other automatically operated valves are used to control flow in water treatment plants and are usually located at some point between tight shut and wide open. These are commonly called modulating valves. A butterfly valve with a hydraulic cylinder operator can be used for this type of service.



The diaphragm-operated globe valve (Figure 18.46) is also used for modulating service These valves can be equipped with pilot control devices to control pressure, flow, or level either singly or in combination. Maintenance on these valves consists of the following:

1. Periodically clean any strainers in the pilot control system Scheduling should be adjusted to accommodate the rate at which the strainer collects foreign material.
2. Check the operation of the valve to see that the controls are, in fact, correctly positioning the valve to accomplish the job.
3. If the valve is used in an application where it seldom or never is wide open, it should periodically be exercised manually to cycle from tight shut to wide open. This is to insure that there is no buildup on the stem that could jam the valve. These valves can be opened wide by drawing all the pressure from the cover chamber. If water does not stop flowing out of the cover chamber, when the valve is wide open, it is an indication that the diaphragm is leaking and should be replaced.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326.

18.26A What is the purpose of valves?

18 26B List six common types of valves found in water treatment facilities

18 26C What is the purpose of a check valve?

18.26D Why is backflow prevention by check valves essential in many applications?

18 26E What maintenance is required by gate valves?

End of Lesson 4 of 5 Lessons on MAINTENANCE

Please answer the discussion and review questions before continuing with Lesson 5.

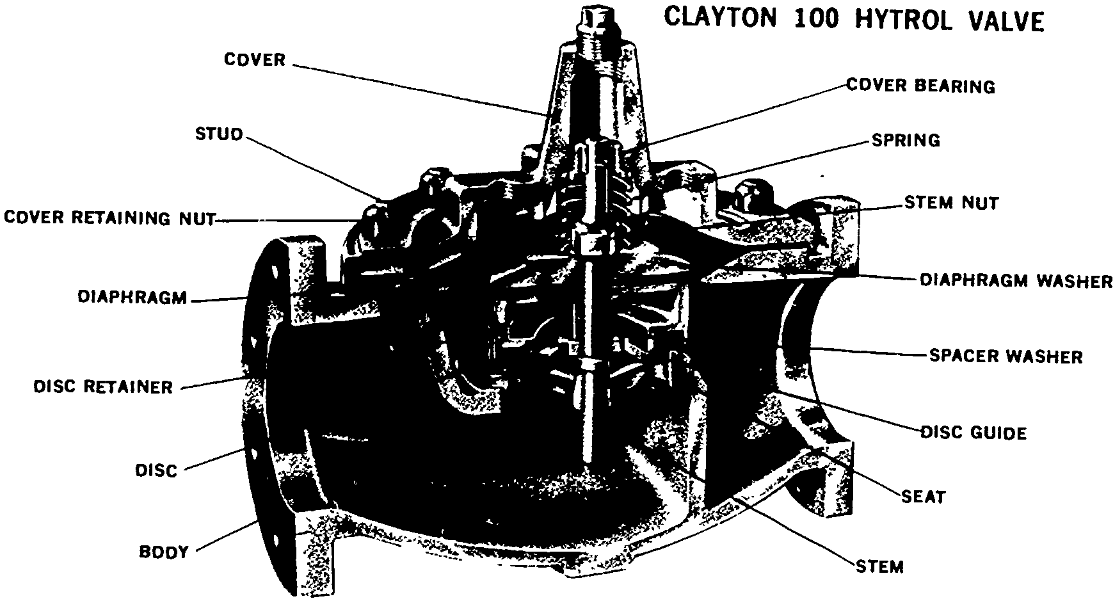
DISCUSSION AND REVIEW QUESTIONS

Chapter 18. MAINTENANCE

(Lesson 4 of 5 Lessons)

Write your answers to these questions in your notebook before continuing. The question numbering continues from Lesson 3.

32. What are the uses of a compressor?
33. What items should be maintained on a compressor?
34 Why should inactive gate valves be operated periodically?
35. What factors can cause wear on gate valve seats?



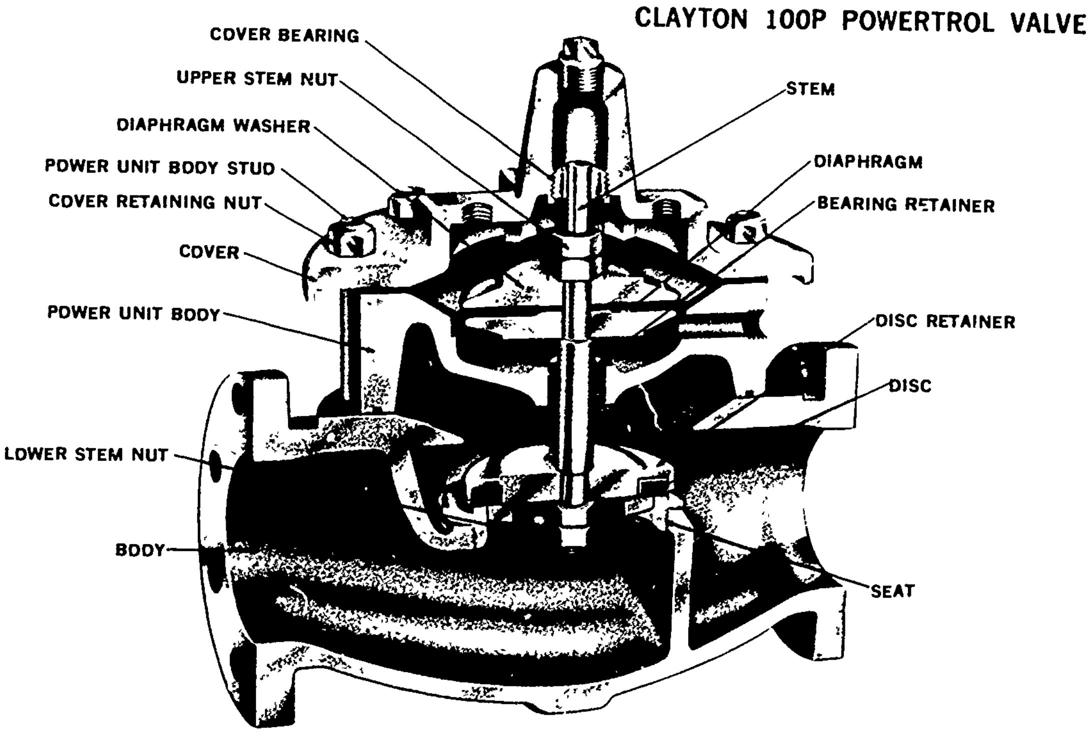


Fig. 18.46 Diaphragm operated globe valve
(Permission of CLA-VAL Co)

CHAPTER 18. MAINTENANCE

(Lesson 5 of 5 Lessons)

18.3 INTERNAL COMBUSTION ENGINES

18.30 Gasoline Engines[19]

18.300 Need to Maintain Gasoline Engines

In the water treatment departments of all cities there is occasion to use gasoline-powered engines that drive pumps, generators, tractors, and vehicles. Although we all drive automobiles that are powered by internal combustion engines, are you aware of the fundamentals?

Very few operators actually do the repair of gasoline-powered engines. Although you may not be able to perform the duties of an engine mechanic, there are a number of steps you can take to ensure that your particular engine is well maintained.

At the end of this section you will have an adequate knowledge of how a gasoline engine operates in order to maintain it so as to provide many hours at optimum performance.

18.301 Maintenance

In order to have an engine that will provide you with many hours of trouble-free operation, it must be well cared for *PLEASE REFER TO THE OWNER/OPERATOR MANUAL FOR YOUR PARTICULAR ENGINE.* Typical maintenance procedures are as follows:

1 Change engine oil regularly every 25 hours,
2 Clean carburetor air filter every 25 hours;
3 Blow dust and chaff from louvered engine vanes regularly;
4 Clean carburetor fuel filter/screen every 100 hours;
5 Lubricate generator and/or starter motor as recommended, every 100 hours;
6. Lubricate throttle linkage every 100 hours.
7. Clean, gap, or replace spark plug every 100 hours; and
8. Remove carbon deposits from top of piston and valves every [illegible]0 to 300 hours.

18.302 Starting Problems

Listed below are some items to check if you have problems starting a gasoline engine

1. No fuel in tank, valve closed
2 Carburetor not choked
3 Water or dirt in fuel lines of carburetor

4 Carburetor flooded
5 Low compression
6 Loose spark plug, and
7. No spark at plug
    a Dirty and improper/gapped plug
    b Broken or wet ignition cables
    c. Breaker points not opening or closing, and
    d Magneto grounded

18.303 Running Problems

Check the following items if a gasoline engine does not run properly

1 Engine misses
    a Faulty spark plug/gapping
    b Weak ignition spark
    c Loose ignition cable
    d Worn breaker points
    e Water in fuel
    f Poor compression
2 Engine surges
    a Carburetor flooding
    b Governor spring connected improperly

---

[19] *For additional information on gasoline engines, see INDUSTRIAL WASTE TREATMENT, Chapter 7, Support Systems, Section 7 4, "Gasoline Engines," in this series of manuals.*

3. Engine stops
   a. Fuel tank empty
   b. Vapor lock
   c. Tank air vent plugged
4. Engine overheats
   a. Low crankcase oil
   b. Ignition timing wrong
   c. Engine overloaded
   d. Restricted air circulation/high ambient temperature
   e. Poor grade of gasoline
5. Engine knocks
   a. Poor grade of gasoline
   b. Engine under heavy load at low speed
   c. Carbon deposits in cylinder head
   d. Spark advanced too far
   e. Loose connecting rod bearing
   f. Worn or loose piston pin
6. Engine backfires through carburetor
   a. Water or dirt in fuel
   b. Cold engine
   c. Poor grade of gasoline
   d. Sticking inlet valves
   e. Spark plug heat range too hot

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326

18.30A List some possible uses of gasoline engines in water treatment plants.

18.30B What items would you check if you had problems starting a gasoline engine?

18.30C What items could cause a gasoline engine to not run properly?

18.304 How to Start a Gasoline Engine

Because of the wide variety of uses for gasoline-powered engines, no one starting sequence will apply to all engines. In general, gasoline engines can be divided into two groups. In the first group are small engines with magneto ignition and recoil start. Larger engines with battery-powered ignition and electric start are in the second group.

18.3040 Small Engines. The procedure for starting small engines is as follows:

1. Check fuel tank for adequate fuel;
2. Ensure fuel shut off valve from the tank to the carburetor is open;
3. Disengage ignition ground ("kill" switch or mechanism that grounds the spark plug);
4. Check crankcase lubricating oil;
5. Set throttle to start position or ¾ full throttle;
6. Set choke lever or pull out choke on carburetor,
7. Pull recoil starter twice,
8. If engine has started, push choke to "off", and
9. If engine does not start after two pulls, disengage the choke and try three or four more times.

If repeated efforts at starting have been unsuccessful, remove the high tension voltage wire from the spark. Hold the end of the wire (grasp the insulated portion, *NOT* the connector) ⅛ inch (3 mm) from the spark plug Pull the recoil starter. You should see a small blue spark This will indicate that the points are opening and closing and providing ignition voltage.

The next step is to remove the spark plug from the cylinder head (use a 13/16 inch (20.6 mm) deep socket). Check for a carbon buildup on the electrode. A piece of carbon may have lodged between the center electrode and the side electrode. Also check to see if the plug is wet with fuel or oil. This could indicate that you have flooded the cylinder with fuel by having the choke on too long. If there is oil residue, it could indicate worn piston rings.

Replace the spark plug with a new one if in doubt. If you must use the one you have, clean it by buffing with a wire brush. Check the "gap" between the center electrode and side electrode; it should be approximately .030 inch (30 thousands of an inch or 0.76 mm).

Try staring the engine as previously described. If the engine does not sputter or pop, close the fuel shut-off valve, remove fuel sedimentation bowl and clean. Open fuel valve. Catch a small amount of fuel in the palm of your hand and examine the fuel for grit or water. If everything looks okay, replace sediment bowl and open fuel valve.

Try to start the engine. If you still cannot achieve ignition, you may have other problems that will require further checking by a small-engine mechanic Do not feel disgruntled, you have checked for the most common problems.

18.3041 Large Engines. The procedure for starting large engines is as follows:

1. Check fuel tank for fuel;
2. Check crankcase for oil;
3. Check radiator for coolant (if water cooled);
4. Set throttle to ½ full position;

5 Pull out choke.

6 Turn on ignition switch and press start button.

7 After four or five engine revolutions, push in the choke, and

8 Engine should start

After repeated tries, further investigation by a mechanic may be needed

NOTE Do not crank engine with the starter motor for more than one minute initially Wait two minutes and try again for 45 seconds After three trys, let starter motor cool for 5 minutes before trying again This will avoid starter motor damage.

Preliminary checks for a large engine that won t start are similar to procedures for small engines

Remove spark plug wires Test each one by holding it ⅛ inch (3 mm) from the spark plug or ground, and turn engine over with the starter. You should see a small blue spark. If you have no spark, the points are not opening or high tension voltage is not present from the ignition coil. Check further as needed

If spark is present, inspect spark plugs. Clean or replace if needed

After checking the ignition system, make sure fuel is present at the carburetor Remove the fuel line at the carburetor and direct it away from you and the engine Engage starter motor for two revolutions. Fuel should spurt from the line if the fuel pump is working satisfactorily Replace fuel line and wipe away any fuel that may be present on the engine.

With fuel and ignition voltage present, it should start. Repeat start procedure If you still cannot start the engine, call on your mechanic to look for the problem.

NOTE: Some engines have a low oil pressure switch that must be manually held in until sufficient oil pressure is present.

Do not use a starting fluid on gasoline engines unless it is a *LAST RESORT* effort to get a critical piece of equipment running. Hard-starting engines should be inspected and repaired by a reliable mechanic

After an engine has been started, give it an opportunity to warm up before applying the load. Follow manufacturer's recommendations for the starting procedure since there is some variation between different makes of engines

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326.

18 30D If a gasoline engine will not start and the spark plug is wet with fuel or oil, what has happened?

18 30E If a gasoline engine will not start and there is an oil residue on the spark plug, what has happened?

18.30F After an engine has started, what should be done before applying the load?

18.31 Diesel Engines[20]

18.310 How Diesel Engines Work (Fig 18 47)

Diesel engines are similar to gasoline engines and are either two or four cycle They can be air or water cooled In general the diesel engine is of heavier construction to withstand the higher pressures resulting from higher compression ratios

The diesel does not use spark plugs, but instead relies on heat generated by air compressed in the cylinder (1,000 degrees F or 540°C) to ignite the fuel mixture. The fuel is a petroleum product that is heavier than gasoline and with a higher flash point Gasoline cannot be used in a diesel because it would start to burn from the heat generated by compression before the piston reached the top of the stroke

A diesel has no carburetor The fuel is sprayed (injected) into the cylinder while the cylinder is compressing air The heat of compression ignites the fuel-air mixture and burns, producing power similar to a gasoline engine The introduction of fuel into the cylinder must be "timed" in the same manner as spark to the plug in a gasoline engine Fuel is pumped by a pumping device that is geared to the crankshaft

Diesel fuel, unlike gasoline, does not vaporize readily The fuel must be broken up in fine particles and sprayed into the cylinder The atomization of fuel is accomplished by forcing the fuel through a nozzle at the top of the combustion chamber As the fuel combines with the air in the cylinder, it becomes a combustible mixture Since the diesel engine depends upon the heat of compressed air to ignite the fuel-air mixture, compression pressure must be maintained Leaking valves or piston rings (causing "blow by") cannot be tolerated

The fuel is also important. The automotive-type diesel is designed to run on a specific type or grade of fuel Trouble can be expected if an attempt is made to use other than the proper type

18.311 Operation

In the two-cycle engine, intake and exhaust takes place during part of the compression and power strokes; whereas, the four-cycle engine requires four strokes to complete the operating cycle During one-half of the cycle, the four-stroke acts as an air pump. The two-stroke must have a blower (air pump) to provide the necessary air to expel the exhaust gases and recharge the cylinder with fresh air

In the two-cycle, a series of ports surround the cylinder at a point higher than the lowest position of the piston. These are the intake ports that allow air into the cylinder The four-cycle engine uses intake valves The incoming air forces the expended gases out the exhaust valve, leaving the cylinder full of clean air

As the piston starts its upward stroke, the exhaust valve closes, the intake ports are sealed off by the piston, and the air in the cylinder is compressed Shortly before the piston reaches the top of the stroke, the required amount of fuel is sprayed into the combustion chamber by the fuel injector. The intense heat of compression ignites the fuel-air mixture with the resulting combustion driving the piston down on its power stroke.

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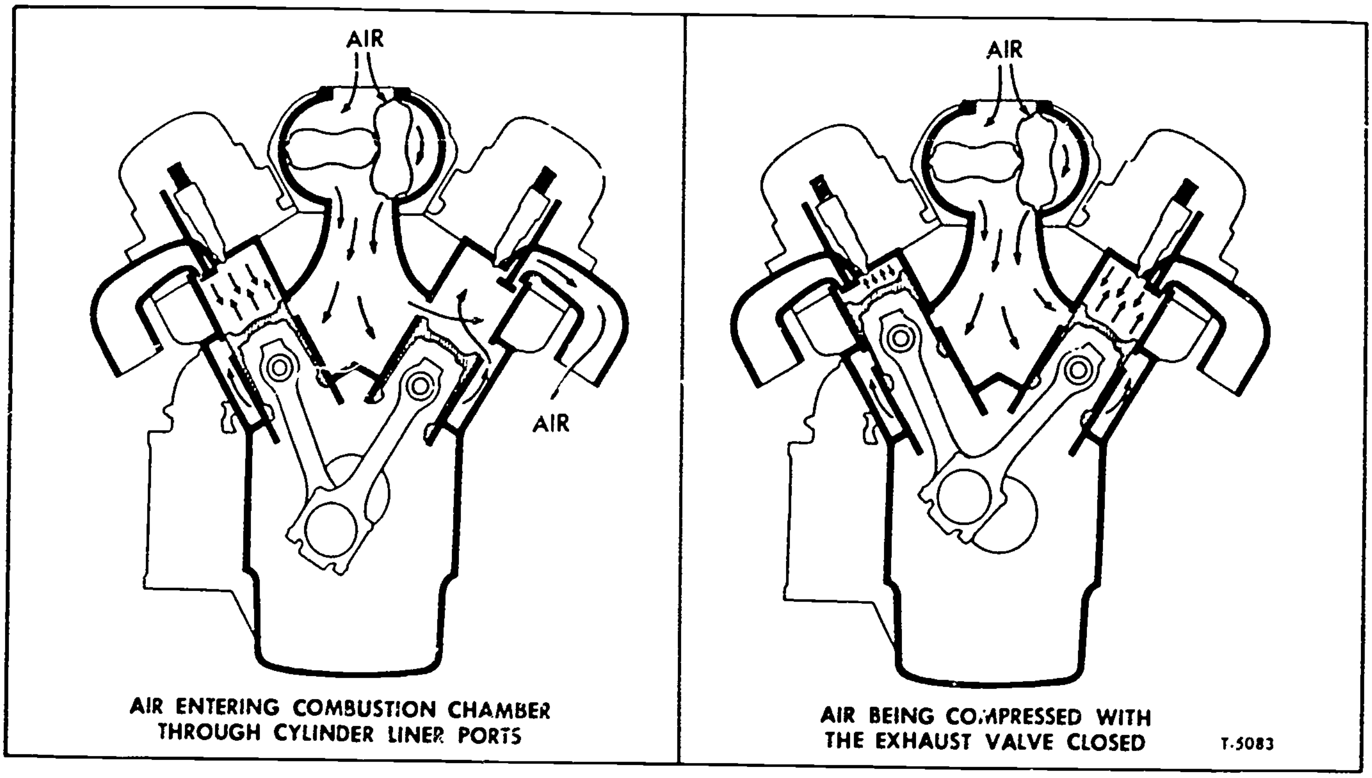
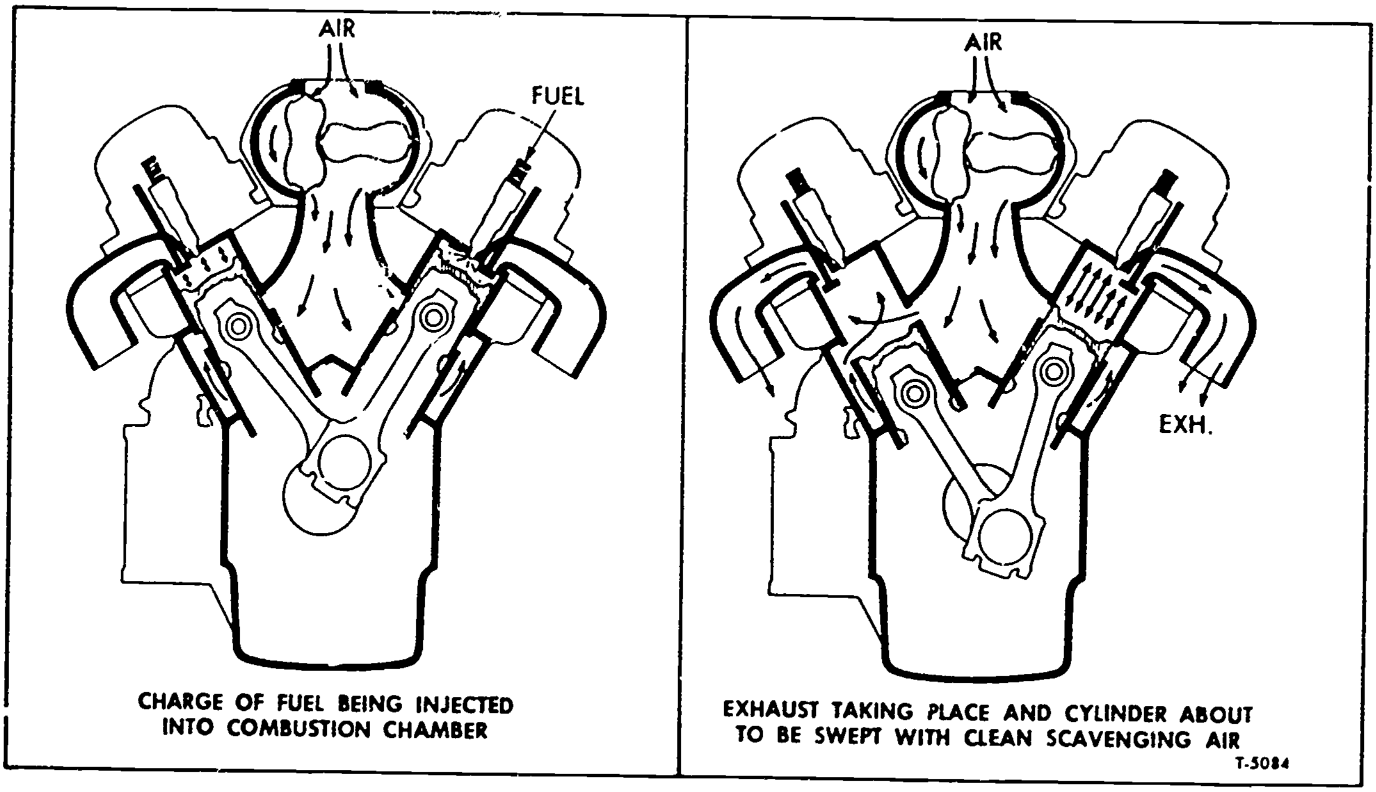
[20] *For additional information on diesel engines, see INDUSTRIAL WASTE TREATMENT, Chapter 7, Support Systems, Section 7.5, "Diesel Engines," in this series of manuals.*



Scavenging and Compression



Power and Exhaust

Fig. 18.47 How diesel engines work

(Source GMC Truck Overhaul Manual Series 53, permission of General Motors Corp.)

As the piston nears the bottom of the stroke, the exhaust valve opens and the spent gases are released, assisted by the incoming fresh air. The cycle is complete.

18.312 Fuel System (Fig. 18.48)

The basic parts of the fuel system are:

1. Primary fuel filter,
2. Secondary fuel filter,
3. Fuel injection pump, and
4. Fuel injector.

The primary filter removes all coarse particles from the fuel and the secondary filter removes any minute particles that remain. This ensures a clean fuel that will not clog the injector pump or fuel injectors. The heart of the fuel system is the injection pump (Fig. 18.49) This pump is a gear-type positive-displacement pump that can deliver fuel to the injector at a very high pressure. Incorporated into the pump is a timing advance mechanism to advance or retard the instant when fuel is injected into the cylinder. At high engine speed, injection would take place sooner in the cycle. The reverse happens for lower speeds.

A governor which uses centrifugal weights and is driven by the pump shaft, activates a fuel control unit. When engine speed increases, the weights are thrown toward their outer limit Geared to the assembly, the fuel control valve is opened wider allowing more fuel to flow to the injector.

We now have higher engine speed, advanced "timing" of injection, and the necessary fuel to sustain the faster operation. When the engine is slowed, the reverse takes place.

Fuel under pressure is fed from the injection pump to the appropriate fuel nozzles. When the pressure reaches approximately 3,000 psi (20,700 kPa or 207 kg/sq cm), the valve in the injector opens allowing fuel to be injected into the combustion chambers As line pressure drops, the return spring closes the nozzle valve. Fuel left in the line is fed back to the pump through "leak off" lines.

18.313 Water-cooled Diesel Engines

Usually the larger diesel engines are of the water-cooled type, similar to gasoline engines. In order to deliver a sustained amount of high horsepower, an effective cooling system is necessary to dissipate the extreme heat of combustion. Because of this fact, a water-cooled engine of comparative horsepower to the air-cooled will cost more to manufacture, and subsequently to maintain.

18.314 Air-cooled Diesel Engines

When a lighter weight, lower horsepower, and more compact engine is desired, the air-cooled engine will serve your needs. You get the benefits of a diesel engine in a smaller package.

There are some definite advantages to the diesel engine over the gasoline engine. The initial cost is greater for the diesel; however, the diesel:

1. Requires less maintenance because there are:
   a. No plugs,
   b. No contact points to pit,
   c. No ignition coils or high tension wires, and
   d. Fewer tune-ups.
2. Is cheaper to operate because:
   a. Diesel fuel may be cheaper, and
   b. Better fuel efficiency

Perhaps the biggest drawbacks against diesel engines are

1. Initial investment costs, and
2. Repair costs

The pros and cons must be weighed to provide you with an engine that will fill your particular needs Whichever engine you select, remember that a well-cared-for engine will be there to serve you when it is needed and will provide trouble-free operation that is essential to most users

18.315 How to Start Diesel Engines

Diesel engines vary in size and use and have varied starting procedures. Follow manufacturer's suggested procedures for your particular engine. As with the gasoline engine, check fuel, oil, and coolant.

To start a diesel engine, the procedures are as follows

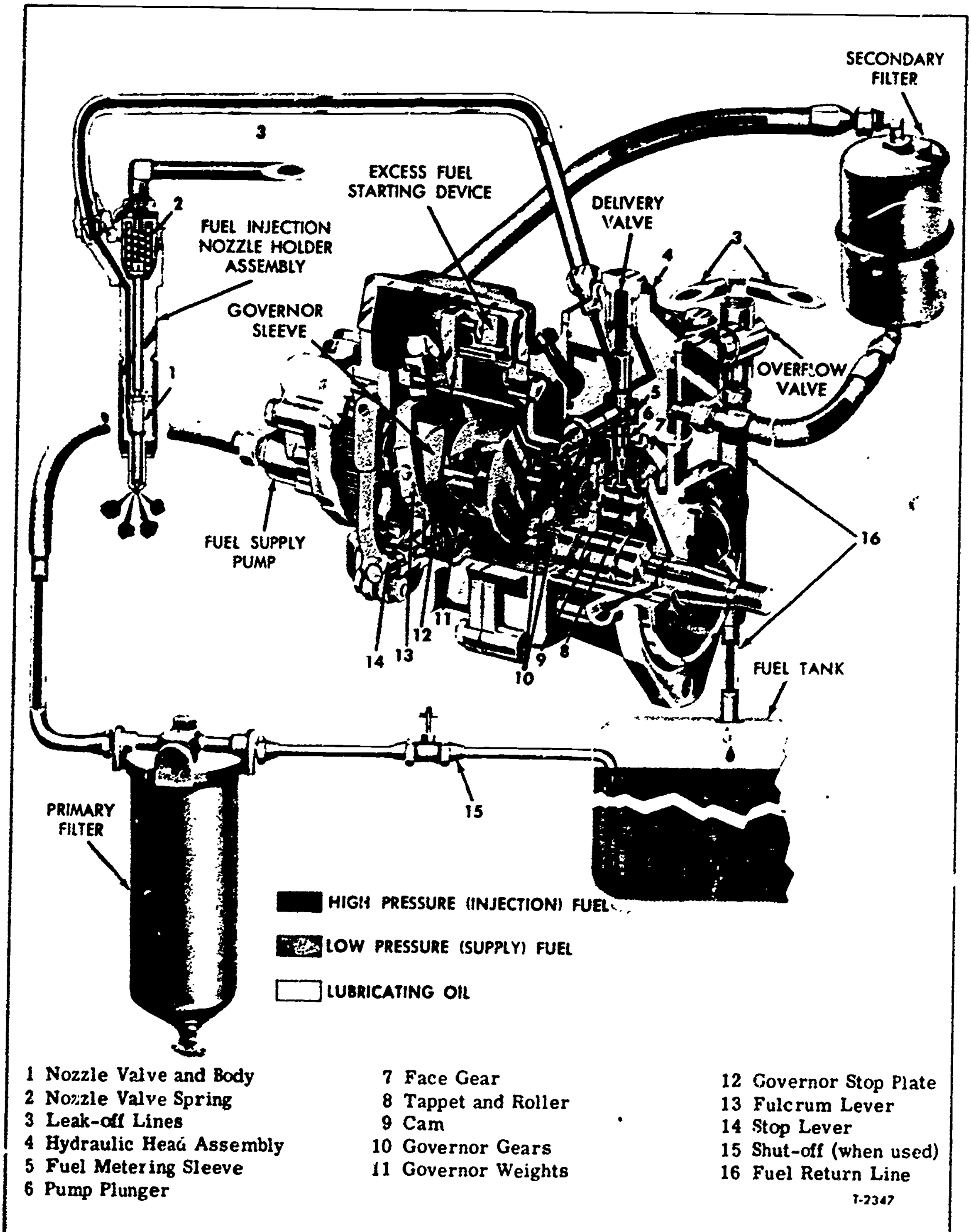
1. Push in "stop" control,
2. Set throttle to ⅓ full,
3. Turn on switch and engage starter, and
4. Engine should start

Some engines have glow plugs that are energized when the switch is placed in the start position. They preheat the air-fuel mixture in the cylinder to aid in starting. After the engine is started, maintain the lower RPM's on the engine tachometer and allow the engine to warm up. The warm-up period is vital to the diesel engine for efficient engine performance. When operating the engine, maintain adequate engine RPM's as recommended by the manufacturer.

When a diesel engine will not start after repeated tries, a small amount of starting fluid sprayed into the air intake may be needed to start the engine. If you use starting fluid, do not get carried away with its use; a little goes a long way. Use it only as a last resort or as specified by the manufacturer. If your efforts have failed to start the engine, have a mechanic that is familiar with diesel engines determine the cause of the problem.

18.316 Maintenance and Troubleshooting

For detailed maintenance procedures for your diesel engine, see your diesel manufacturer's service manual.



1 Nozzle Valve and Body
2 Nozzle Valve Spring
3 Leak-off Lines
4 Hydraulic Head Assembly
5 Fuel Metering Sleeve
6 Pump Plunger
7 Face Gear
8 Tappet and Roller
9 Cam
10 Governor Gears
11 Governor Weights
12 Governor Stop Plate
13 Fulcrum Lever
14 Stop Lever
15 Shut-off (when used)
16 Fuel Return Line

Fig. 18.48 Diesel engine fuel system
(Source Maintenance Manual, permission of General Motors Corp.)

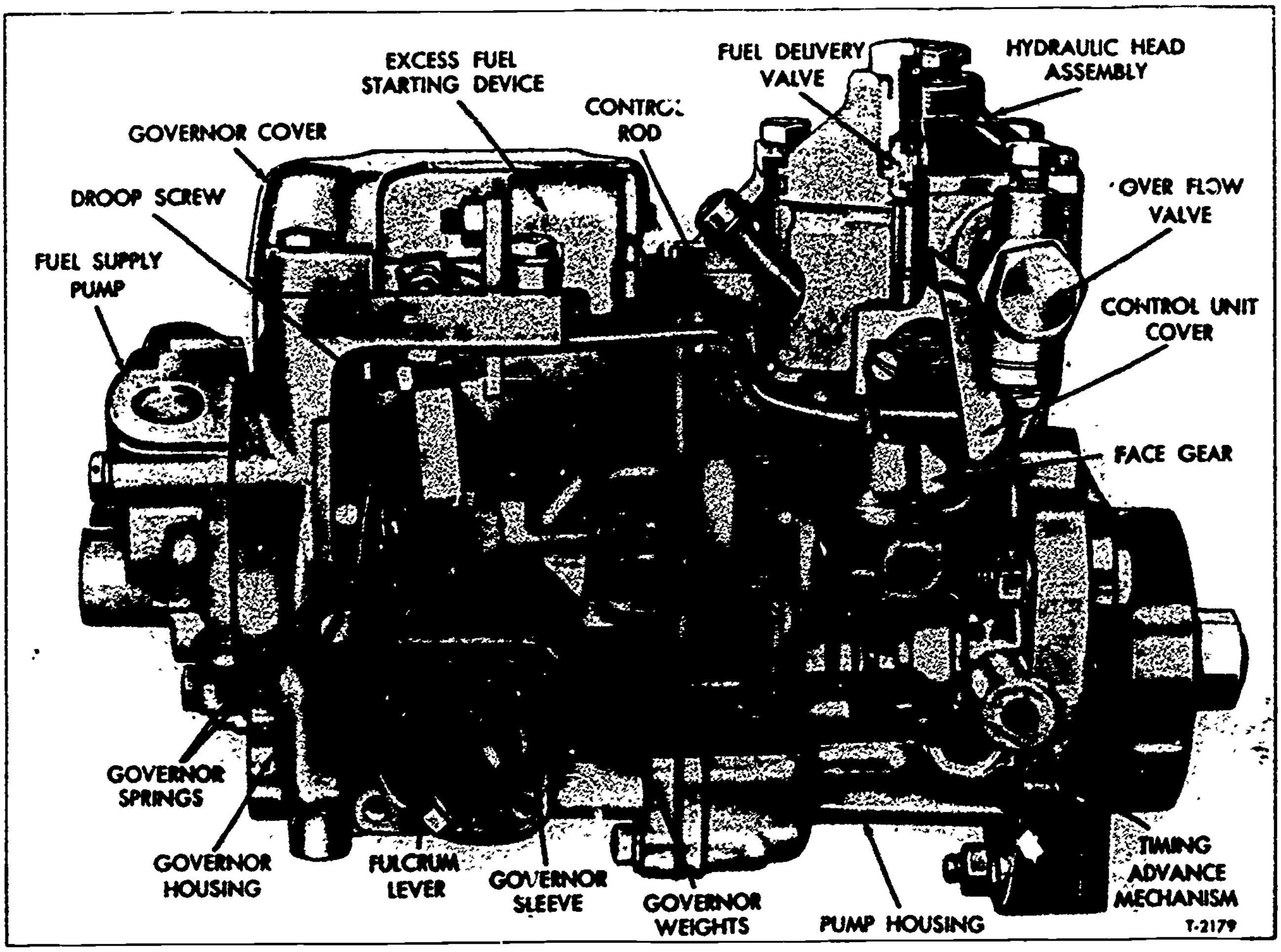


Fig. 18.49 Cut-away view of fuel injection pump for 6-cylinder engine

(Source Maintenance Manual, permission of General Motors Corp)

TROUBLESHOOTING

Certain abnormal conditions which sometimes interfere with satisfactory engine operation are listed in this section.

Satisfactory engine operation depends primarily on:

1. An adequate supply of air compressed to a sufficiently high compression pressure.
2. The injection of the proper amount of fuel at the right time.

Lack of power, uneven running, excessive vibration, stalling at idle speed and hard starting may be caused by either low compression, faulty injection in one or more cylinders, or lack of sufficient air.

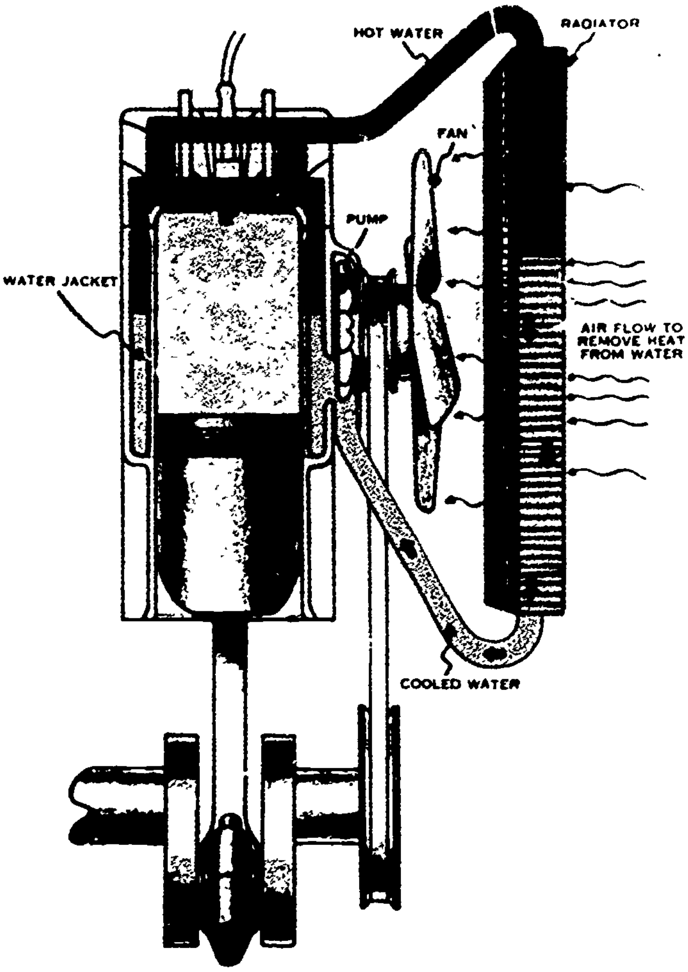
Since proper compression, fuel injection and the proper amount of air are important to good engine performance, possible problems are listed below:

1. Misfiring cylinders,
2. Improper compression pressure,
3. Engine out of fuel,
4. Proper fuel flow,
5. Excessive crankcase pressure,
6. Excessive back pressure.
7. Improper air box pressure,
8. Restricted air inlet,
9. Low oil pressure, and
10. Improper engine coolant operating temperature.

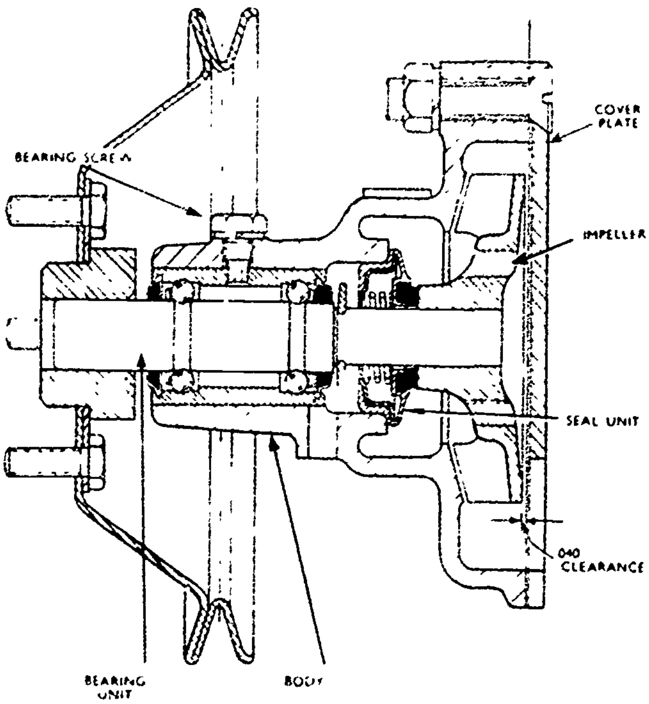
Solutions to these problems can be found in the operation and maintenance instructions for the engines.

18.32 Cooling Systems (Fig. 18.50)

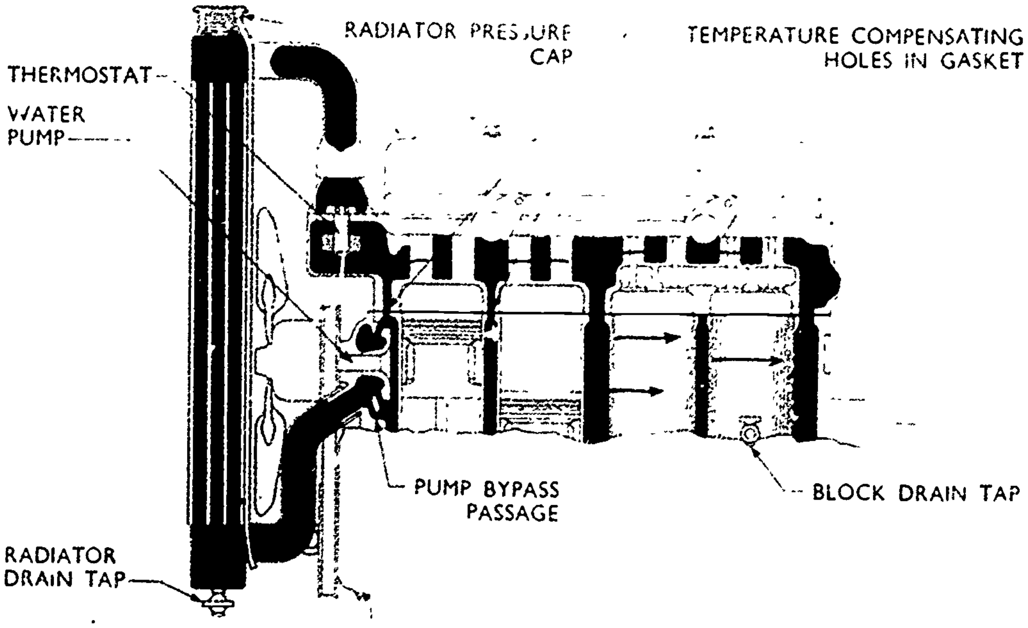
In an air-cooled engine, the heat generated by combustion is dissipated by the air circulating past the louvered cylinder block. With a water-cooled system, the same effect is achieved by using water. Each cylinder is surrounded with a water jacket through which coolant circulates. This is accomplished by a water pump that is belt-driven from the crankshaft. The heat transfers from the cylinder wall to the water which, in turn, is pumped back to the radiator where the heat is dissipated. A fan mounted on the same shaft as the water pump ensures that a large volume of air is blown across the radiator coils to facilitate rapid disbursement of heat. The cooled water is then pumped back into the engine.



Engine temperatures are regulated by transferring excess heat to surrounding air.



Shaft ball bearings are sealed at each end to keep lubricant in and water out of bearings. A spring-loaded seal (in color) is used to avoid water leakage around pump shaft. Note clearance between impeller and cover plate



With water jackets entirely around each cylinder and valve, there is a great amount of area exposed to the circulating coolant.

Fig. 18.50 Water cooling system

(Source Automotive Encyclopedia, permission of the Goodheart-Wilcox Co Inc)

Internal combustion engines operate more efficiently when their temperature is maintained within narrow limits This objective is achieved with the insertion of a thermostat in the cooling system which is called a "temperature actuated valve." When the engine is cold, the thermostat remains closed not allowing the water to circulate back to the radiator As the engine temperature increases to normal operating temperature, the thermostat opens.

The radiator cap provides a function other than preventing coolant from splashing out the filter opening The cap is designed to seal the cooling system so that it operates under pressure This improves cooling efficiency and prevents evaporation of coolant. The boiling point of water is 212 degrees F (100°C) However, for every pound of pressure applied to the system, the boiling point rises 3.25 degrees F (1.8°C). If your cooling system had a 15 psi (100 kPa or 1 kg/sq cm) radiator cap and used water for coolant, it would have a boiling point near 260 degrees F (127°C)

The use of coolant/anti-freeze provides protection against the radiator coolant freezing and rupturing the system and also provides better heat transfer and heat dissipation characteristics than water. Most of the name-brand coolants contain rust inhibitors. Rust buildup in the cooling system interferes with good heat transfer and the sloughing of rust scale can block narrow passages.

Stationary internal combustion engines such as those that are used to drive pumps and generators at the water treatment plants, are often installed in a building where free circulation of air for radiator cooling may not be possible. For these installations, a liquid-to-liquid heat exchanger often replaces the radiator (which is a liquid-to-air heat exchanger). In this case, instead of the heat in the cooling jacket water being transferred to the surrounding air, it is transferred to another liquid, usually tap water. This water may be wasted, if the engine is a standby unit and not operated very much, or the cooling water may be recovered in a cooling tower if the engine is in regular use.

In liquid-to-liquid heat exchanger systems a thermostatically controlled valve is usually installed to regulate the flow of cooling water through the exchanger. This valve should be checked periodically to see that it: (1) provides sufficient water flow when the engine is running and (2) closes off tight when the engine is shut down to prevent waste.

Cooling water from a heat exchanger should not be put back into a potable water system Any leakage in the heat exchanger could result in engine jacket coolant contaminating the potable water supply.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326.

18 31A Why is gasoline not used as a fuel in diesel engines?

18 31B List the four basic parts of a diesel fuel system

18.31C What is the purpose of the fuel injection pump?

18.32A How is heat removed from the cylinders in a water-cooled engine?

18.33 Fuel Storage

18.330 Code Requirements

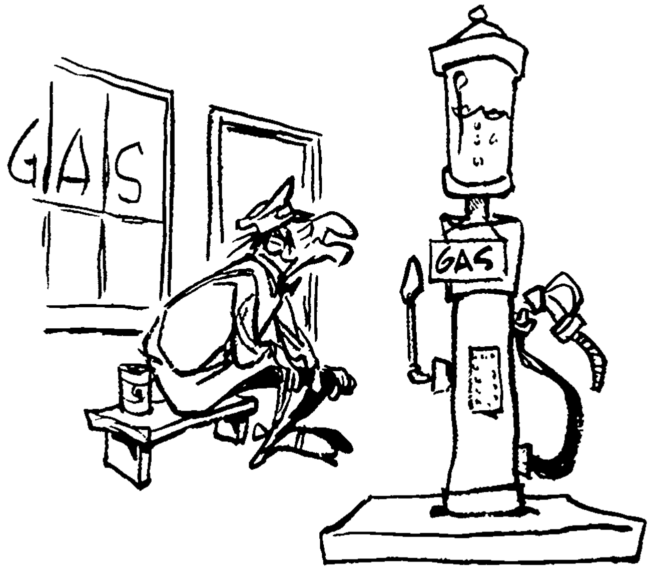
Storage and use of fuels for internal combustion engines must always be in accordance with local building and fire marshal codes In addition, the water treatment plant operator should be familiar with the particular problems associated with each of the commonly used fuels

18.331 Diesel

DIESEL This fuel comes in two grades known as #1 and #2 Be sure to use the grade recommended by the engine manufacturer. Be aware that the fuel grade recommendation may vary with the season. Diesel fuel is often stored in above ground tanks. The fuel may be kept in storage for years without deteriorating To protect stored diesel from water contamination, keep the storage tanks full and use special additives.

18.332 Gasoline

GASOLINE Except for very small quantities, gasoline is stored in underground tanks This can result in problems for the operator If the storage tank develops a leak, either fuel can leak out or water can leak in. Either condition is undesirable Fuel loss can not only be an unwanted operating expense, but can be a danger to underground plant piping. Gasoline deteriorates rubber and if the piping is put together with rubber gaskets or rings, the deterioration can result in major leaks and broken couplings. Fuel loss can best be monitored by careful accounting.



Water leakage into underground fuel tanks can result in engine stoppages and possible damage to the engine. Special devices are available for detecting water in gasoline tanks and such a test should be run routinely. These devices can be obtained by contacting your local wholesale fuel distributor

Gasoline, unlike diesel, deteriorates in storage. For engines that are in normal everyday use, this is not a problem. However, fuel storage for standby, engine-driven equipment requires further consideration. Engine operation and fuel tank replenishment should be scheduled so that at least one half of the gasoline in storage is used each year. Failure to do this can result in engines that are hard to start and in the formation of varnish and gummy deposits that can cause malfunctions in the parts of the fuel system.

18.333 Liquified Petroleum Gas (LPG)

LIQUIFIED PETROLEUM GAS (LPG). LPG is usually a mixture of propane and butane. The proportions of each is varied according to the weather temperature. The cooler the weather, the greater the proportion of propane.

This fuel is always stored under pressure in above-ground tanks that are located out in the open. LPG does not deteriorate in storage and therefore can be kept for many years.

LPG is heavier than air and will collect in low areas if there is any leakage. This poses an extremely dangerous explosive threat that treatment plant operators must constantly guard against.

18.334 Natural Gas

NATURAL GAS. This fuel is usually obtained from the local gas company through a metered connection from their distribution system. There is no on-site storage.

Natural gas, being lighter than air, tends to rise and dissipate from leaks and therefore is less dangerous to handle than LPG. Explosions can occur, however, if the leakage is confined inside a building.

18.34 Standby Engines

Internal combustion engines must be run periodically to ensure that, when needed, they will function properly. An engine that is not in regular service should be started up and test run at least once a week. The test run should be long enough for the engine to come up to its normal operating temperature before the engine is shut down. If at all possible, run the engine under its normal load. Just idling an engine for 20 minutes doesn't give you much of an indication as to whether it can handle a load. Check and make note of the engine instruments. Look for changes that may indicate a need for repairs. Lube oil pressure and intake manifold pressure (on spark ignition engines without supercharging or fuel injection) are two key indicators of engine condition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 326.

18.33A The storage and use of fuels for internal combustion engines must be in accordance with what codes?

18 33B List four types of fuels commonly used by internal combustion engines.

18.34A How often should standby internal combustion engines be test run when not in regular service?

18.34B Under what conditions should standby engines be test run?

18.4 CHEMICAL STORAGE AND FEEDERS[21]

18.40 Chemical Storage

Certain dry chemicals such as alum, ferric chloride, and soda ash are *HYGROSCOPIC.*[22] These chemicals require special considerations to protect them from moisture during storage. Dry quicklime should be kept dry because of the tremendous heat which is generated when it comes in contact with water. This heat is sufficient to cause a fire

Some liquid chemicals such as sodium hydroxide (caustic soda) should not be exposed to air because of the formation of calcium carbonate (a solid) due to the carbon dioxide in the air Also some liquid chemicals may "freeze." A 50 percent sodium hydroxide solution becomes crystalized (forms a solid) at temperatures below 55°F (13°C). Therefore a heater may be required to keep the storage area warm or the solution may have to be diluted down to a 25 percent solution.

Potassium permanganate can be kept indefinitely if stored in a cool dry area in closed containers. The drums should be protected from damage that could cause leakage. Potassium permanganate should be stored in fire-resistant buildings, having concrete floors as opposed to wooden floors. It should not be exposed to intense heat, or stored next to heated pipes Any organic solvent, such as greases and oils in general, should be kept away from stored $KMnO_4$.

Potassium permanganate spills should be swept up and removed immediately. Flushing with water is an effective way to eliminate spillage on floors. Potassium permanganate fires should be extinguished with water.

Carbon should be stored in a clean, dry place, in single or double rows, and with access aisles around every stack for frequent fire inspections. The removal of burning carbon will thus be facilitated. Carbon should never be stored in large stacks.

The storage area should be of fireproof construction, with self-closing fire doors separating the carbon room from other sections. Storage bins for dry bulk carbon should be of fireproof construction equipped for fire control by the installation of carbon dioxide equipment, or should be so arranged that they can be flooded with a fine spray of water.

Carbon storage areas should be protected from contact with flammable materials. (Carbon dust mixed with oily rags or chlorine compounds can ignite in spontaneous combustion.) *SMOKING SHOULD BE PROHIBITED AT ALL TIMES DURING THE HANDLING AND UNLOADING OF CARBON AND IN THE STORAGE AREA.* Carbon should not be stored where a spark from overhead electric equipment could start a fire. If a fire occurs, the carbon monoxide hazard should be taken into account.

Electric equipment should be protected from carbon dust and cleaned frequently or, better, explosion-proof electric wiring and equipment should be used. (The heat from a motor may ignite the accumulated carbon dust, this material, especially when damp, is a good conductor of electricity and could short-circuit the mechanism.)

Polymer solutions will be degraded (lose their strength) by biological contamination. A good cleaning of polymer storage tanks is recommended before a new shipment is delivered to the plant.

Liquid chemical storage tanks should have a berm or earth bank around the tanks to contain any chemicals released if the tank fails due to an earthquake, corrosion or any other reason.

Some chemicals such as chlorine and fluoride compounds are harmful to the human body when they are released as the result of a leak. Continual surveillance and maintenance of the storage and feeding systems are required.

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[21] *For additional information on chemical feeders, see Chapter 13, Fluoridation, Section 13 30, "Chemical Feeders "*

[22] *Hygroscopic (HI-grow-SKOP-ick). Absorbing or attracting moisture from the air.*

18.41 Drainage from Chemical Storage and Feeders

Safety regulations prohibit a single drainage pit which can accept and contain both acid and alkali chemicals because of the possibility of an explosion whenever these two types of chemicals come in contact. Also, any organic chemical waste such as a polymer solution should not be allowed to be discharged into a pit or sump which could also receive a waste from oxidizing chemicals such as potassium permanganate ($KMnO_4$) because of the possibility of a fire. Therefore, separate drainage systems or a high dilution of certain chemicals are necessary for a safe drainage system.

18.42 Use of Feeder Manufacturer's Manual

Water treatment plants will have a number of chemical feeders to accurately control the rate at which chemicals are fed into the water as a part of the treatment processes There are many types of feeders and they work on many different principles. Study the feeder manufacturer's manual that you should find in the treatment plant library for details on maintaining the equipment. Additional information on chemical feeders is contained in specific chapters on treatment processes that require the use of chemical feeders.

18.43 Solid Feeders

Solid feeders usually handle powdered material and usually have many moving mechanical parts that need adjustment, lubrication, and replacement when worn. The chemical supply is usually stored in a hopper. Keep the hopper and feeder clean and dry in order to prevent "bridging" (a hardened layer which can form an arch and prevent flow) of the chemical in the hopper and clogging in the feeder.

18.44 Liquid Feeders

Liquid feeders handle many types of chemicals, some of which may be corrosive and/or have a tendency to plug up the mechanism. The key to reliable operations is constant vigilance and cleaning as needed

18.45 Gas Feeders

The principal chemical found in gaseous form at water treatment plants is chlorine Chlorine is quite poisonous to humans and must be handled with great caution

18.46 Calibration of Chemical Feeders[23]

To ensure chemical feed rates, liquid-chemical metering pumps and dry-chemical feed systems should be tested and calibrated when first installed and at regular intervals thereafter. This section presents general procedures for calibrating several types of liquid- and dry-chemical feeders.

18.460 Large-Volume Metering Pumps

Pumps metering chemicals such as liquid alum deliver a relatively large volume of chemical in a short time period. These pumps can be accurately calibrated with a clear plastic sight tube and a stopwatch (Figure 18.51).

To calibrate the pump, fill the sight tube from the chemical solution tank, then set the valve so the tube is the only source of liquid chemical entering the pump. Run the pump for exactly one minute (use the stopwatch) at each of five or six representative settings of the pump-control scale. Record the amount pumped at each setting as observed in the sight tube Use this information to develop curves of pump setting vs chemical dose in mg/L or chemical feed in gallons per day for your plant (Figure 18.52).

The graph developed by this process is called a calibration curve It can be used to determine the pump setting needed to deliver a required chemical feed rate, or the commonly used range of feed rates can be marked in gallons per day directly on the pump control panel.

18.461 Small-Volume Metering Pumps

Pumps metering a chemical such as sodium hexametaphosphate, a lime feed solubility enhancer, feed a very small volume per day. The procedure for calibration of these pumps is similar to the procedure for large-volume units. For very low feed rates, pumping times of longer than one minute may be required to give accurately measurable results.

Once the test data have been recorded, convert the test results to appropriate units and draw a calibration curve to be used as for the larger pumps.

18.462 Dry-Chemical Systems

Dry-chemical feed systems are used for chemicals such as activated carbon, fluoride, and lime. Two types of systems are common, the rocker-dump type and the helix-feed type The rocker-dump chemical feed uses a scraper moving back and forth on a platform located at the bottom of a hopper filled with dry chemical The platform may be adjusted up and down to regulate the thickness of the ribbon of chemical, and the length of stroke for the scraper can be adjusted, usually by means of an indicator on an exterior arm.

The helix-type feeder feeds the dry chemical with a rotating screw (helix). The feed rate is adjusted by varying the drive-motor speed. The speed can usually be varied from 0 to 100 percent.

To calibrate either type of feed system, choose five or six representative settings of the arm (rocker-dump) or of the motor speed control (helix type), and a. each of the settings catch the amount of chemical fed during a precisely measured time interval. Next, weight each volume of chemical as accurately as possible and convert the information into pounds per day. Use the data to construct a calibration curve with one axis representing feeder settings and the other representing pounds per day. The curve is used in the same manner as the curves for liquid-feed pumps.

FORMULAS

To determine the chemical feed rate or flow from a chemical feeder, we need to know the amount or volume fed during a known time period. The flow from a chemical feeder can be calculated by knowing the volume pumped from a chemical storage tank and the time period.

$$\text{Flow, GPM} = \frac{\text{Volume Pumped, gal}}{\text{Pumping Time, minutes}}$$

$$\text{or Flow, GPM} = \frac{\text{(Volume Pumped, gal) (24 hr/day)}}{\text{(Pumping Time, hour)}}$$

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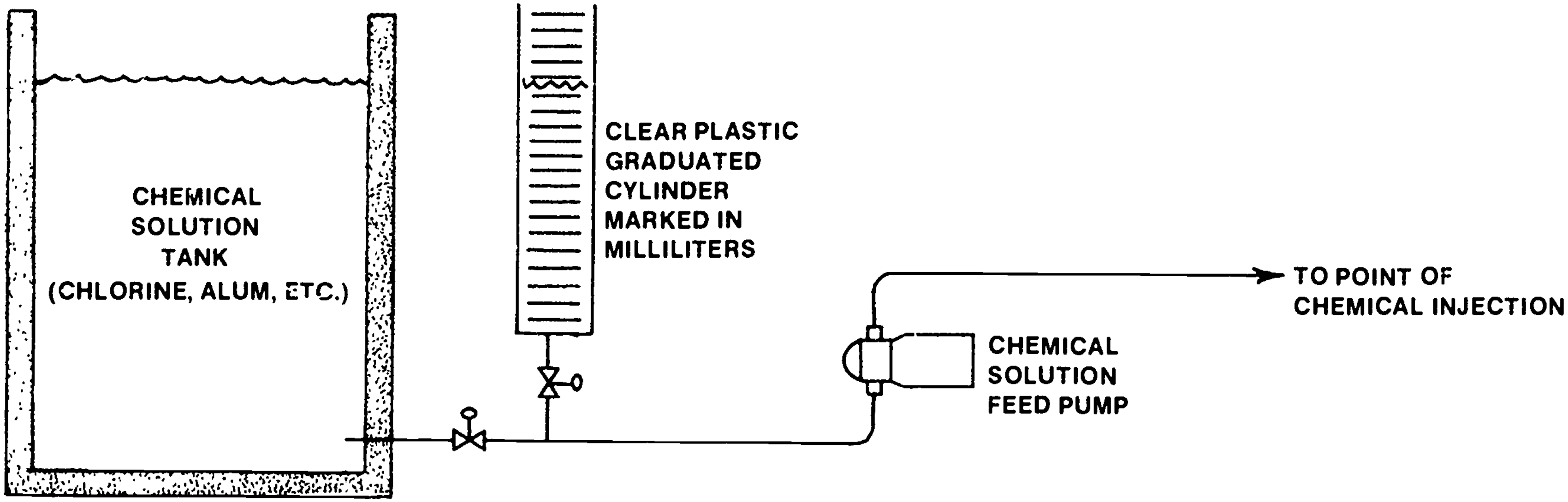
[23] *For additional information on calibration of chemical feeders, see Volume I, Appendix Section A 131, 'Chemical Doses, pages 567-570.*



THE FEED RATE OF A CHEMICAL SOLUTION FEED PUMP CAN BE DETERMINED BY MEASURING THE AMOUNT OF SOLUTION WITHDRAWN FROM A GRADUATED CYLINDER IN A GIVEN TIME PERIOD. ALLOW THE CYLINDER TO FILL WITH SOLUTION. THEN CLOSE THE VALVE ON THE LINE FROM THE TANK SO THE FEED PUMP TAKES SUCTION FROM THE CYLINDER ONLY. OBSERVE THE MILLILITERS OF SOLUTION USED IN ONE MINUTE. COMPARE THIS RESULT WITH THE DESIRED FEED RATE AND ADJUST THE FEED PUMP ACCORDINGLY.

Fig. 18.51 Calibration of a chemical feed pump

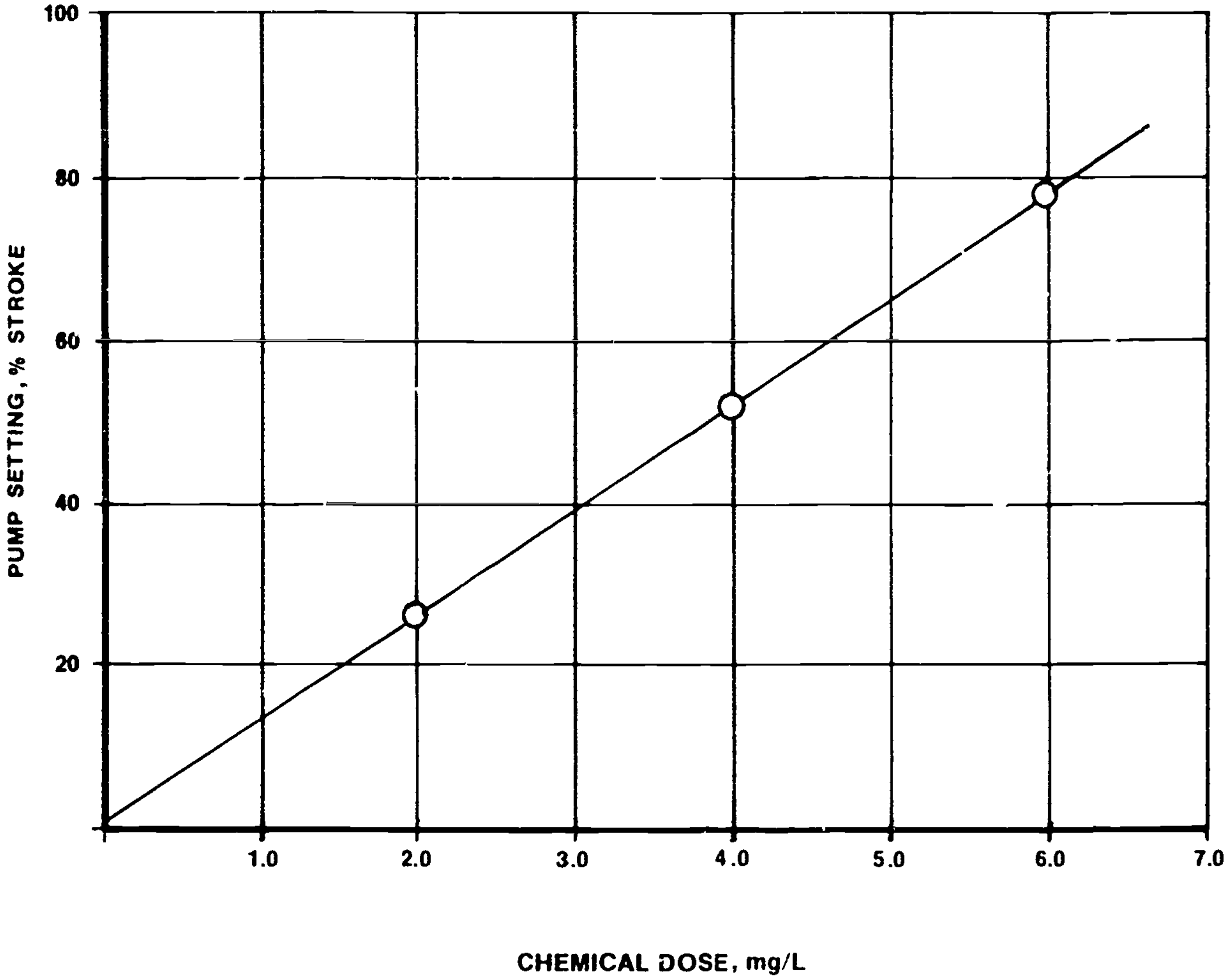


Fig. 18.52 Chemical feed pump settings for various chemical doses

Liquid polymer feed rates are often measured in pounds per day. To calculate this feed rate we need to know the strength of the polymer solution as a percent or as milligrams per liter, the specific gravity of the solution, the volume pumped and the time period.

$$\text{Polymer Feed, lbs/day} = \frac{(\text{Poly Conc, mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

To determine the actual feed from a dry chemical feeder, we need to know the pounds of chemical fed and the time period.

$$\text{Chemical Feed, lbs/day} = \frac{(\text{Chemical Fed, lbs})(60\text{ min/hr})(24\text{ hr/day})}{\text{Time, minutes}}$$

EXAMPLE 2

A chemical feed pump lowered the chemical solution in a four-foot diameter chemical storage tank two feet during a seven-hour period. Estimate the flow delivered by the pump in gallons per minute and gallons per day.

Known		Unknown
Tank Diameter, ft	= 4 ft	Flow, GPM
Chemical Drop, ft	= 2 ft	Flow, GPD
Time, hr	= 7 hr	

1. Determine the volume of water pumped in gallons.

$$\begin{aligned}\text{Volume, gal} &= (0.785)(\text{Diameter, ft})^2(\text{Drop, ft})(7.48\text{ gal/cu ft})\\ &= (0.785)(4\text{ ft})^2(2\text{ ft})(7.48\text{ gal/cu ft})\\ &= 188\text{ gal}\end{aligned}$$

2. Calculate the flow from the chemical feed pump in gallons per minute.

$$\begin{aligned}\text{Flow, GPM} &= \frac{\text{Volume Pumped, gal}}{(\text{Pumping Time, hr})(60\text{ min/hr})}\\ &= \frac{188\text{ gal}}{(7\text{ hr})(60\text{ min/hr})}\\ &= 0.45\text{ GPM}\end{aligned}$$

3. Calculate the flow from the chemical feed pump in gallons per day.

$$\begin{aligned}\text{Flow, GPD} &= \frac{(\text{Volume Pumped, gal})(24\text{ hr/day})}{\text{Pumping Time, hr}}\\ &= \frac{(188\text{ gal})(24\text{ hr/day})}{7\text{ hr}}\\ &= 645\text{ GPD}\end{aligned}$$

EXAMPLE 3

Determine the chemical feed in pounds of polymer per day from a chemical feed pump. The polymer solution is 2.0 percent or 20,000 mg polymer per liter. Assume a specific gravity of the polymer solution of 1.0. During a test run the chemical feed pump delivered 750 m*L* of polymer solution during six minutes.

Known	Unknown
Polymer Solution, % = 2.0%	Polymer Feed, lbs/day
Polymer Conc, mg/*L* = 20,000 mg/*L*	
Polymer Sp Gr = 1.0	
Volumed Pumped, m*L* = 750 m*L*	
Time Pumped, min = 6 min	

Calculate the polymer feed by the chemical feed pump in pounds of polymer per day.

$$\text{Polymer Feed, lbs/day} = \frac{(\text{Poly Conc, mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= \frac{(20{,}000\text{ mg/L})(750\text{ mL})(60\text{ min/hr})(24\text{ hr/day})}{(6\text{ min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= 7.9\text{ lbs polymer/day}$$

EXAMPLE 4

Determine the actual chemical fed in pounds per day from a dry chemical feeder. A pie tin placed under a chemical feeder collected 1000 grams of chemical in five minutes.

Known	Unknown
Dry Chemical, gm = 1000 gm	Chemical Feed, lbs/day
Time, min = 5 min	

Determine the chemical feed in pounds of chemical applied per day.

$$\text{Chemical Feed, lbs/day} = \frac{(\text{Chemical Applied, gm})(60\text{ min/hr})(24\text{ hr/day})}{(454\text{ gm/lb})(\text{Time, min})}$$

$$= \frac{(1000\text{ gm})(60\text{ min/hr})(24\text{ hr/day})}{(454\text{ gm/lb})(5\text{ min})}$$

$$= 635\text{ lbs/day}$$

18.47 Chlorinators

Chlorine gas leaks around chlorinators or containers of chlorine will cause corrosion of equipment. Check every day for leaks. Large leaks will be detected by odor; small leaks may go unnoticed until damage results. A green or reddish deposit on metal indicates a chlorine leak. Any chlorine gas leakage in the presence of moisture will cause corrosion. Always plug the ends of any open connection to prevent moisture from entering the lines. Never pour water on a chlorine leak because this will only create a bigger problem by enlarging the leak.. Chlorine gas reacts with water to form hydrochloric acid.

WARNING

ANOTHER IMPORTANT REASON FOR PREVENTING CHLORINE LEAKS IS THAT THE GAS IS TOXIC TO HUMANS.

Ammonia water will detect any chlorine leak. A small piece of cloth, soaked with ammonia water[24] and wrapped around the end of a short stick, makes a good leak detector. Wave this stick in the general area of the suspected leak (do not touch the equipment with it). If chlorine gas leakage is occuring, a white cloud of ammonium chloride will form. You should make this test at all gas pipe joints, both inside and outside the chlorinators, at regular intervals. Bottles of ammonia water should be kept tightly capped to avoid loss of strength. All pipe fittings must be kept tight to avoid leaks. *NEW GASKETS SHOULD BE USED FOR EACH NEW CONNECTION.*

CAUTION

TO LOCATE A CHLORINE LEAK, DO NOT SPRAY OR SWAB EQUIPMENT WITH AMMONIA WATER. WAVE AN AMMONIA-SOAKED RAG OR PAINT BRUSH IN THE GENERAL AREA AND YOU CAN DETECT THE PRESENCE OF MANY LEAKS. SOME OPERATORS PREFER TO WAVE A STICK WITH A CLOTH ON THE END IN FRONT OF THEM WHEN THEY ARE LOOKING FOR CHLORINE LEAKS

Do not use a spray bottle in a room where large amounts of chlorine gas have already leaked into the air. After one squeeze, the entire area may be full of white smoke and you will have trouble locating the leak. Under these conditions, use a cloth soaked in ammonia water to look for leaks.

The exterior casing of chlorinators should be painted as required, however, most chlorinators manufactured recently have plastic cases that do not require protective coatings. A clean machine is a better operating machine. Parts of a chlorinator handling chlorine gas must be kept dry to prevent the chlorine and moisture from forming hydrochloric acid. Some parts may be cleaned, when required, first with water to remove water soluble material, then with wood alcohol, followed by drying. The above chemicals leave no moisture residue. Another method would be to wash them with water and dry them over a pan or heater to remove all traces of moisture.

Water strainers on chlorinators frequently clog and require attention. They may be cleaned by flushing with water or, if badly fouled, they may be cleaned with dilute hydrochloric acid, followed with a water rinse.

The atmosphere vent lines from chlorinators must be open and free. These vent lines evacuate the chlorine to the outside atmosphere when the chlorinator is being shut down. Place a screen over the end of the pipe to keep insects from building a nest in the pipe and clogging it up.

When chlorinators are removed from service, as much chlorine gas as possible should be removed from the supply lines and machines. The chlorine valves at the containers are shut off and the chlorinator injector is operated for a period to remove the chlorine gas. In "V" notch chlorinators, the rotameter goes to the bottom of the manometer tube when the chlorine gas has been expelled.

All chlorinators will give continuous trouble-free operation if properly maintained and operated. Each chlorinator manufacturer provides with each machine a maintenance and operations instruction booklet with line diagrams showing the operation of the component parts of the machine. Manufacturer's instructions should be followed for mainte-

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[24] *Use a concentrated ammonia solution containing 28 to 30 percent ammonia as NH_3 (this is the same as 58 percent ammonium hydroxide, NH_4OH, or commercial 26° Baume).*

nance and lubrication of your particular chlorinator. If you do not have an instruction booklet, you may obtain one by contacting the manufacturer's representative in your area

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327

18.4A How can an operator locate information on how to operate, control and maintain chemical feeders?

18.4B List three common types of chemical feeders

18.4C Why should chlorine leaks be detected and repaired?

18.4D How would you search for chlorine leaks?

18.5 TANKS AND RESERVOIRS[25]

18.50 Scheduling Inspections

Plant tanks should be drained and inspected at regular intervals If the interior is well protected, five-year intervals between inspections may be sufficient If the tank is below the surface of the ground, be sure the groundwater level is down far enough (below the bottom of the tank) so the tanks will not float on the groundwater when empty or develop cracks from groundwater pressure.

Schedule inspections of tanks and channels during periods of low plant demand so that plant operation won't be disrupted

18.51 Steel Tanks

All steel tanks must be protected from rusting Once metal is lost because of rusting, it can't be recovered. The exteriors of the tanks are easily inspected — don't forget the roof — and should be repainted, as needed, not only to protect the steel surface but to provide a pleasing appearance. The interiors of steel tanks are exposed to a much harsher environment due either to being constantly submerged or to constant high humidity.

Protective coatings for steel tank interiors must be carefully selected to provide superior protection and at the same time impart neither taste nor odors to the water Proper surface preparation and application is as important as the coating materials in getting interior protection that will last a reasonable period of time

When interior tank recoating is required, schedule the work when plant demand is low but not during rainy weather when it may be impossible to maintain a dry steel surface warm enough to ensure proper curing of the coating. This type of work is usually done by outside contractors. Constant inspection is a must if the work is going to be completed according to the specifications.

18.52 Cathodic Protection[26]

An alternative to repainting the submerged interior surfaces of a steel water tank is installation of a cathodic protection system. The rusting of steel is accompanied by the flow of small electrical currents. Cathodic protection systems prevent rusting of bare steel surfaces by causing an electrical current to flow from anodes hung in the water to the tank surface The polarity of this current is opposite to what it would be if rust were forming The current can be obtained from sacrificial anodes that make the tank into a giant low voltage battery, or from electronic rectifiers that are powered from the commercial power lines.

Cathodic protection systems provide protection only so long as they are operating and properly adjusted Systems with rectifiers should be checked weekly. The inspection consists of reading and recording the DC volt and ammeter readings Compare the readings with previous readings and with the readings recommended by the corrosion engineer or technician Deviations from normal should be investigated without delay

Once a year, a corrosion specialist should be called in to take potential profile readings on the inside of the tank and to set the rectifier and recommend new normal current settings. Over the years, as more and more of the interior tank coating fails, the bare surface area to be protected by the cathodic protection system will increase. For this reason, it is to be expected that the current required to provide protection will increase in small amounts or increments each year

18.53 Concrete Tanks

Concrete tanks are not usually coated on the inside and are painted on the exterior for appearance purposes only. This would seem to indicate that maintenance on concrete tanks is minimal, but this may not be true Concrete tanks are all reinforced with steel Steel can rust. If too much steel is lost to rust, the structural strength of the tank can be threatened Periodically inspect the tank for signs of rusting. This is particularly important for pre-stressed concrete tanks that have a tensioned wire wrap on the exterior. The wires are small in diameter and even a small amount of rust could reduce the size of the wire to the point where it might fail.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

18.5A How often should tanks and reservoirs be drained and inspected?

18.5B Why must the groundwater level be below the bottom of a tank before it is drained?

18.5C What is an alternative to applying a protective coating to prevent corrosion of a steel tank?

18.6 BUILDING MAINTENANCE

Building maintenance is another program that should receive attention on a regular schedule Buildings in a treatment plant are usually built of sturdy materials to last for many years, if they are kept in good repair. In selecting paint for a treatment plant, it is always a good idea to have a painting expert help the operator select the types of paint needed to protect the buildings from deterioration. The expert also will have some good ideas as to color schemes to help blend the plant in with the surrounding area. Consideration should also be given to the quality of paint A good quality, more expensive material will usually give better service over a longer period of time than the economy-type products.

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[25] *Also see WATER DISTRIBUTION SYSTEM OPERATION AND MAINTENANCE, Chapter 2, Storage Facilities, Section 2.4, "Maintenance," in this series of manuals.*

[26] *Also see Chapter 8, Corrosion Control, Section 8.36, "Catholic Protection," in WATER TREATMENT PLANT OPERATION, Volume 1.*

Building maintenance programs depend on the age, type and use of a building. New buildings require a thorough check to be certain essential items are available and working properly. Older buildings require careful watching and prompt attention to keep ahead of leaks, breakdowns, replacements when needed, and changing uses of the building. Attention must be given to the maintenance requirements of many items in all plant buildings, such as electrical systems, plumbing, heating, cooling, ventilating, floors, windows, roofs, and drainage around the buildings. Regularly scheduled examinations and necessary maintenance of these items can prevent many costly and time-consuming problems in the future.

In each plant building, periodically check all stairways, ladders, catwalks, and platforms for adequate lighting, head clearance, and sturdy and convenient guardrails. Protective devices should surround all moving equipment. Whenever any repairs, alterations, or additions are built, avoid building accident traps such as pipes laid on top of floors or hung from the ceiling at head height, which could create serious safety hazards.

Organized storage areas should be provided and maintained in an accessible and neat manner.

KEEP ALL BUILDINGS CLEAN AND ORDERLY. Janitorial work should be done on a regular schedule. All tools and plant equipment should be kept clean and in their proper place. Floors, walls, and windows should be cleaned at regular intervals in order to maintain a neat appearance. A treatment plant kept in a clean, orderly condition makes a safe place to work and aids in building good public and employer relations.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

18.6A What items should be included in a building maintenance program?

18.6B What factors influence the type of building maintenance program that might be needed for your water treatment plant?

18.7 ARITHMETIC ASSIGNMENT

Turn to the appendix at the back of this manual and read Section A.35, "Maintenance." Also work the example problems and check the arithmetic using your calculator. You should be able to get the same answers.

18.8 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 19, "Treatment Plant Maintenance and Accident Prevention."
2. *TEXAS MANUAL*, Chapter 13, "Pumps and Measurement of Pumps."

18.9 ACKNOWLEDGMENTS

Major portions of this chapter were taken from the following California State University, Sacramento, Operator Manuals.

1. *OPERATION OF WASTEWATER TREATMENT PLANTS*

   Volume 11, Chapter 15, "Maintenance," by Norman Farnum, Stan Walton, John Brady, Roger Peterson and Malcolm Carpenter.

2. *OPERATION AND MAINTENANCE OF WASTEWATER COLLECTION SYSTEMS*

   Chapter 9, "Equipment Maintenance," by Lee Doty.

3. *INDUSTRIAL WASTE TREATMENT*

   Chapter 7, "Maintenance," by Roger Ham.

**End of Lesson 5 of 5 Lessons
on
MAINTENANCE**

DISCUSSION AND REVIEW QUESTIONS

Chapter 18. MAINTENANCE

(Lesson 5 of 5 Lessons)

Write your answers to these questions in your notebook before continuing to the objective test on page 327. The question numbering continues from Lesson 4.

36. What factors could cause gasoline engine starting problems?
37. Why is rust a problem in water-cooled systems?
38. What is the purpose of the filters in the diesel fuel system?
39. What are the advantages of air-cooled diesel engines as compared with water-cooled types?
40. How should large quantities of gasoline be stored?
41. Why is "idling" not a satisfactory method of testing standby engines?
42. Why should dry chemical feeders and hoppers be kept clean and dry?
43. What problems can be caused by chlorine gas leaks around chlorinators or containers of chlorine?

SUGGESTED ANSWERS

Chapter 18. MAINTENANCE

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 220

18 0A A good maintenance program is essential for a water treatment plant to operate at peak efficiency.

18 0B The most important item is maintenance of the mechanical equipment — pumps, valves, scrapers, and other moving equipment. Other items include plant buildings and grounds.

18 0C A good record system tells when maintenance is due and also provides a record of equipment performance. Poor performance is a good justification for replacement or new equipment. Good records help keep your warranty in force.

18.0D Both cards are vital in a good recordkeeping system. The equipment service record card is a permanent or master card that indicates when or how often certain maintenance work should be done. The service record card is a record of who did that work on what date and is helpful in determining when the future maintenance work is due.

18 0E Emergency phone numbers for a treatment plant should include the phone numbers for police, fire, hospital and/or physician, responsible plant officials, local emergency disaster office, emergency team and CHEMTREC, (800) 424-9300.

18.0F A training program for an emergency team should include:

1. Use of proper equipment (self-contained breathing apparatus, repair kits and repair tools),
2. Properties and detection of hazardous chemicals,
3. Safe procedures for handling and storage of chemicals,
4. Types of containers, safe procedures for shipping containers, and container safety devices,
5. Installation of repair devices, and
6. Simulated field emergencies

Answers to questions on page 221.

18.10A Unqualified or inexperienced people must be extremely careful when attempting to troubleshoot or repair electrical equipment because they can be seriously injured and damage costly equipment if a mistake is made.

18.10B When machine is not shut off, locked out, and tagged properly, the following accidents could occur:

1. Maintenance operator could be cleaning pump and have it start, thus losing an arm, hand or finger;
2. Electrical motors or controls not properly grounded could lead to possible severe shock, paralysis, or death; and
3. Improper circuits such as a wrong connection, safety devices jumped, wrong fuses, or improper wiring can cause fires or injuries due to incorrect operation of machinery.

Answers to questions on page 225.

18 11A The two types of current are Direct Current (D.C.) and Alternating Current (A C).

18 11B Amperage is a measurement of work being done or "how hard the electricity is working."

18 11C The proper voltage and allowable current in amps for a piece of equipment can be determined by reading the name plate information or the instruction manual for the equipment.

Answers to questions on page 230.

18 12A You test for voltage by using a voltage tester

18 12B A voltage tester can be used to test for voltage, open circuits, blown fuses, single phasing of motors and grounds.

18.12C Before attempting to change fuses, turn off power and check both power lines for voltage Use a fuse puller.

18.12D If the voltage is unknown and the voltmeter has different scales that are manually set, always start with the highest voltage range and work down. Otherwise the voltmeter could be damaged.

18.12E Amp readings different from the name plate rating could be caused by low voltage, bad bearings, poor connections, plugging or excessive load.

18 12F Motors and wirings should be megged at least once a year, and twice a year if possible.

18 12G An ohm meter is used to test the control circuit components such as coils, fuses, relays, resistors and switches.

Answers to questions on page 231.

18.13A The two types of safety devices in main electrical panels or control units are fuses or circuit breakers.

18.13B Fuses are used to protect operators, wiring, circuits, heaters, motors, and various other electrical equipment.

18.13C A fuse must never be by-passed or jumped because the fuse may be the only protection the circuit has; without it, serious damage to equipment and possible injury to operators can occur.

18 13D A circuit breaker is a switch that is opened automatically when the current or the voltage exceeds or falls below a certain limit. Unlike a fuse that has to be replaced each time it "blows," a circuit breaker can be reset after a short delay to allow time for cooling.

18.13E Motor starters can be either manually or automatically controlled.

18.13F Magnetic starters are generally used to start pumps, compressors, blowers and anything where automatic or remote control is desired.

Answers to questions on page 234.

18.14A Electrical energy is commonly converted into mechanical energy by electric motors.

18.14B An electric motor usually consists of a stator, rotor, end bells, and windings.

18.14C Motors can be kept trouble free with proper lubrication and maintenance.

18.14D Motor name plate data should be recorded, compared with manufacturer's data sheets and instructions, and placed in a file for future reference. Many times the name plate is painted, corrodes or is missing from the unit when the information is needed to repair the motor or replace parts

Answers to questions on page 236.

18.14E The key to effective troubleshooting is practical, step-by-step procedures combined with a common sense approach.

18.14F When troubleshooting:

A. Gather preliminary information.
B. Inspect:
  1. Contacts,
  2. Mechanical parts, and
  3. Magnetic parts.

18.14G Types of information that should be recorded regarding electrical equipment include every change, repair and test.

Answers to questions on page 246.

18.15A A qualified electrician should perform most of the necessary maintenance and repair of electrical equipment to avoid endangering lives and to avoid damage to equipment.

18.15B The purpose of a "kirk-key" system (one key is used for two locks) is to insure proper connection of standby power into your power distribution system. The commercial power system must be locked out by the use of switch gear before the standby power is connected to your power distribution system.

18.15C Battery-powered lighting units are considered better than engine-driven power sources because they are more economical. If you have a momentary power outage, the system responds without an engine-generator startup.

18.15D If water lost from a lead-acid battery is replaced with tap water, the impurities in the water will become attached to the lead plates and shorten the life of the battery.

Answers to questions on page 247.

18.16A Electricity is transmitted at high voltage to reduce the size of transmission lines.

18.16B If outdoor transformers have exposed high voltage wires, the following precautions must be taken:

1. An eight foot (2.4 m) high fence is required to prevent accessibility by unqualified or unauthorized persons; and
2. Signs attached to the fence must indicate "High Voltage."

18.16C The treatment plant operator must keep the exterior and surroundings of the switch gear clean.

18.16D Symptoms that a power distribution transformer may be in need of maintenance or repair include unusual noises, high or low oil levels, oil leaks or high operating temperatures.

Answers to questions on page 247.

18.17A Rusted conduits are of concern because they could become the source of a spark which could cause an explosion.

18.17B Electrical safety check lists are used to make operators aware of potential electrical hazards in their water treatment plant.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 258

18.20A Pieces of equipment and special tools commonly found in a pump repair shop include welding equipment, lathes, drill press and drills, power hack saw, flame-cutting equipment, micrometers, calipers, gages, portable electric tools, grinders, a forcing press, metal-spray equipment, and sand-blasting equipment.

18.21A The purpose of a pump impeller is to suck water in the suction piping and to throw water out between the impeller blades.

18.21B A suitable screen should be installed on the intake end of suction piping to prevent foreign matter (sticks, refuse) from being sucked into the pump and clogging or wearing the impeller.

18.21C Suction piping must be up-sloping to prevent air pockets from forming in the top of a pipe where air could be drawn into the pump and cause the loss of suction.

18.21D Cavitation is the formation and collapse of a gas pocket or bubble on the blade of an impeller. The collapse of this gas pocket or bubble drives water into the impeller with a terrific force that can cause pitting on the impeller surface.

18.21E An advantage of a double-suction pump is that the longitudinal thrust from the water entering the impeller is balanced.

Answers to questions on page 263.

18.22A The purpose of lubrication is to reduce friction between two surfaces and to remove heat caused by friction.

18.22B Oils in service tend to become acid (contaminated) and may cause corrosion, deposits, sludging and other problems.

18.22C To ensure proper lubrication of equipment, determine the proper lubrication schedule, lubricant, and amount of lubricant and prepare a lubrication chart.

Answers to questions on page 264

18.22D A soft grease has a low viscosity index as compared with a hard grease.

18.22E Oil is used with higher speeds.

18.22F Overfilling with oil or grease can result in high pressures and temperatures, and ruined seals or other components.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 272

18.23A A cross-connection is a connection between two piping systems where an undesirable water (water from water seal) could enter a domestic water supply.

18.23B Yes. A slight leakage is desirable when the pumps are running to keep the packing cool and in good condition.

18.23C To measure the capacity of a pump, measure the volume pumped during a specific time period

$$\text{Capacity, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

or

$$\text{Capacity, } \frac{\text{liters}}{\text{sec}} = \frac{\text{Volume, liters}}{\text{Time, sec}}$$

18.23D

$$\begin{aligned}\text{Capacity, GPM} &= \frac{\text{Volume, gallons}}{\text{Time, minutes}}\\ &= \frac{(10\text{ ft})(15\text{ ft})(1.7\text{ ft})(7.5\text{ gal/cu ft})}{5\text{ minutes}}\\ &= 382.5\text{ GPM}\end{aligned}$$

or

$$\begin{aligned}\text{Capacity } \frac{\text{liters}}{\text{sec}} &= \frac{\text{Volume, liters}}{\text{Time, sec}}\\ &= \frac{(3\text{ m})(5\text{ m})(0.5\text{ m})(1000\text{ L/cu m})}{(5\text{ minutes})(60\text{ sec/min})}\\ &= 25\text{ liters/sec}\end{aligned}$$

18.23E Before a prolonged shutdown, the pump should be drained to prevent damage from corrosion, sedimentation, and freezing. Also, the motor disconnect switch should be opened to disconnect motor

Answers to questions on page 274

18.23F Shear pins commonly fail in reciprocating pumps because of (1) a solid object lodged under piston, (2) a clogged discharge line, or (3) a stuck or wedged valve

18.23G A noise may develop when pumping thin sludge due to water hammer, but will disappear when heavy sludge is pumped.

18.23H Higher than normal discharge pressures in a progressive cavity pump may indicate a line blockage or a closed valve downstream

Answers to questions on page 274

18.23I When checking an electric motor, the following items should be checked periodically, as well as when trouble develops:

1. Motor condition,
2. Note all unusual conditions,
3. Lubricate bearings,
4. Listen to motor, and
5. Check temperature.

18.23J The purpose of a stethoscope is to magnify sounds and carry them to the ear. This instrument is used to detect unusual sounds in electric motors such as whines, gratings, or uneven noises.

Answers to questions on page 278.

18.23K A properly adjusted horizontal belt has a slight bow in the slack side when running. When idle, it has an alive springiness when thumped with the hand. Vertical belts should have a springiness when thumped. To check for proper alignment, place a straight edge against the puller face or faces. If a ruler won't work, use a transit for long runs, or the belt may be examined for wear.

18.23L Always replace sprockets when replacing a chain because old, out-of-pitch sprockets cause as much chain wear in a few hours as years of normal operation

Answers to questions on page 280

18.23M Improper original installation of equipment, settling of foundations, heavy floor loadings, warping of bases, and excessive bearing wear could cause couplings to become out of alignment.

18.23N Shear pins are designed to fail if a sudden overload occurs that could damage expensive equipment.

Answers to questions on page 283.

18.24A Pumps must be lubricated in accordance with manufacturer's recommendations. Quality lubricants should be used.

18.24B In lubricating motors, too much grease may cause bearing trouble or damage the winding

Answers to questions on page 283.

18.24C If a pump will not start, check for blown fuses or tripped circuit breakers and the cause. Also check for a loose connection, fuse, or thermal unit.

18.24D To increase the rate of discharge from a pump, you should look for something causing the reduced rate of discharge, such as pumping air, motor malfunction, plugged lines or valves, impeller problems, or other factors.

Answers to questions on page 284.

18.24E If a pump that has been locked or tagged out for maintenance or repairs is started, an operator working on the pump could be seriously injured and also equipment could be damaged.

18.24F Normally a centrifugal pump should be started after the discharge valve is opened. Exceptions are treatment processes or piping systems with vacuums or pressures that cannot be dropped or allowed to fluctuate greatly while an alternate pump is put on the line. If the pump is not equipped with a check valve and the discharge pressure is higher than the suction pressure under static conditions, the pump could run backwards and cause damage to the equipment.

Answers to questions on page 286.

18.24G Before stopping an operating pump:

1. Start another pump (if appropriate); and
2. Inspect the operating pump by looking for developing problems, required adjustments, and problem conditions of the unit.

18.24H A pump shaft or motor will spin backwards if water being pumped flows back through the pump when the pump is shut off. This will occur if there is a faulty check valve or foot valve in the system.

18.24I The position of all valves should be checked before starting a pump to ensure that the water being pumped will go where intended.

Answers to questions on page 286.

18.24J The most important rule regarding the operation of positive displacement pumps is to NEVER start the pump against a closed discharge valve.

18.24K If a positive displacement pump is started against a closed discharge valve, the pipe, valve or pump could rupture from excessive pressure. The rupture will damage equipment and possibly seriously injure or kill someone standing nearby.

18.24L Both ends of a sludge line should never be closed tight because gas from decomposition can build up and rupture pipes or valves.

ANSWERS TO QUESTIONS IN LESSON 4

Answers to questions on page 289.

18.25A Compressors are used with water ejectors, pump control systems (bubblers), valve operators, and water pressure systems. Also they are used to operate portable pneumatic tools such as jack hammers, compactors, air drills, sand blasters, tapping machines, and air pumps.

18.25B The frequency of cleaning a suction filter on a compressor depends on the use of a compressor and the atmosphere around it. The filter should be inspected at least monthly and cleaned or replaced every three to six months. More frequent inspection, cleaning and replacement are required under dusty conditions such as operating a jack hammer on a street.

18.25C Compressor oil should be changed at least every three months, unless manufacturer states differently. If there are filters in the oil system, these also should be changed.

18.25D Drain the condensate from the air receiver daily.

18.25E Before testing belt tension on a compressor with your hands, MAKE SURE COMPRESSOR IS LOCKED OFF.

Answers to questions on page 305.

18.26A Valves are the controlling devices placed in piping systems to stop, regulate, check, divert, or otherwise modify the flow of liquids or gases.

18.26B Six common types of valves found in water treatment facilities include gate valves, globe valves, eccentric valves, butterfly valves, check valves and plug valves.

18.26C The purpose of the check valve is to allow water to flow in one direction only.

18.26D Backflow prevention by check valves is essential in many applications to:

1. Prevent pumps from reversing when power is removed,
2. Protect water systems from being cross-connected,
3. Aid in pump operation as a dampener, and
4. Ensure "full pipe" operation.

18.26E The most common maintenance required by gate valves is oiling, tightening, or replacing the stem stuffing box packing.

ANSWERS TO QUESTIONS IN LESSON 5

Answers to questions on page 308.

18.30A Gasoline engines may be used in water treatment plants to drive pumps, generators, tractors, and vehicles

18.30B If a gasoline engine will not start, check the following items:

1. No fuel in tank, valve closed,
2. Carburetor not choked,
3. Water or dirt in fuel lines of carburetor,
4. Carburetor flooded,
5. Low compression,
6. Loose spark plug, and
7. No spark at plug.

18.30C A gasoline engine may not run properly due to:

1. Engine missing,
2. Engine surging,
3. Engine stopping,
4. Engine overheating,
5. Engine knocking, and
6. Engine backfiring through carburetor.

Answers to questions on page 309.

18.30D If a gasoline engine will not start and the spark plug is wet with oil or fuel, this could indicate that the cylinder is flooded with fuel by having the choke on too long.

18.30E If a gasoline engine will not start and there is an oil residue on the spark plug, this could indicate worn piston rings.

18.30F After an engine has started, give it an opportunity to warm up before applying the load.

Answers to questions on page 315.

18.31A Gasoline is not used as a fuel in diesel engines because it would start to burn from the heat generated by compression before the piston reaches the top of the stroke.

18.31B The four basic parts of a diesel fuel system are:

1. Primary fuel filter,
2. Secondary fuel filter
3. Fuel injection pump, and
4. Fuel injector.

18.31C The purpose of the fuel injection pump is to deliver fuel to the injector at a very high pressure.

18.32A Heat is removed from the cylinders by a water cooling system. Each cylinder is surrounded with a water jacket through which the coolant (water) circulates and pulls heat from the cylinder. This is accomplished by a water pump that is belt-driven from the crankshaft.

Answers to questions on page 316.

18.33A The storage and use of fuels for internal combustion engines must be in accordance with building and fire marshal codes.

18.33B Four types of fuels commonly used by internal combustion engines include (1) diesel, (2) gasoline, (3) liquified petroleum gas (LPG), and (4) natural gas.

18.34A Standby internal combustion engines not in regular service should be started up and test run at least once a week.

18.34B Standby engines should be test run long enough for the engine to come up to its normal operating temperature. If at all possible, the engine should be run under its normal load

Answers to questions on page 321.

18.4A Information on how to operate, control and maintain chemical feeders may be found in the feeder manufacturer's literature.

18.4B The three common types of chemical feeders are (1) solid feeders, (2) liquid feeders, and (3) gas feeders.

18.4C Chlorine is toxic to humans and will cause corrosion damage to equipment

18.4D Large chlorine leaks can be detected by smell. Small leaks are detected by soaking a cloth with ammonia water and holding the cloth near areas where leaks might develop. A white cloud will indicate the presence of a leak.

Answers to questions on page 321

18.5A Tanks and reservoirs should be drained and inspected at least once every five years if the interior is well protected; more often if it is not well protected.

18.5B The groundwater level should be below the bottom of a tank before it is drained so the tank will not float on the groundwater when empty or develop cracks from groundwater pressure.

18.5C Cathodic protection is an alternative to applying a protective coating to prevent corrosion of a steel tank.

Answers to questions on page 322.

18.6A A building maintenance program will keep the building in good shape and includes painting when necessary. Attention also must be given to electrical systems, plumbing, heating, cooling, ventilating, floors, windows, and roofs. The building should be kept clean, tools should be stored in their proper place, and essential storage should be available.

18.6B Factors that influence the type of building maintenance program needed by a water treatment plant include the age, type and use of each building.

OBJECTIVE TEST

Chapter 18. MAINTENANCE

Please mark correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. An Equipment Service Card is another name for a Service Record Card.
   1. True
   2. False

2. Building maintenace is *NOT* part of a treatment plant operator's duties.
   1. True
   2. False

3. A treatment plant library should contain copies of the plant's drawings and specifications.
   1. True
   2. False

4. Pumps in water treatment plants are driven only by electric motors.
   1. True
   2. False

5. If a pump is going to be shut down for a long period of time. the pump should be drained.
   1. True
   2. False

6. An empty clear well drained for inspection purposes could float up out of the ground when the groundwater level is high.
   1. True
   2. False

7 All gate valves have non-rising valve stems.
   1. True
   2. False

8 The most practical form of emergency lighting is that provided by standby power generators.
   1. True
   2. False

9 Standby power generators should be operated once a week at full load.
   1. True
   2. False

10 Diesel engines can use gasoline for fuel.

1. True
2. False

11 Diesel engines use spark plugs

1. True
2. False

12. A qualified electrician should perform most of the necessary maintenance and repair of electrical equipment

1. True
2. False

13. When a pump is not shut off, locked out, and tagged properly, a plant operator could be maintaining a pump, the pump could start, and the operator could lose a finger.

1. True
2. False

14 Most electrical equipment does not indicate the proper voltage on the name plate

1. True
2. False

15. Closing an electrical circuit is like closing a valve on a water pipe.

1. True
2. False

MULTIPLE CHOICE

16 Which of the following items are parts of an electric motor?

1. Impeller
2. Rotor
3. Stator
4. Volute
5. Windings

17 Centrifugal pump parts include

1. Diaphragm.
2. Impeller
3. Piston
4. Rotor.
5. Volute.

18. Wearing rings are installed in a pump to

1. Hold the shaft in position.
2. Keep the impeller in place.
3. Plug internal water leakage.
4. Wear instead of impeller.
5. Wear out the sleeves.

19. What could be the cause of a pump's electric motor not starting?

1. Fuse or circuit breaker out
2. Incorrect power supply
3. No power supply
4. Pump not hooked to motor
5. Rotating parts of motor may be jammed mechanically

20. Equipment name plate data must be recorded and filed because the

1. Filing cabinet is supposed to have this information.
2. Information is needed to order replacement parts.
3. Manufacturer doesn't keep the information on older models.
4. Name plate could become corroded.
5. Name plate could get lost

21 Compressor maintenance includes

1. Cleaning cylinder or casing fins weekly.
2. Examining the oil reservoir dipstick or sight glass.
3. Inspecting the suction filter of the compressor regularly
4. Keeping the belts as tight as possible
5. Washing off the compressor weekly.

22 What is the purpose of an equipment preventive maintenance program?

1. To extend equipment life.
2. To insure proper and efficient operation of the equipment.
3. To keep operators looking at equipment.
4. To protect the public's investment spent buying the equipment.
5. To provide jobs for operators when they visit a facility.

23 When belts are used to drive equipment, important considerations include

1. Belt dressing should be used monthly for pliability of belts
2. Belts must be matched sets
3. Guards are required on all belt drives that are exposed.
4. Noise or squeal on startup can be corrected by proper tension
5. Proper number of belts.

24 Some of the advantages of mechanical seals over packing include

1. Continual adjusting, cleaning, or repacking is not required.
2. Lower initial cost.
3. Pump does not have to be dismantled for repair.
4. They last longer, thus resulting in labor savings.
5. Usually there isn't any damage to shaft sleeve when they need replacing.

25 What information must be on a warning tag attached to a locked out switch?

1. Directions for removing tag
2. Name of company that printed tag
3. Name of equipment
4. Signature of person who locked out switch and who is only person authorized to remove tag
5. Time to unlock switch

26 Operators should not do actual electrical repairs or troubleshooting because

1. Costly damage can be done to equipment by unauthorized persons.
2. It is too dangerous.
3. Many are not adequately trained
4. They realize their own limitations regarding electrical work.
5. This is a highly specialized field.

27. If a pump will not start, check for
    1. Loose terminal connections
    2. Nuts, bolts, scrap iron, wood, or plastic in the wrong places
    3. Shaft binding or sticking
    4. Tripped circuit breakers.
    5. Water in the wet well.

28. How can a chlorine leak be detected?
    1. By an explosiometer
    2. By checking the rotameter
    3. By waving an ammonia-soaked rag
    4. Green or reddish deposits on metal
    5. Smell

29 What can heppen if you *DO NOT* periodically drain and inspect plant tanks and channels?
    1. An emergency situation may develop during a period of high demand.
    2. Costly repairs could result.
    3. Serious maintenance problems could develop.
    4. The operator will not know if cracks are developing in underground tanks and channels.
    5. The operator will stay out of trouble.

30 Pump maintenance includes
    1. Checking operating temperature of bearings.
    2. Checking packing gland.
    3. Lubricating the impeller.
    4. Operating two or more pumps of the same size alternately to equalize wear.
    5. Preventing all water seal leaks around packing glands

31 Preventive maintenance of electric motors includes
    1. Checking temperature of motor.
    2. Frequently starting and stopping the motor to give it a rest.
    3. Keeping motor free from dust, dirt and moisture.
    4. Keeping motor outdoors where it can stay cool.
    5. Lubricate bearings.

32. Maintenance of gate valve includes
    1. Lubricating bearing.
    2. Lubricating with Prussian Blue.
    3. Operating inactive valves to prevent sticking.
    4. Refacing leaky valve seats.
    5. Tightening or replacing the stem stuffing box packing.

33 Proper selection of an emergency lighting unit for a particular location requires careful consideration of which of the following items?
    1. Costs
    2. Lighting requirements
    3. Nearness of vendor to repair failures
    4. Necessary switch gear
    5. Types of batteries

34. Possible causes of a gasoline engine not starting include
    1. Carburetor choked.
    2. Carburetor flooded.
    3. Loose spark plugs.
    4. Spark at plug.
    5. Water in fuel lines of carburetor.

35. The ignition system for a gasoline engine consists of the
    1 Battery
    2. Coil.
    3. Distributor
    4. Filter
    5. Thermostat.

36. If a compressor fails to operate or provide rated capacity, what could be the cause of the problem?
    1 Air cleaner, cap and/or screen clogged
    2 Air used by compressor is polluted
    3. Engine fails to develop proper RPMs
    4. Faulty oil seal
    5. Pressure regulator improperly adjusted

37. Maintenance of automatic valves includes
    1 Adjusting the check valve.
    2 Cleaning any strainers in the pilot control system.
    3. Determining if controls are properly positioning valve.
    If valve is inactive, manually exercise valve from tight shut to wide open position.
    5 Reversing the flow through the valve.

38 Problems that may be encountered when storing gasoline include
    1. Deterioration of gasoline stored for a long time.
    2 Easy starting of engines.
    3 Gasoline leaking into an underground water supply.
    4 Lack of gummy deposits on parts of the fuel system.
    5 Water leaking into the gasoline storage tank.

39. Steel tanks may be protected from rusting by
    1. Alternately wetting and drying walls.
    2. Cathodic protection.
    3 Maintaining humidity in tank
    4 Protective coatings.
    5 Washing tank walls.

40 Equipment service cards and service record cards should
    1. Identify the piece of equipment that the record card represents.
    2. Indicate the work done.
    3 Indicate the work to be done.
    4 Maintain selective service records.
    5 Record sick leave.

41 Estimate the pumping capacity of a pump in gallons per minute if 11 minutes are required for the water level in a tank to drop 3 feet. The tank is 6 feet in diameter.
    1 8 GPM
    2. 10 GPM
    3. 36 GPM
    4 58 GPM
    5. 74 GPM

42 Calculate the feed rate of a dry chemical feeder in pounds per day if two pounds of chemical are caught in a weighing tin during nine minutes.
    1. 320 lbs/day
    2. 2394 lbs/day
    3. 2670 lbs/day
    4. 2860 lbs/day
    5. 3200 lbs/day

End of Objective Test

CHAPTER 19

INSTRUMENTATION

by

Leonard Ainsworth

TABLE OF CONTENTS

Chapter 19 Instrumentation

LESSON 1

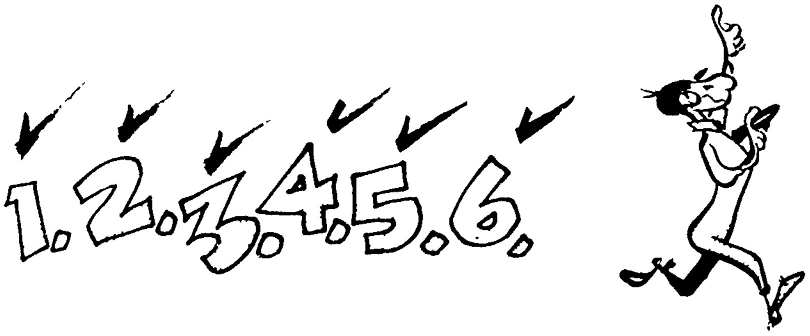
LESSON 2

OBJECTIVES

Chapter 19. INSTRUMENTATION

Following completion of Chapter 19, you should be able to:

1. Explain the purpose and nature of measurement and control systems,
2. Identify, avoid and correct safety hazards associated with instrumentation work,
3. Recognize various types of sensors and transducers,
4. Operate and maintain measurement and control instruments,
5. Read instruments and make proper adjustments in operation of waterworks facilities, and
6. Determine location and cause of measurement and control system failures and take corrective action.



GLOSSARY

Chapter 19. INSTRUMENTATION

ACCURACY ACCURACY

How closely an instrument measures the true or actual value of the process variable being measure or sensed.

ALARM CONTACT ALARM CONTACT

A switch that operates when some pre-set low, high or abnormal condition exists.

ANALOG ANALOG

The readout of an instrument by a pointer (or other indicating means) against a dial or scale.

ANALYZER ANALYZER

A device which conducts periodic or continuous measurements of some factor such as chlorine, fluoride or turbidity. Analyzers operate by any of several methods including photocells, conductivity or complex instrumentation.

CALIBRATION CALIBRATION

A procedure which checks or adjusts an instrument's accuracy by comparison with a standard of reference

CONTACTOR CONTACTOR

An electrical switch, usually magnetically operated.

CONTROL LOOP CONTROL LOOP

The path through the control system between the sensor, which measures a process variable, and the controller, which controls or adjusts the process variable.

CONTROL SYSTEM CONTROL SYSTEM

A system which senses and controls its own operation on a close, continuous basis in what is called proportional (or modulating) control.

CONTROLLER CONTROLLER

A device which controls the starting, stopping, or operation of a device or piece of equipment.

DESICCANT (DESS-uh-kant) DESICCANT

A drying agent which is capable of removing or absorbing moisture from the atmosphere in a small enclosure

DESICCATION (DESS-uh-KAY-shun) DESICCATION

A process used to thoroughly dry air; to remove virtually all moisture from air.

DETECTION LAG DETECTION LAG

The time period between the moment a change is made and the moment when such a change is finally sensed by the associated measuring instrument.

DIGITAL READOUT DIGITAL READOUT

The use of numbers to indicate the value or measurement of a variable. The readout of an instrument by a direct, numerical reading of the measured value.

EFFECTIVE RANGE EFFECTIVE RANGE

That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy. Also see RANGE and SPAN.

FEEDBACK
FEEDBACK

The circulating action between a sensor mesuring a process variable and the controller which controls or adjusts the process variable

HERTZ (HURTS)
HERTZ

The number of complete electromagnetic cycles or waves in one second of an electrical or electronic circuit Also called the frequency of the current Abbreviated Hz.

INTEGRATOR
INTEGRATOR

A device or meter that continuously measures and calculates (adds) total flows in gallons, million gallons, cubic feet, or some other unit of volume measurement. Also called a TOTALIZER.

INTERLOCK
INTERLOCK

An electrical switch, usually magnetically operated Used to interrupt all (local) power to a panel or device when the door is opened or the circuit is exposed to service.

LEVEL CONTROL
LEVEL CONTROL

A float device (or pressure switch) which senses changes in a measured variable and opens or closes a switch in response to that change In its simplest form, this control might be a floating ball connected mechanically to a switch or valve such as is used to stop water flow into a toilet when the tank is full.

LINEARITY (LYNN-ee-AIR-it-ee)
LINEARITY

How closely an instrument measures actual values of a variable through its effective range, a measure used to determine the accuracy of an instrument.

MEASURED VARIABLE
MEASURED VARIABLE

A characteristic or component part that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

OFFSET (or DROOP)
OFFSET

The difference between the actual value and the desired value (or set point), characteristic of proportional controllers that do not incorporate reset action.

PRECISION
PRECISION

The ability of an instrument to measure a process variable and to repeatedly obtain the same result. The ability of an instrument to reproduce the same results

PRESSURE CONTROL
PRESSURE CONTROL

A switch which operates on changes in pressure Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).

PRIMARY ELEMENT
PRIMARY ELEMENT

The hydraulic structure used to measure flows. In open channels weirs and flumes are primary elements or devices. Venturi meters and orifice plates are the primary elements in pipes or pressure conduits.

PROCESS VARIABLE
PROCESS VARIABLE

A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or industrial plant.

RANGE
RANGE

The spread from minimum to maximum values that an instrument is designed to measure. Also see EFFECTIVE RANGE and SPAN.

RECEIVER
RECEIVER

A device which indicates the value of a measurement Most receivers in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a moving chart with movable pen such as on a circular-flow recording chart. Also called an INDICATOR.

RECORDER
RECORDER

A device that creates a permanent record, on a paper chart or magnetic tape, of the changes of some measured variable.

REFERENCE REFERENCE

A physical or chemical quantity whose value is known exactly, and thus is used to calibrate or standardize instruments

ROTAMETER (RODE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered calibrated tube. Inside the tube is a small ball or a bullet-shaped float (it may rotate) that rises or falls depending on the flow rate The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.

SENSOR SENSOR

An instrument that measures (senses) a physical condition or variable of interest Floats and thermocouples are examples of sensors.

SET POINT SET POINT

The position at which the control or controller is set This is the same as the desired value of the process variable

SOFTWARE PROGRAMS SOFTWARE PROGRAMS

Computer programs, the list of instructions that tell a computer how to perform a given task Some software programs are designed and written to monitor and control distribution systems and water treatment processes

SOLENOID (SO-lu-noid) SOLENOID

A magnetically (electrical coil) operated mechanical device. Solenoids can operate pilot valves or electrical switches

SPAN SPAN

The scale or range of values an instrument is designed to measure. Also see RANGE.

STANDARD STANDARD

A physical or chemical quantity whose value is known exactly, and is used to calibrate or standardize instruments Also see REFERENCE

STANDARDIZE STANDARDIZE

To compare with a standard. (1) In wet chemistry, to find out the exact strength of a solution by comparing with a standard of known strength. This information is used to adjust the strength by adding more water or more of the substance dissolved (2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

STARTERS STARTERS

Devices used to start up motors. Special motor starters gradually start large motors to avoid severe mechanical shock to a driven machine and to prevent disturbance to the electrical lines (causing dimming and flickering of lights)

TELEMETRY (tel-LEM-uh-tree) TELEMETRY

The electrical link between the transmitter and the receiver Telephone lines are commonly used to serve as the electrical link

THERMOCOUPLE THERMOCOUPLE

A heat-sensing device made of two conductors of different metals joined at their ends A thermoelectrical current is produced when there is a difference in temperature between the ends.

TIME LAG TIME LAG

The time required for processes and control systems to respond to a signal or to reach a desired level

TIMER TIMER

A device for automatically starting or stopping a machine or other device at a given time

TOTALIZER TOTALIZER

A device or meter that continuously measures and calculates (adds) total flows in gallons, million gallons, cubic feet or some other unit of volume measurement. Also called an INTEGRATOR.

TRANSDUCER (trans-DUE-sir) TRANSDUCER

A device which senses some varying condition and converts it to an electrical or other signal for transmission to some other device (a receiver) for processing or decision making.

TURN-DOWN RATIO
TURN-DOWN RATIO

The ratio of the design range to the range of acceptable accuracy or precision of an instrument. Also see EFFECTIVE RANGE.

VARIABLE, MEASURED
VARIABLE, MEASURED

A factor (flow, temperature) that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

VARIABLE, PROCESS
VARIABLE, PROCESS

A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

SYMBOLS

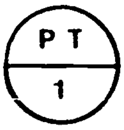
Chapter 19. INSTRUMENTATION

Special symbols are used for simplicity and clarity on circuit drawings for instruments. Usually instrument manufacturers and design engineers provide lists of symbols they use with an explanation of the meaning of each symbol. This section contains a list of typical instrumentation abbreviations and symbols used in this chapter and also used by the waterworks profession.

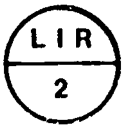
ABBREVIATIONS

A — **Analyzer**, such as used to measure a water quality indicator (pH, temperature).
C — **Controller**, such as a device used to start, operate or stop a pump.
D — **Differential**, such as a "differential pressure" or **D**. P. cell used with a flow meter.
E — **Electrical** or Voltage.
    Element, such as a primary element.
F — **Flow rate** (*NOT* total flow).
H — **Hand** (manual operation).
    High as in hi-level.
I — **Indicator**, such as the indicator on a flow recording chart.
    I = E/R where I is the electrical current in amps.
L — **Level**, such as the level of water in a tank.
    Low, as in a lo-level switch.
    Light, as in indicator light.
M — **Motor**.
    Middle, as in a mid-level switch.
P — **Pressure** (or vacuum).
    Pump.
    Program, as in a software program.
Q — **Quantity**, such as a totalized volume (Σ for summation is also used).
R — **Recorder** (or printer), such as a chart recorder.
    Receiver.
    Relay.
S — **Switch**.
    Speed, such as an increase in the RPM (revolutions per minute) of a motor.
    Starter, such as a motor starter.
    Solenoid.
T — **Transmitter**
    Temperature.
    Tone.
V — **Valve**.
    Voltage.
W — **Weight**.
    Watt.
X — Special or unclassified variable.
Y — Computing function, such as a square-root ($\sqrt{\quad}$) extraction.
Z — Position, such as a percent valve opening.

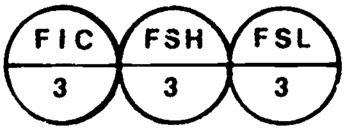
TYPICAL SYMBOLS

1. 

Pressure transmitter #1

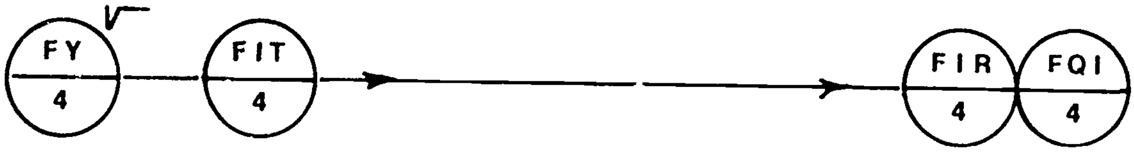
2. 

Level indicator-recorder #2

3. 

Flow indicator-controller #3 with hi-low control switches

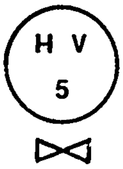
4\.



Flow rate computer
and indicator-transmitter
4- 20 ma D.C

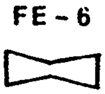
Flow recorder
and totalizer
(loop #4)

5



Hand valve #5

6

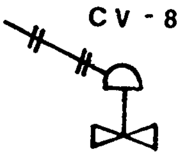


Flow element (tube) #6

7\.

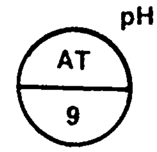
Electric control valve #7

8



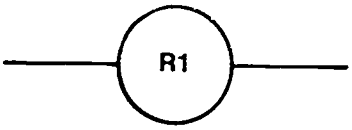
Pneumatic control valve #8

9\.

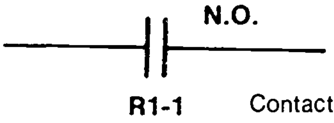


Analyzer (pH) transmitter
(either at location 9 or the pH
level is at 9)

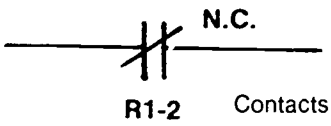
10\.



Relay #1

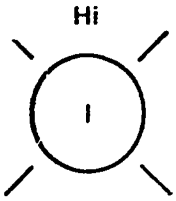


Contacts Normally Open



Contacts Normally Closed

11\.

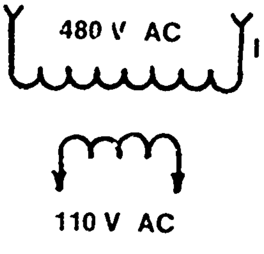


Hi-level
Indicator light (red)

12\.

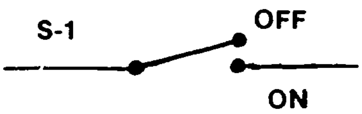
Resistor
100 ohms

13\.



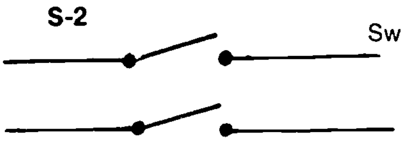
Transformer
(step-down)

14.



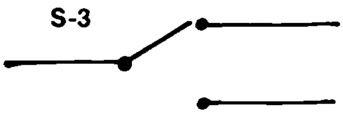
Switch #1 (SPST)*

15.



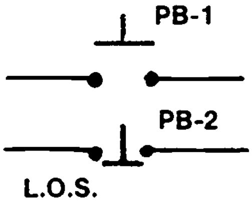
Switch #2 (DPST)*

16.



Switch #3 (SPDT)*

17

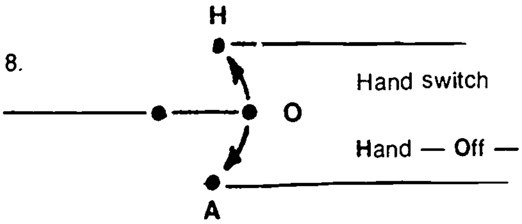


Push button switches
#1 push to make

#2 push to break

Lock-out stop safety feature

18.

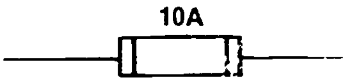


Hand switch

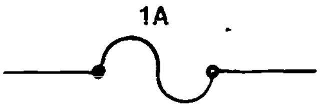
Hand — Off — Automatic

19.

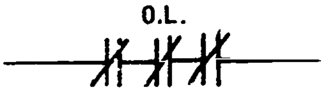
FUSES



10 amp cartridge



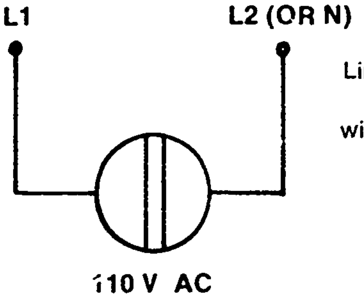
1 amp line fuse



overload contacts

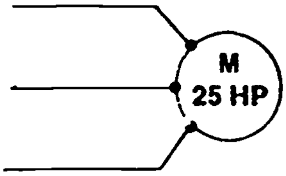
20 amp circuit breaker

20.



Line 1 and Line 2
(neutral)
with duplex outlet

21.



Electric motor, 3 phase power 25 horsepower

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* SPST means Single Pole, SingleThrow
DPST means Double Pole, Single Throw
SPDT means Single Pole, Double Throw

CHAPTER 19. INSTRUMENTATION

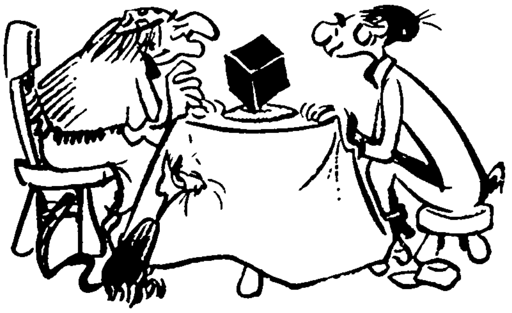
(Lesson 1 of 2 Lessons)

19.0 IMPORTANCE AND NATURE OF MEASUREMENT AND CONTROL SYSTEMS

19.00 Need for Understanding Measurement and Control Systems

In this chapter, you will learn some basic concepts about waterworks measurement instruments and their associated control systems. Since the water treatment plant operator frequently must monitor, and sometimes control, the distribution system supplied from the plant, both in-plant and field-type instrumentation will be discussed. You will become generally acquainted with the *WHAT, HOW,* and *WHY* instrument systems measure, and how some measured quantities are controlled automatically. However, this chapter is not intended to teach you how to "fix" a malfunctioning instrument, though some general preventive maintenance steps are included in the discussion.

Your understanding of the measurement and control basics presented here enhance the efficient and effective operation of your plant and/or system. Specifically, if you can recognize a meter as faulty (by the way the pointer acts, for example), your treatment/distribution decisions will then be based upon that knowledge rather than a blind-faith-in-the-black-box attitude you might otherwise have to assume.



Also, the operator who recognizes the general operating principles of typical instrumentation systems is prepared to perform not only routine preventive maintenance, but also to take the minor corrective action sometimes really necessary to keep the system operating. The operator who knows enough to free a stuck pen, safely replace a fuse, or drain an air line can avoid a lot of personal worry and the expense of an electrician's service call while still protecting the operational integrity of the plant or system.

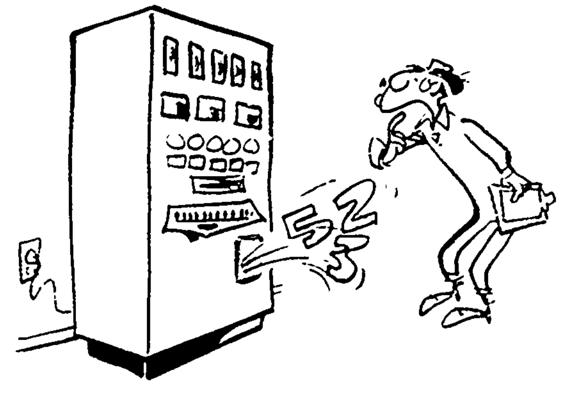
19.01 Importance to Waterworks Operator

In a real sense, measurement instruments can be considered extensions of your human senses, comparable in many ways to your own wide-ranging and exact eyes and ears. The associated automatic control systems, in turn, are like having extra sets of far-reaching and strong hands, to constantly and precisely manipulate valves, motors and switches. In effect then, instrumentation provides you with a staff of hard-working assistants, always on the job to help you operate your plant and system easily. If you have failed to adequately appreciate the advantages of automation, consider the alternative methods of operating your plant. For example, in the recent past, or for some older operations in existence today, the situation described in the following paragraph could have occurred.

You have a complete and unrestorable power failure in the circuit which supplies all of the instruments and control systems in your conventional water filtration plant. As the operator you must try to keep the plant on-line manually by controlling influent and effluent flows, basin levels, pump operation, chemical feeders, and filter valves. You must do all of this by watching and listening, and running to manipulate valves, start and stop pumps, and reset chemical feeders. Even if you could do it (and some nights on shift it seems like that *IS* what you have to do) for a small plant, you certainly couldn't exercise close control and do it for a long time. If you are trying to operate a larger plant, continued operation would be impossible without the instrumentation systems functioning. Accordingly, you would do well to familiarize yourself now with these "eyes, ears, and hands" that are so essential to your effective performance as a professional waterworks operator.

19.02 Purpose and Nature of the Measurement Process

Instrument capabilities can greatly extend our range of personal observations. They also have an additional and quite important advantage over our senses in that instruments provide quantitative or measurable information, whereas only qualitative information is available from our senses. That is to say, instruments provide us with numbers; the direct senses can only tell us that an observation is "more than" or "less than" what the observation was the last time it was recently observed. Some very simple water supply operations can and do get by with such imprecise



visual observations of a chemical process, rate of flow, or basin level. However, modern water facilities must operate "by the numbers" so to speak. and only instrumentation can provide these numbers (Figure 19.1).

A measurement is, by definition, the comparison of the quantity or *PROCESS VARIABLE,*[1] in question to an accepted standard unit of measure. Certain basic units of length, volume, weight, and time have been agreed upon by international convention to serve as "primary standards." All measurements of length (level, area, volume, capacity, weight, pressure, and rate of flow encountered in waterworks practice ultimately refer to these standards. Thus, the weight of a 100-pound sack of chemicals, for instance, amounts to 100 times that of the standard pound; or, the capacity of a tank could be 1000 times larger than the standard gallon. Some important terms often encountered in measurement practice will be discussed in the following paragraphs.

ACCURACY refers to how closely an instrument determines the true or actual value of the process variable being measured. Accuracy depends upon the *PRECISION*, or general quality and condition of the instrument, as well as upon its *CALIBRATION*. An instrument is calibrated in order to standardize its measurements. That is, the instrument itself is made to measure the value of a standard unit or reference and its indicator is adjusted accordingly. *STANDARDIZATION* is a simple calibration procedure done regularly (by the operator). Most instruments are accurate to about one or two parts in one hundred; this is expressed as ± 1 to 2 percent error (or at times 98 to 99 percent accuracy). The *RANGE* of an instrument is the spread between the minimum and the maximum value of the variable it is designed to measure accurately. The *EFFECTIVE RANGE* is that portion of its complete range within which acceptable accuracy can be expected, usually from 10 to 90+ percent of its nominal (design) range, though it is technically not the same *LINEARITY* refers to how closely the instrument measures actual values of the variable through its effective range, and thus bears upon its stated accuracy. An *ANALOG* readout of an instrument has a pointer (or other indicating means) reading against a dial or scale, a *DIGITAL* display provides a direct, numerical reading.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381.

19.0A How can measurement instruments be considered an extension of your human senses?

19.0B What water treatment processes and equipment could be monitored or controlled by measurement and control systems?

19.0C What is an advantage of instruments over our human senses?

19.0D What is an analog readout?

19.03 Explanation of Control Systems

The terms "controller" and "control systems" are used in the waterworks field in two different senses. The electrical panel which controls only the starting/stopping of an electric motor is referred to as a "controller." This controller may control a pump's operation or a chemical feeder motor. The control exercised may be manual, through push-buttons or switches, or automatic with a switch responding to a value of level, pressure, or other variable — such as is usually the case with a "Hand-Off-Automatic" (H.O.A.) function switch.

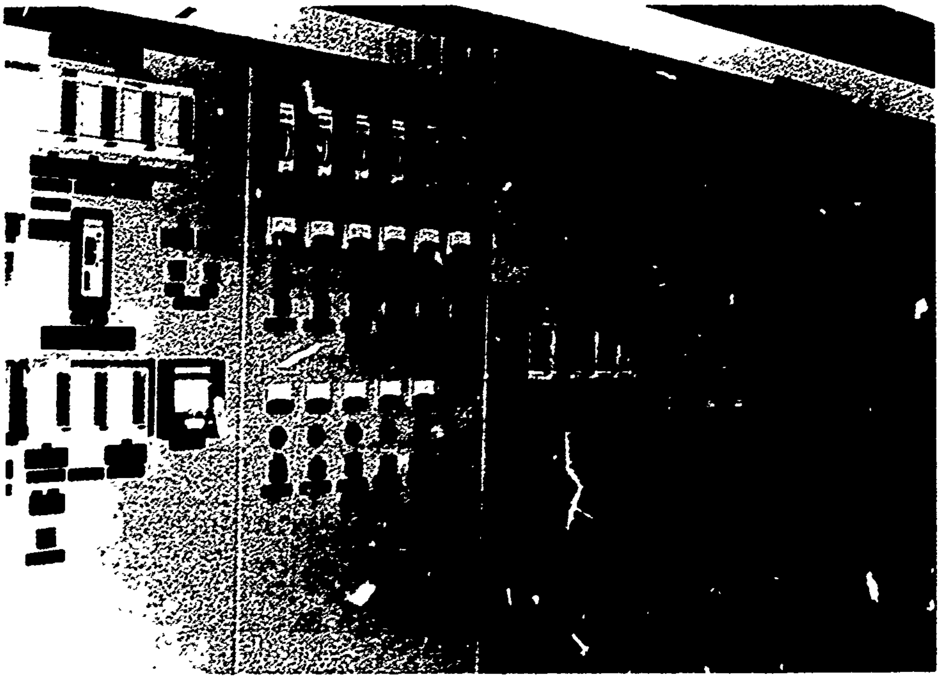


Fig. 19.1 Main control panel of a modern water treatment plant

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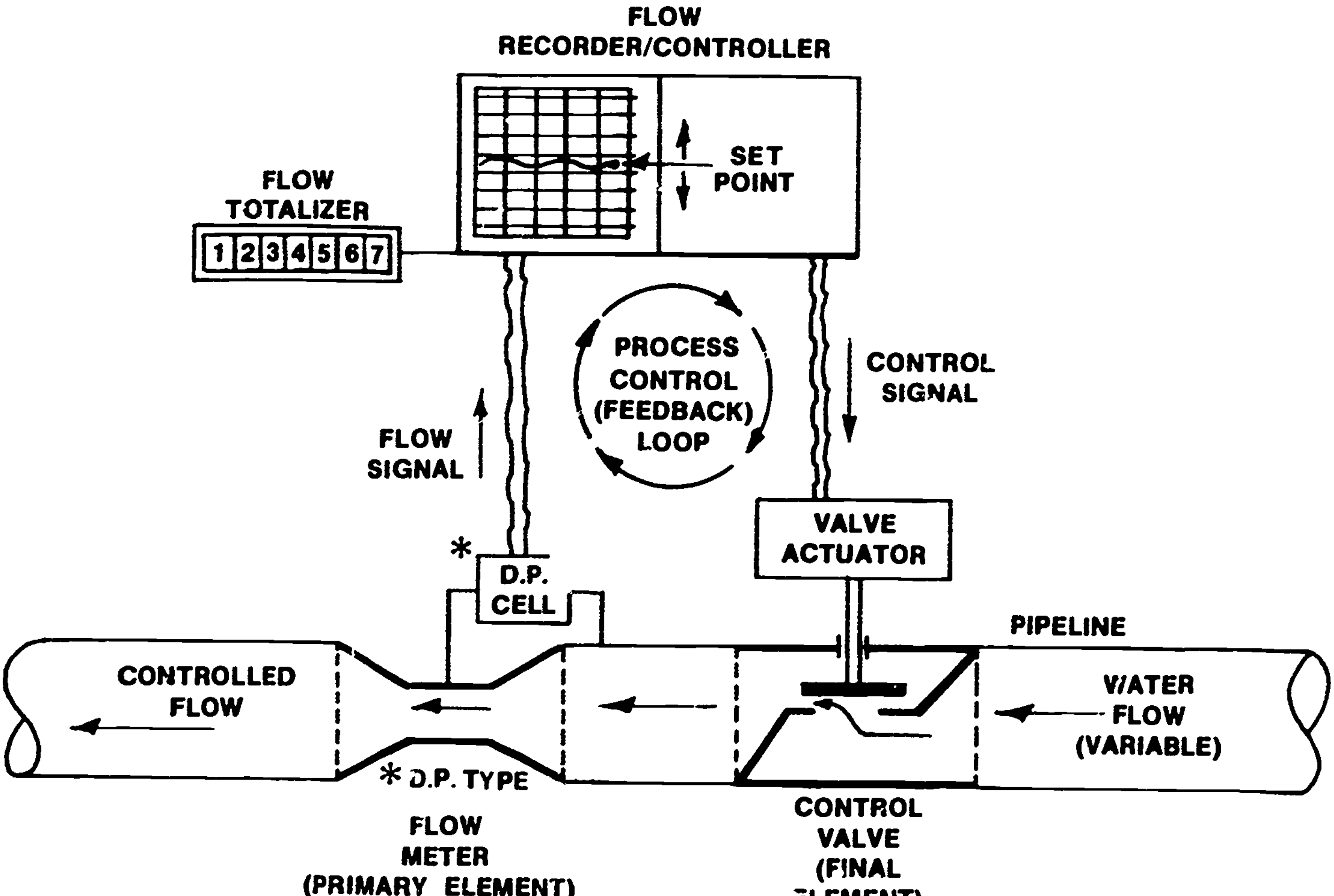
[1] *Process Variable. A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or industrial plant*

This type of so-called controller is more correctly termed a motor control station or panel, and will be discussed later. The other, technically proper, usage of the terms controller and control system identify a system which senses and controls its own operation on a close, continuous basis, in what is called proportional (or modulating) control. This type of true controller will be discussed first (Figure 19.2).

In order for a process variable, whether pressure, level, weight, or flow, to be closely controlled, it must be measured precisely and continuously. The measuring device sends a signal (electrical or pneumatic, as discussed in a following section) proportional to the value of the variable, to the actual controller. Within the controller, the signal is compared to the desired or set-point value (Figure 19.3). A difference between the actual and desired values results in the controller sending out a command signal to the "controlled element," usually a valve, pump, or feeder. Such an "error signal" produces an adjustment in the system that causes a corresponding change in the original measured variable making it more closely match the set-point. This continuous "cut and try" process can result in very fine ongoing control of variables requiring constant values, such as some flow rates, pressures, levels, or chemical feeds. The term applied to this circulating action of the variable in such a controller is *FEEDBACK*. The path through the control system is the *CONTROL LOOP*. The internal settings of the true controller can be quite critical since close control depends upon sensitive adjustments. Thus, you should not try to adjust any such control system unless you know exactly what you are doing. Many plant and system operations have been drastically upset due to such efforts, however well intentioned, of unqualified personnel.

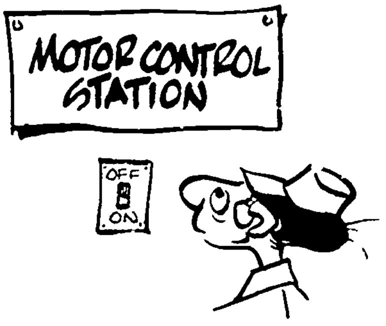
Examples of the above proportional control of waterworks operations which may be encountered are: (1) chlorine residual analyzer/controller; (2) chemical feed; flow-paced (open loop); (3) pressure- or flow-regulating valves; (4) continuous level control of filter basins; and (5) variable-speed pumping systems for flow/level control.



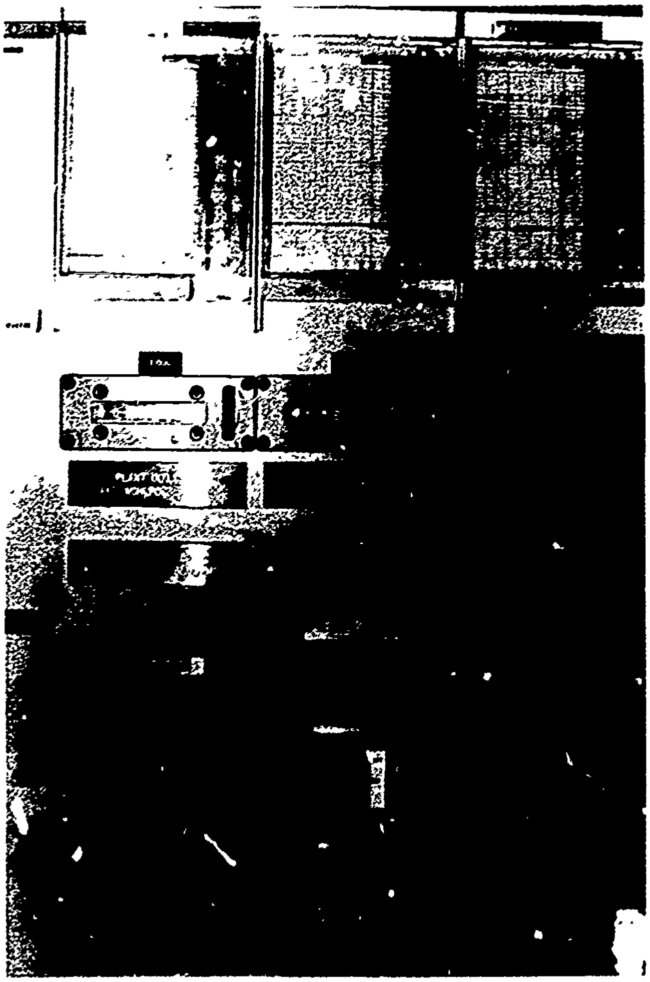
NOTE: ELECTRIC SYSTEM SHOWN MAY BE PNEUMATIC ALSO

* D.P. MEANS "DIFFERENTIAL PRESSURE"

Fig. 19.2 Automatic control system diagram, flow (closed loop proportional)



The *MOTOR CONTROL STATION* (Figures 19.4 and 19.5), as mentioned, essentially provides only for on-off operation of an electric motor, which in turn powers a pump, valve, or chemical feeder. Primarily it is a standard electric motor panel, with manual operation push-buttons, overload relays, and function switch (H.O.A. or Hand-Off-Automatic). Additionally it may include, in good electrical design practice, provisions for power failure or loss-of-phase ("fail-safe" circuitry), and such protective devices as high or low pressure/temperature/level cut-off switches. For this type of panel even to be considered a controller (within our secondary meaning of the term), its operation must be controlled by the value or values of some variable, not merely by a device such as a timer In other words, it must be turned on and off as a result of a measurement of a level, pressure, flow, chemical concentration, or other variable which reaches a predetermined setting. In the automatic mode (A on the H.O.A. switch) then, its operation is in fact automatic in the sense that the variable is controlled, even though the limits of its value are quite wide compared to those attainable with a true controller as previously described. Whereas a filter basin level controller may allow only an inch or so of water level change, an on-off system might operate within a few feet of level difference. In many applications, however, such wide control is of no particular disadvantage, and sometimes is even desirable (such as with a distribution system reservoir level). However, one problem with level controllers in some water treatment plants is that small changes in the water level over the filters will cause the effluent controller to modulate suddenly. In cases of rising levels the effluent valve will open suddenly and turbid water from within the filter may be discharged as treated water.



NOTE: Controller in photo is the lower instrument with set point at 10 MGD.

Fig. 19.3 Photo of flow recorder/controller in Fig. 19.2

Terms used in control practice can be now defined operationally in this paragraph. *FEEDBACK* and *CONTROL LOOP* have been mentioned previously, however, the term *CONTROL LOOP* needs qualification. An *OPEN-LOOP* control system controls one variable on the basis of another. A good example of this is a chlorinator "paced" by flow signals (rather than by the chlorine residual analyzer). *CLOSED-LOOP* control remains as discussed previously, the true controller. *PROPORTIONAL-BAND, RESET* and *DERIVATIVE* actions are adjustments of the controller that bear upon effectiveness and speed of control action. *OFFSET* is the difference between the desired value of the variable (the *SET-POINT*) and the controlled (actual) value. *DETECTION LAG*, common to chlorinator control systems, refers to the prolonged period between the moment when a change in control is effected and the moment when such change is finally sensed by the associated measuring instrument

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381.

19.0E What does an on-off type "controller" control?

19.0F List three examples of "proportional control" in waterworks operations.

19.0G What is the purpose of a motor control station?

19.1 SAFETY HAZARDS OF INSTRUMENTATION WORK

19.10 Be Careful

The general principles for safe performance on the job, summed up as always avoiding unsafe acts and correcting unsafe conditions, apply as much to instrumentation work as to other plant operations. However, there are some special dangers associated with instrument systems, mainly electrical shock hazards, that merit special mention in this section. Repetition is well justified for the sake of safe practice!

19.11 Electrical Hazards

A hidden aspect of energized electrical equipment is that it "looks normal," that is, there are no obvious signs that tend to discourage one from touching. In fact, there seems to be a peculiar fascination to "see if it's really live" by touching circuit components with a tool, often a screwdriver (usually

———— ELECTRICAL WIRE

- - - - - - - - - - MECHANICAL LINK ("GANGED")

A	AMPERE: 100A (RATING)
DS	DISCONNECT SWITCH
HOA	HAND-OFF-AUTO: H SS, OO, A SS
HP/LP	HIGH/LOW PRESSURE
LOS	LOCK-OUT STOP
PB	PUSH-BUTTON: ON OFF
R	RELAY: RELAY COIL (R1) R1-a RELAY CONTACTS
SW	SWITCH: OPEN CLOSED
L1/L2	LINE 1 (HOT) 2 (NEUTRAL)
VAC POWER	60 Hz 3∅ VOLTS AC (60 CYCLES, 3 PHASE)
CB	CIRCUIT BREAKER (MAGNETIC)
MS	MOTOR STARTER (CONTACTOR)
AUX	AUXILIARY CONTACTS

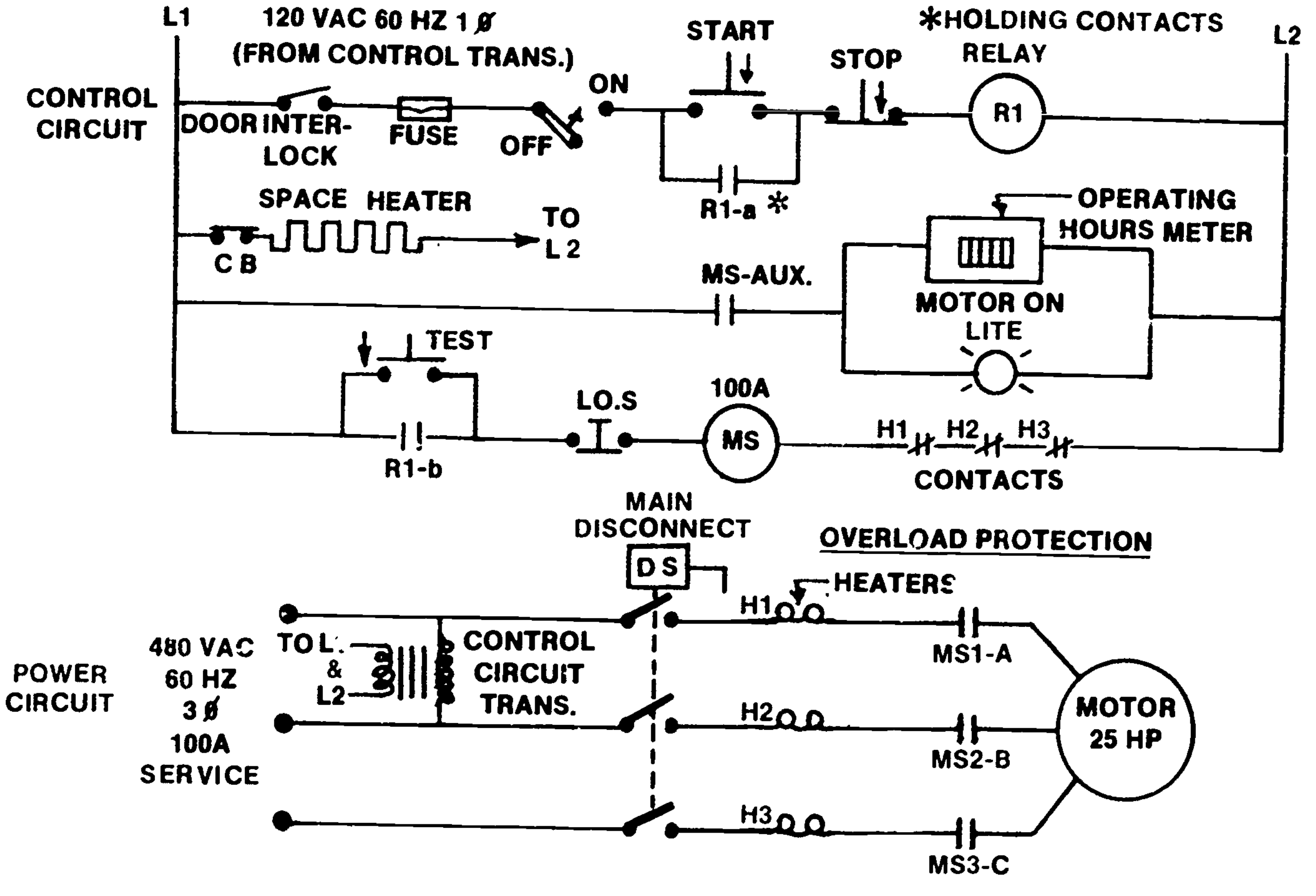


Fig. 19.4 Motor control panel (simplified double-line schematic)

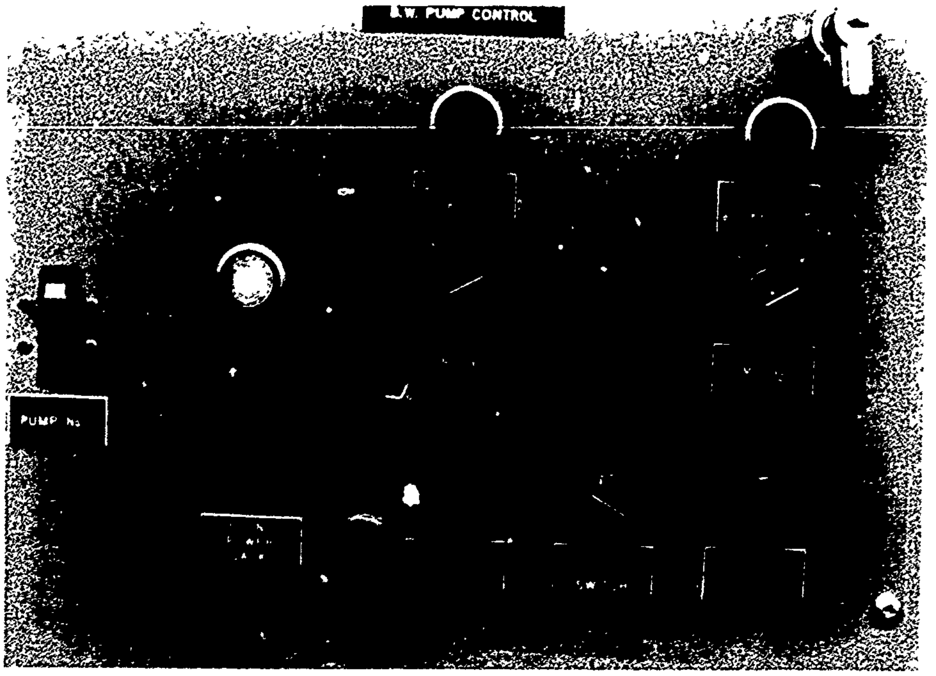


Fig. 19.5 Photo of motor control panel

having an insulated handle. fortunately) but even with the finger Only training, coupled with bad experience at times, is effective in squelching this morbid curiosity Even so, most practicing electricians' tools have an "arc-mark trademark" or two. evidence of the need for continuing self-discipline in this area Though such mention may conjure up humorous images of the maintenance person's surprise and "shock" upon such an incident, one only need consider that electrical shock can and does regularly cause disfigurement and even death (by asphyxiation due to paralysis of the muscles used in breathing and/or burning) to bring the problem into sober perspective. Also, the expense and effort caused by a needless shorting-out of an electrical device could be significant. The point is, *RESIST THE URGE* to "test" any electrical device with a tool or part of your body!

If there is *ANY* doubt in your mind that *ALL* sources of voltage (not merely the local switch) have been switched off, then *DON'T TOUCH*, except possibly with the probes of a test meter Remember, you can't "see" even the highest voltage, and an unverified presumption of a dead circuit is worthless and may be deadly

Do not simulate a known electrical action, for example pressing down a relay armature. within an electrical panel without a *POSITIVE* understanding of the circuitry. Your innocent action may cause an electrical "explosion" to shower you with molten metal or startle you into a bumped head or elbow, or a bad fall. Again the adage, *WHEN IN DOUBT — DON'T.*

Usually the operator does not have the test equipment nor the technical knowledge to correct an electrical malfunction, other than possibly resetting a circuit breaker, regardless of how critical the device's function is to plant operations. Though the foregoing applies mainly to motor control centers. there also may be a shock hazard within measurement instrument cases — and the sure destruction of expensive components — when the foolhardy "tool-touch-test" is used.

Most panels have an *INTERLOCK* on the door that interrupts all (local) power to a panel or device when the door is opened or the circuit is exposed for service Do not disconnect or disable interlocks that interrupt all (local) power. Warning labels, insulating covers (over "hot" terminals), safety switches, lock-outs, and other safety provisions on electrical equipment must be used at all times. Your attention to this crucial aspect of your work place may save a life, and as the slogan goes, it could be your own!

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381

19.1A What are the general principles for safe performance on the job?

19.1B How can electrical shock cause death?

19.1C What could happen to you as a result of an electrical "explosion?"

19.12 Mechanical Hazards

There exists a special danger when working around powered mechanical equipment. such as electric motors, valve operators, and chemical feeders which are operated remotely or by an automatic control system Directly stated, the machinery may *START* or *MOVE* when you are not expecting it! Most devices are powered by motors with enough torque or RPM to severely injure anyone in contact with a moving part Even when the exposed rotating or meshing elements are fitted with "guards" in compliance with safety regulations, a danger may exist A motor started remotely may catch a shirt tail, finger, or tool hanging near a loose or poorly-fitted shaft guard

The sudden automatic operation of equipment, even if half-expected, may startle one nearby into a fall or slip. Signs indicating that "This equipment may start at anytime" tend to be ignored after a while Accordingly, you must stay alert to the fact that any automatic device may begin to operate at any time, even if by "off-chance " You must stay well clear of automatic equipment, especially when it is not operating.

Lock-out devices on electrical switches must be respected at all times. The electrician who inserts one to physically prevent the operation of an electrical circuit is, in effect, trusting his life and health to the device. Once the lock-out device is attached to the switch (whether the switch is tagged-off or actually locked with lock and key), the electrician will consider the circuit de-energized and safe and will feel free to work on it. Consider the potential consequences then of an unauthorized operator who removes a lock-out to place needed equipment back into service, presuming the electrician is finished (as might occur after several hours' work). The point cannot be overstressed:

RESPECT ALL LOCK-OUT DEVICES AND ALL TAGGED OFF EQUIPMENT AS IF A LIFE IS ENTRUSTED TO YOU,

IT MAY WELL BE.

Operators often use power tools on instrumentation and associated equipment. All power tools present not only a shock hazard, waterworks being damp places at times, but a mechanical hazard as well. The use of power tools in the performance of instrumentation work, with its special nature, should wait until the operator can have an observer on hand in case of an accident.

19.13 Vaults and Other Confined Spaces

Included as part and parcel of measurement and control systems are those remotely installed sensors and control valves. Quite often these are found in meter or valve vaults, or other closed concrete structures. There are some special precautions beyond those stated in Chapter 20, "Safety " Be sure the ventilation equipment is working properly before entering The use of power tools, including a soldering iron, can be even more dangerous in wet environments. *NEVER* stand in water with a power tool, even when off. Brace yourself, if necessary, in such a way that electrical current cannot flow from arm to arm in case of an ungrounded tool. Shocks through the upper body involve your heart and/or your head, whose importance to you is self-evident!

19.14 Falls

All the general safety measures to guard the operator against falls, a leading cause of lost-time accidents, are covered in Chapter 20, "Safety," and need not be repeated in this instrumentation chapter However, if one considers that an electrical shock of even minor intensity can result in a serious fall, a special mention herein is justified. When working above ground on a ladder, even though you position it safely, use the proper non-conductive type (such as fiberglass), are duly cautious on the way up, and comply with all other considerations of safety, a slight shock can still ruin all your precautions! When required to do preventive maintenance from a ladder, turn off the power to the equipment if at all possible If not feasible, take special care to stay out of contact with any component inside the enclosure of a measuring or operating mechanism, and well away from terminal strips, unconduited wiring ,and "black-boxes " Though not commonly considered essential, the wearing of thin rubber or plastic gloves can reduce your chances of electric shock markedly (whether on a ladder or off).

Make provisions for carrying tools or other required objects on an electrician's belt rather than in your hands when climbing up or down ladders Finally, never leave tools or any object on a step or platform of the ladder when you climb down, even temporarily. *YOU* might be the one upon whom they fall if the ladder is moved or even steadied from below In this regard, it is always a good idea (even if not required) for preventive maintenance personnel to wear a hard hat whenever working on or near equipment, especially when a ladder must be used

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381.

19.1D Why should operators be especially careful when working around powered automatic mechanical equipment?

19.1E What is the purpose of an electrical lock out device?

19.1F Why should you brace yourself when operating power equipment so that electrical current cannot flow from arm to arm in case of an ungrounded tool?

19.1G What kind of specific protective clothing items could be worn to protect you from electrical shock?

19.2 MEASURED VARIABLES AND TYPES OF SENSORS/TRANSMITTERS

19.20 How Variables are Measured

A measured variable is any quantity which is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor. In waterworks practice pressure, level, and flow are the most common measured variables, sometimes chemical feed rates and some physical or chemical water quality characteristics are also sensed

The sensor is often a transducer of some type, in that it converts energy of one kind into some other form to produce a readout or signal. For example, one type of flow meter converts the hydraulic action of the water into the mechanical motions necessary to drive a meter indicator, and also into an electrical signal for a remote readout device. If such a signal is produced, be it electric or pneumatic, the sensor is then considered a transmitter.

The signal produced is frequently not a continuous one proportional to the variable (such as an analog signal), but merely a switch which is set to detect when the variable goes above or below pre-set limits. In this type of on-off control, the pre-determined settings are called control points. This distinction between continuous and set-point operation bears upon the two types of controllers discussed previously. The remainder of this section discusses each of the common variables sensed in waterworks practice.

19.21 Pressure

Since pressure is defined as a force per unit of area (pound per square inch or kiloPascal), you might expect that sensing pressure would entail the movement of some flexible element subjected to a force. In fact, that is how pressure is always measured. Such pressure elements (a class of primary elements) consists of strain gages and mechanically deformable devices such as the Bourdon tube (Figures 19.6 and 19 7), bellows, and diaphragm arrangements. The slight motion each exhibits, proportional to the applied force, is then amplified mechanically by levers or gears to position a pointer on a scale or to provide an input for an associated transmitter. (*NOTE:* A "blind" transmitter, of any variable, has no local indicator.) Again, the sensing of pressure can take place only at important points, such as with pump control systems.

There being many classes and brands of pressure sensors, it serves no purpose to elaborate further on specific types. Some sensors are fitted with surging and overrange protection (dampeners) to limit the effect pressure spikes or water hammer have on the sensor. Most protection devices function by restricting flow into the sensing element. Surge protection equipment prevents sudden pressure surges from overranging instrumentation which can easily damage many pressure sensors. One type of overrange protection uses a mechanical device to prevent the pressure element from exceeding its upper limit. The actual degree of protection necessary depends on the type and range of the sensor.

A second surge protection device is a snubber (Figure 19.8) which consists of a restrictor through which the pressure producing fluid must flow. A simple restrictor is made of a short section of capillary (very small) tubing fitted into a plug in the pressure pipe to form an orifice. A more elaborate mechanical snubber responds to surges by moving a piston or plunger that effectively controls the size of the orifice. Some snubbers are subject to clogging or being adjusted so tight as to prevent any response at all to pressure changes. If a pressure sensor is not performing properly, look first for clogging or adjustment that is too tight.

A third device is an air cushion chamber (Figure 19.9) which is simply constructed yet very effective. The top half of the chamber contains air. Water flows into the bottom half. A sudden change in water pressure compresses the air within the chamber. The rate of response can easily be regulated by placing a small orifice in the pipe on the water side of the air cushion chamber

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381.

19.2A What is a sensor?

19.2B How is pressure measured?

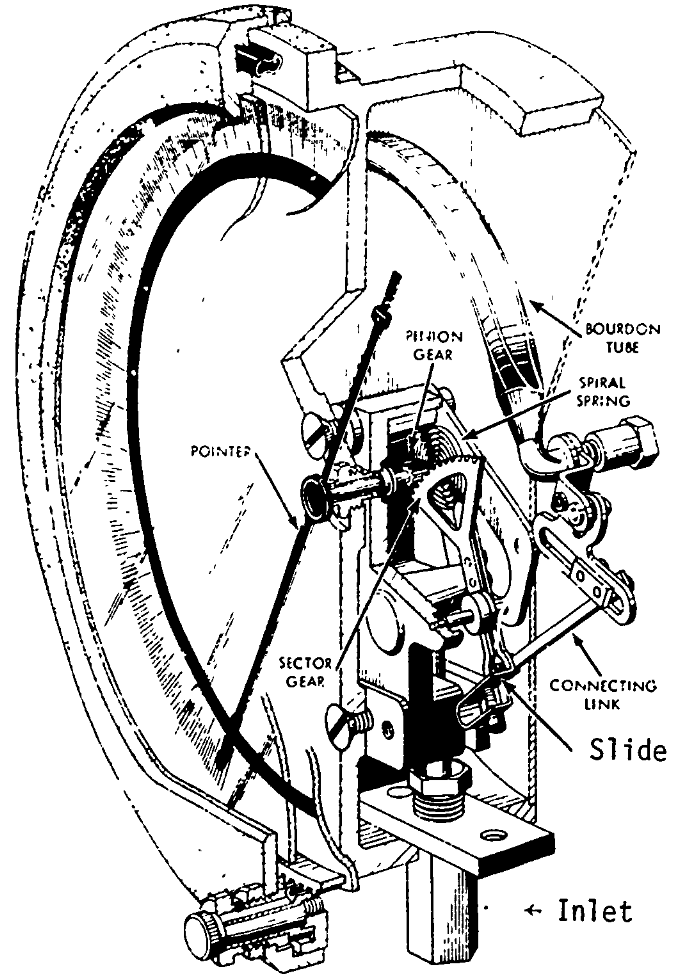
19 2C Why are some pressure sensors fitted with surging and overrange protection?

19.22 Level

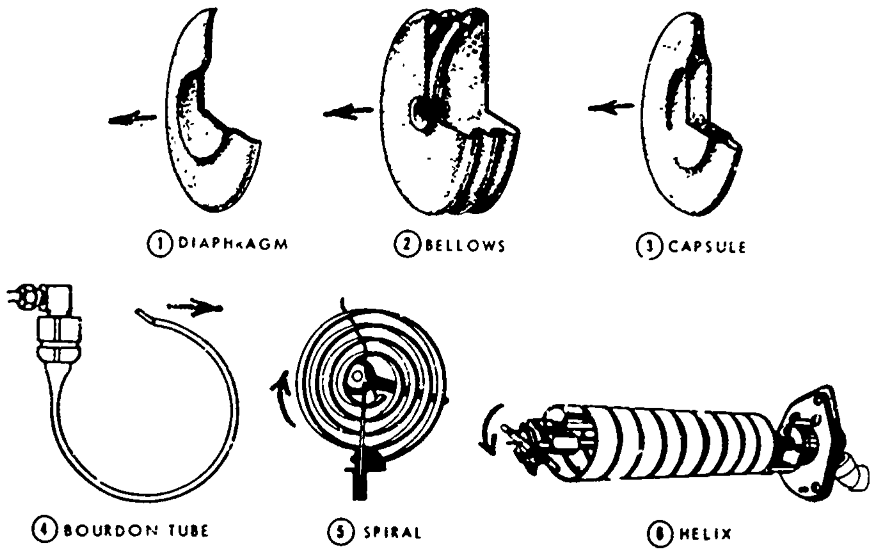
Systems for sensing the level of water or any other liquid level, either continuously or single-point, are probably the most common sensors found in waterworks. Pumps are controlled, filters operated, clear wells monitored basins and tanks filled, chemicals fed and ordered, sumps emptied, and distribution system reservoirs controlled on the basis of liquid level. Fortunately, level sensors usually are simple devices. A float, for example, is a reliable liquid level sensor. Other types of level sensing devices include direct pressure, pneumatic bubblers, sonar and capacitance probes. Single-point detection of level is very common to levels controlled by pumps and valve operation.

A float on the end of a cable (see Figure 19.10) is frequently used to continuously measure and/or to key pump/valve operation at control points. For distribution reservoir or local tank measurement only, the cable rides over a pulley on the lip of the tank, the other end terminating at a "target" which moves and reads against a vertical scale on the tank's side. These simple systems read out backwards (for example, high levels result in lower scale readings as shown in Figure 19.10), but are entirely satisfactory for many purposes. Though the action of the float can key switches to signal high or low levels, no continuous transmission of level to a remote instrument is commonly used with the simple float-cable system. Targets are often read through binoculars when this system is used on a remote distribution system reservoir.

Variations on this scheme to measure liquid levels use either a perforated steel tape riding on a toothed pulley or fine cable riding over a grooved drum The cable transmits the level sensed as a signal (electrical) proportional to pulley or drum rotation (Figures 19.11a and 19 11b). Most of these devices use a counter-weight on the end of the tape/cable opposite the float to insure tautness. Also, all types of float-operated sensors work best with the float traveling within a long tube called a stilling well, which dampens out unwanted liquid turbulence or waves.



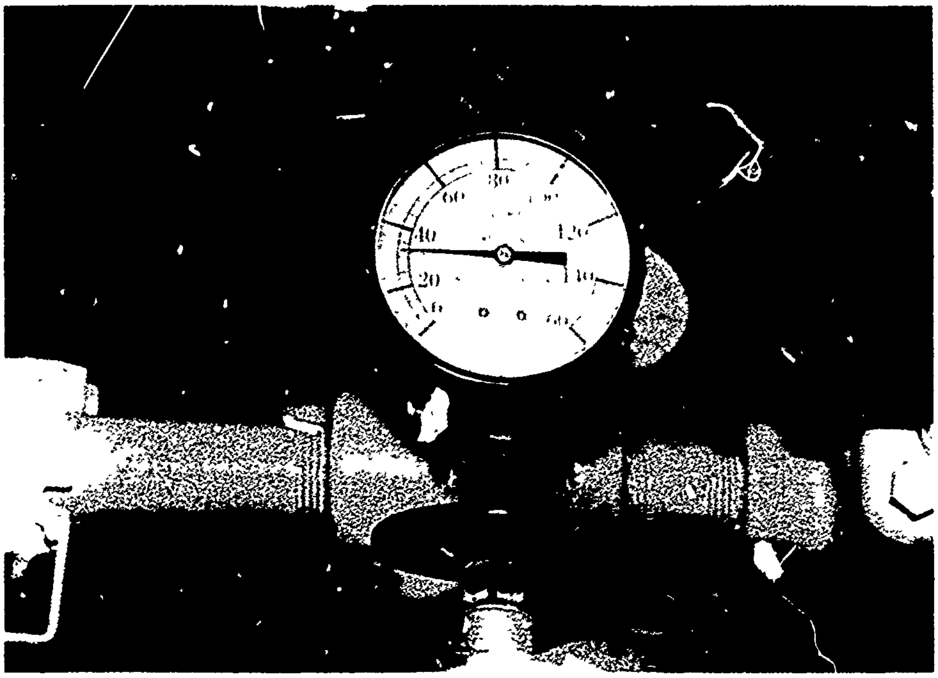
An industrial pressure gage with a Bourdon pressure element



Elastic deformation elements. Pressure tends to expand or unroll elements as shown by arrows.

Fig. 19.6 Bourdon tube and other pressure sensing elements

(Permission of Heise Gauge, Dresser Industries)



NOTE: Capsule (round disk) below gage protects sensing element from corrosion by chlorine gas.

Fig. 19.7 Photo of a chlorine pressure gage

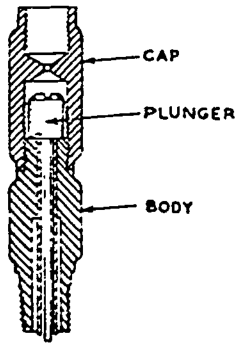


Fig. 19.8 Snubber arrangement for surge protection

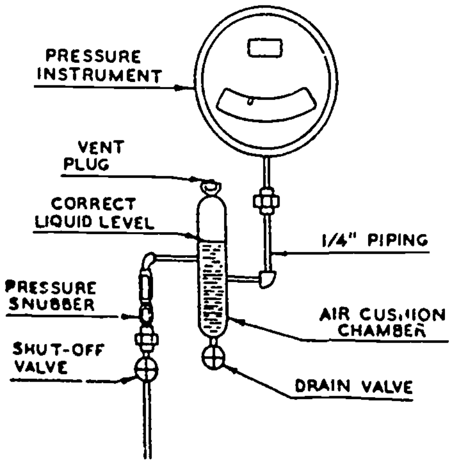
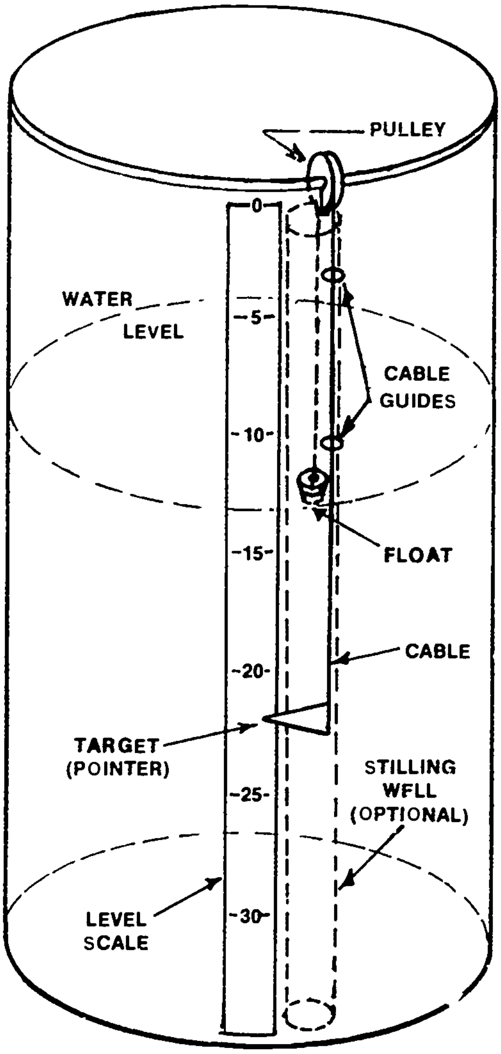


Fig. 19.9 Air cushion chamber for surge protection



NOTE. As liquid level drops, float falls and pointer (target) rises and vice versa. Therefore, pointer indicates depth of water in tank "backwards."

Fig. 19.10 Reservoir level gage, float/target type

Another common system of level sensing is the displacer type (Figure 19.11c). By its nature only single-point determinations of level can be obtained. But this type of sensing for on-off control is adequate for many purposes. The displacer is a weight, usually of a non-corroding heavy material such as porcelain, which hangs down on a cable into the liquid within a stilling well. The cable is supported by a spring which is sized so as to keep an electrical switch (a mercury vial, usually) in one position with the displacer immersed, but allowing it to switch to another position when the displacer is out of the liquid. The basic principle is that the weight is buoyed up by the liquid when immersed, thus weighing less. Accordingly, the motion of the displacer is very slight, typically less than one inch (25 mm) so this design is more reliable than a float device which may be subject to sticking in its stilling well.

An alternative to a float or displacer, both of which are mechanical systems, is the use of electrical probes to sense liquid level (Figure 19.11d). Again, only single-point determinations can be made this way, though several probes can be set up to detect several different levels. Level probes are used where a mechanical system is impractical, such as within sealed or pressurized tanks, or with chemically active liquids.

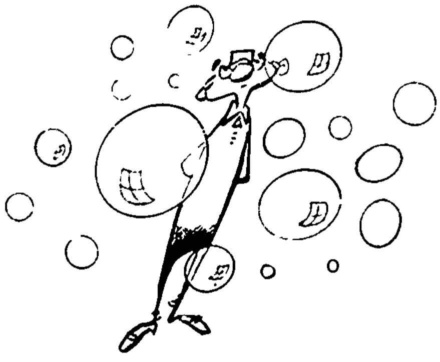
The probes are small-diameter stainless steel rods that are inserted into a tank through a special fitting, usually through the top but at times in the side of the vessel. Each rod is cut to length corresponding to a specific liquid level in the case of the top-entering probes; in the side-entering setup, a short rod merely enters the vessel at the appropriate height or depth. One problem encountered with probes is the accumulation of scum or caking (by $CaCO_3$) on the surface of the rods.

A small voltage is applied to the probe(s) by the system's power supply, with current flowing only when the probe "sees liquid," that is, becomes immersed. When current flow is sensed, a switch activates a pump/valve control or alarm(s) at as many control points as necessary. Though at times only a single probe is used, with the metal tank completing the circuit as a ground, usually at least two probes are found — the ground probe extending all the way to the bottom of the tank so as to be in constant contact with the electrically-conducting liquid (a liquid ground as it were).

Levels can be sensed continuously by measurement of liquid pressure near the bottom of a vessel or basin. The pressure elements used for level sensing must be quite sensitive to the low pressures created by liquid level (23 feet of water column equals only 10 psi, or 7 meters of water column equals 7 kPa or 0.7 kg/sq cm). Therefore, simple pressure gages such as are found on pumps are not used to measure water levels. Water level sensors are used to measure levels of water in systems on filter basins, or in chemical storage tanks where control or monitoring must be close, continuous, and positive. Rather than being calibrated in units of pressure (psi), these gages read directly in units of liquid level (feet). Single-point control/alarm contacts can be made a part of this, or any continuous type of level sensor.

A very precise method of measuring liquid level is the bubbler tube, with its associated pneumatic instrumentation (Figure 19.12). The pressure created by the liquid level is sensed, but not directly as with a mechanical pressure element. Air pressure is created in a bubbler tube to just match the pressure applied by the liquid above the open end immersed to some pre-determined depth in the tank or basin. This *AIR* pressure is then measured (sensed) as proportional to liquid level *ABOVE THE END OF THE TUBE.* This indirect determination of level using air permits the placement of the instrumentation anywhere above or below the liquid's surface, whereas direct pressure-to-level gages must be installed at the very point where liquid pressure must be sensed.

These pneumatic devices are adjusted so air *JUST BEGINS* to bubble out of the submerged end of the sensing



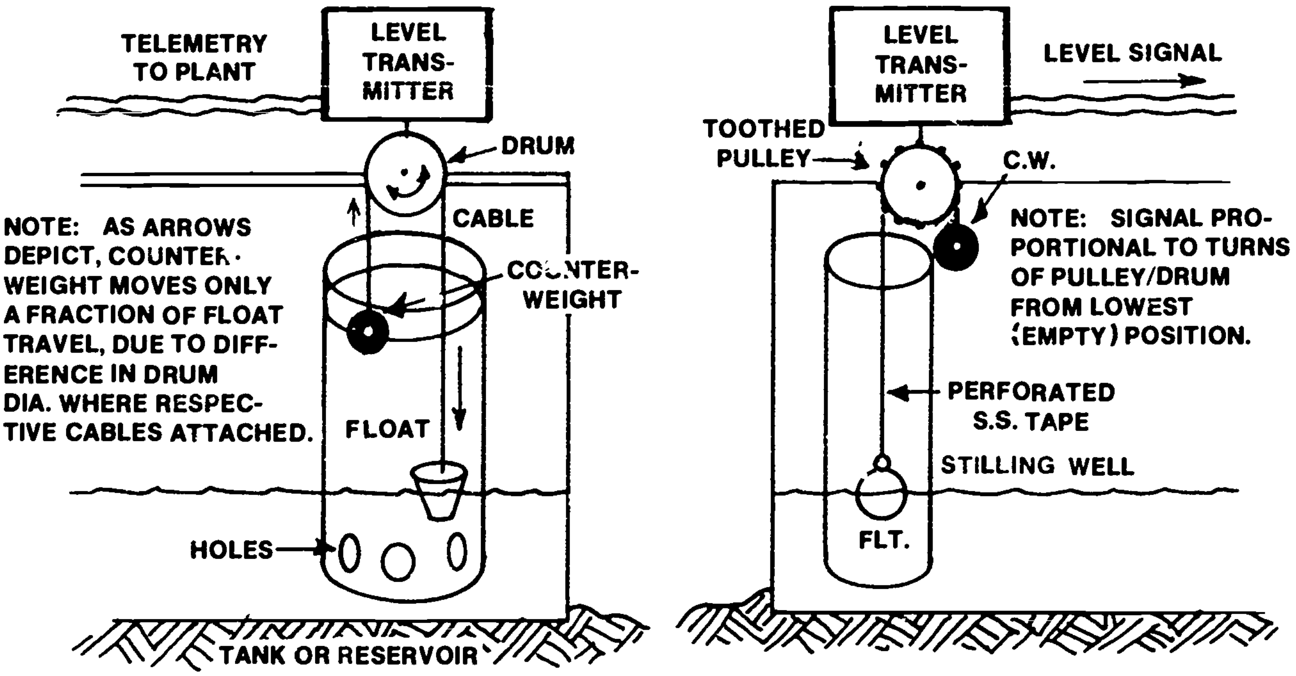


Fig. 19.11a Float and cable (continuous)

Fig. 19.11b Float and tape (continuous)

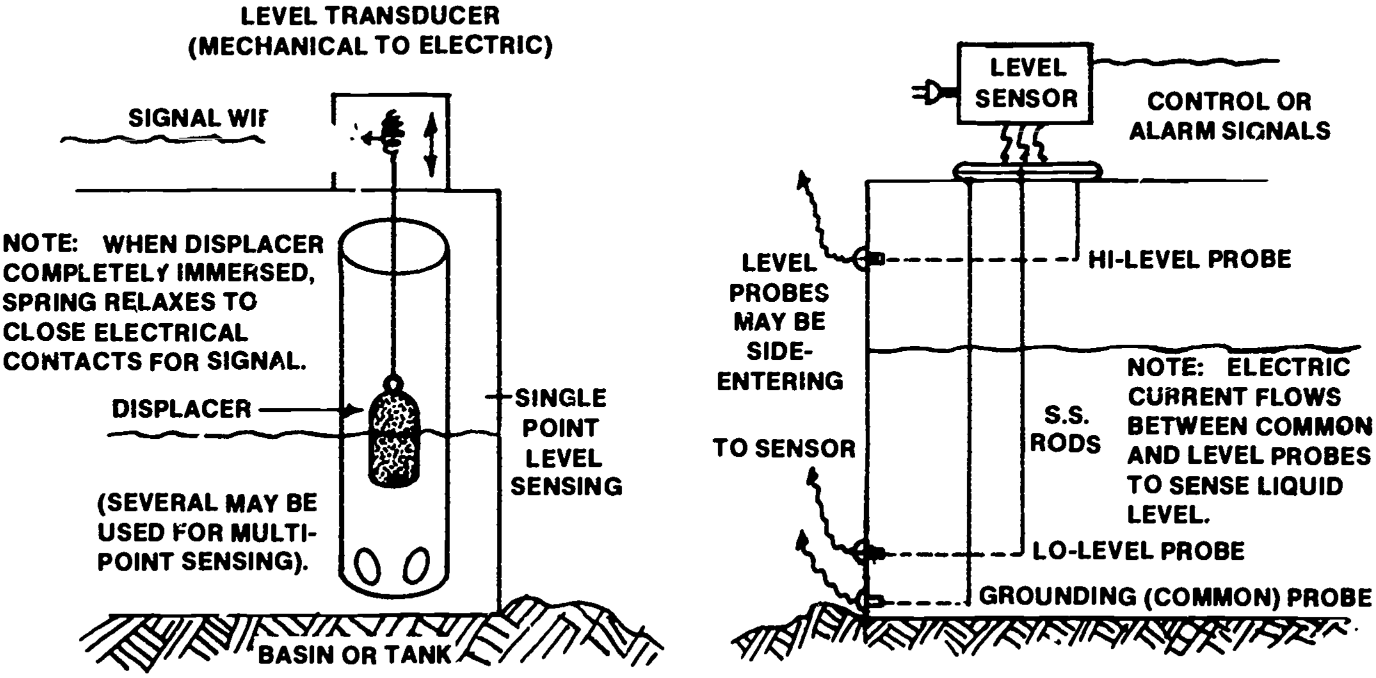
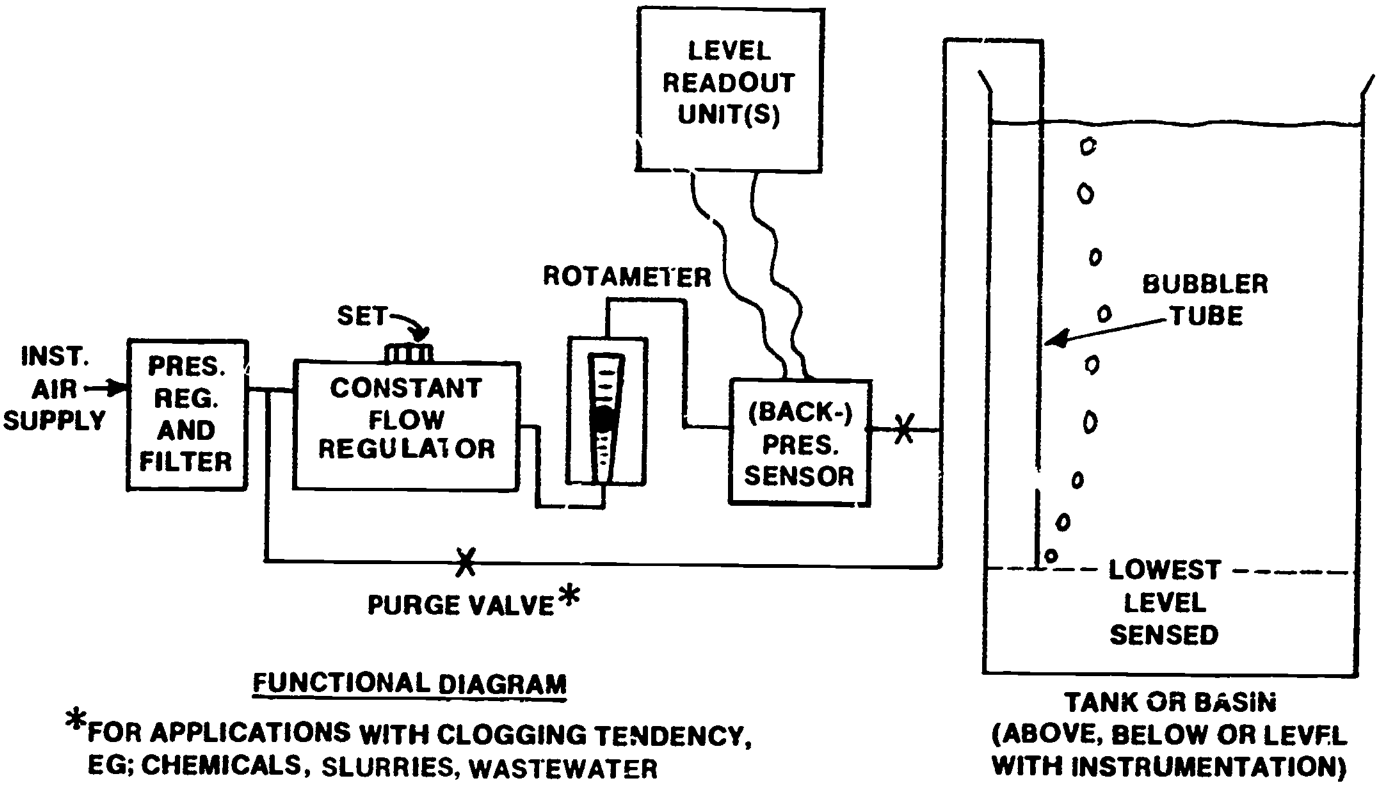


Fig. 19.11c Displacer (single-point)

Fig. 19.11d Electrical probes (multi-point)

Fig. 19.11 Liquid-level sensing systems
(Level measurement and single-point sensing)



Constant-flow regulator and rotameter on left, back-pressure sensor (DP cell) to right.

Fig. 19.12 Bubbler tube system for measuring liquid level tube. They automatically compensate for changes in liquid level by providing a small, constant flow of air. There is no advantage to "turning-up-the-amount-of-air" to create more intense bubbling (the pressure will still depend on the water level). In fact, such action may create a sizeable measuring error in the system and any air flow changes should be left to qualified instrument service personnel.

Bubbler tube systems are common in filter-level controllers which must maintain water levels within a range of a few inches (or centimeters). Usually the level transmitter for this use is "blind" since it only controls liquid level and does not provide an indication or readout of the level.

QUESTIONS

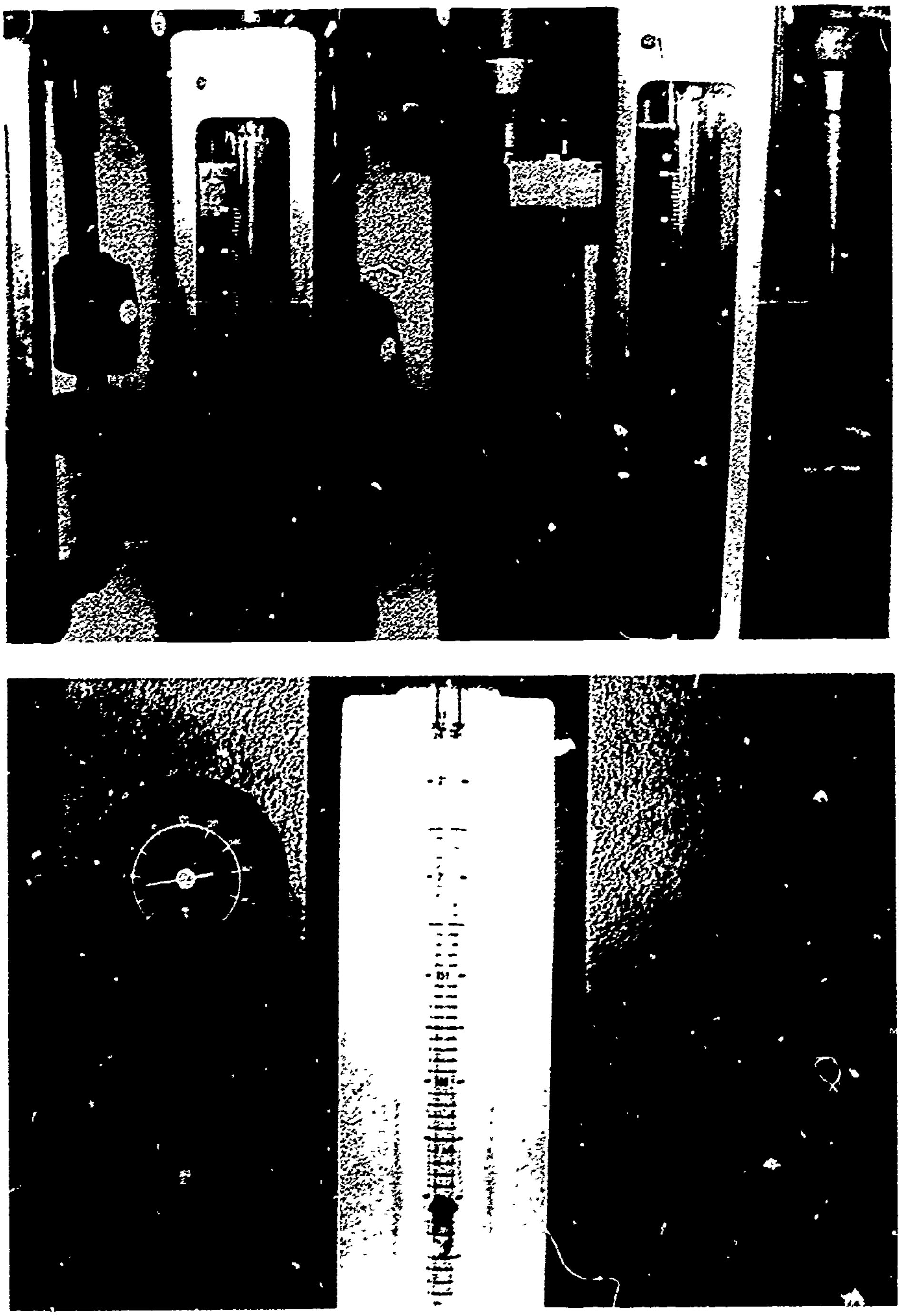
Write your answers in a notebook and then compare your answers with those on page 381.

19.2D List the major types of liquid level sensors.

19.2E How can a signal be generated by a float element?

19.2F Under what circumstances are probes used to measure liquid level instead of mechanical systems (floats)?

19.2G How does a bubbler measure the level of a liquid?



Rotameters (*RATE*-of-flow)

Fig. 19.13 Flow sensing devices

19.23 Flow (Rate of Flow and Total Flow)

The term "flow" can be used to refer to either *RATE OF FLOW*, such as MGD, CFS, and GPM (volume per unit of time), or to *TOTAL FLOW* in simple units of volume such as gallons or cubic feet. Such volumes are usually obtained as a running total, with a comparatively long time period for the flow delivery (such as a month). This distinction is important in the understanding of flow instrumentation, most of which provides *BOTH* values (for rate of flow and total flow). Some flow meters, however, provide only total flow readings.

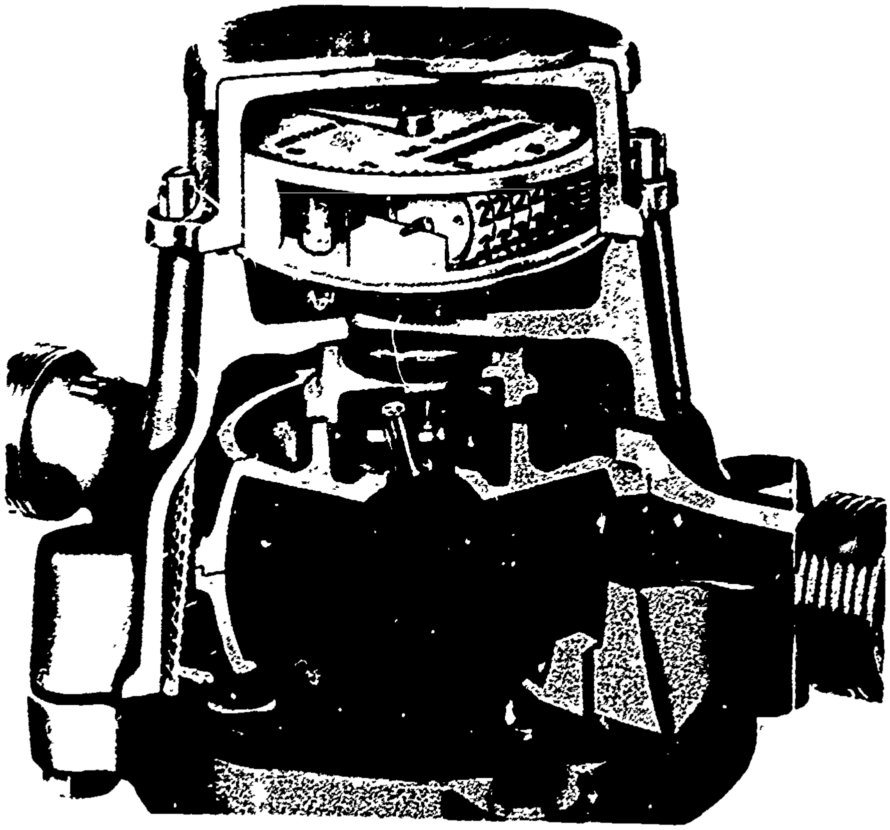
While it is possible in principle to measure flow directly, such as is done with pressure and most level sensing devices, it is quite impractical. Direct measurement would involve the constant filling and emptying of, say, a gallon container with water flowing from a pipe on a timed basis. This method is simply not practical. Therefore, sensing of flows in waterworks practice is done *INFERENTIALLY*, that is, by inferring what the flow is from the observation of some associated hydraulic action of the water. The inferential techniques that are used in waterworks flow measurement are (1) velocity sensing, (2) differential-pressure sensing, (3) magnetic, and (4) ultrasonic. First, let's look at a few other methods used in flow sensing for specialized applications before studying velocity sensing devices.

ROTAMETERS (Figure 19.13) are transparent tubes with a tapered bore containing a ball (or float). The ball rises up within the tube to a point corresponding to a particular rate of flow. The rotameter tube is set against, or has etched upon the tube, marks calibrated in whatever flow rate unit is appropriate. Rotameters are used to indicate approximate liquid flow or gas flow, such as those installed at the readout device of a gas chlorinator. Sometimes a simple rotameter is installed merely to indicate a flow or no-flow condition in a pipe such as found on chlorinator-injector supply lines.

Service meters are the type of flow meters used to record total water usage through individual service connections in a distribution system (Figure 19.14). The smaller service meters are usually one of the positive-displacement types. The larger service meters use the velocity-sensing principle.

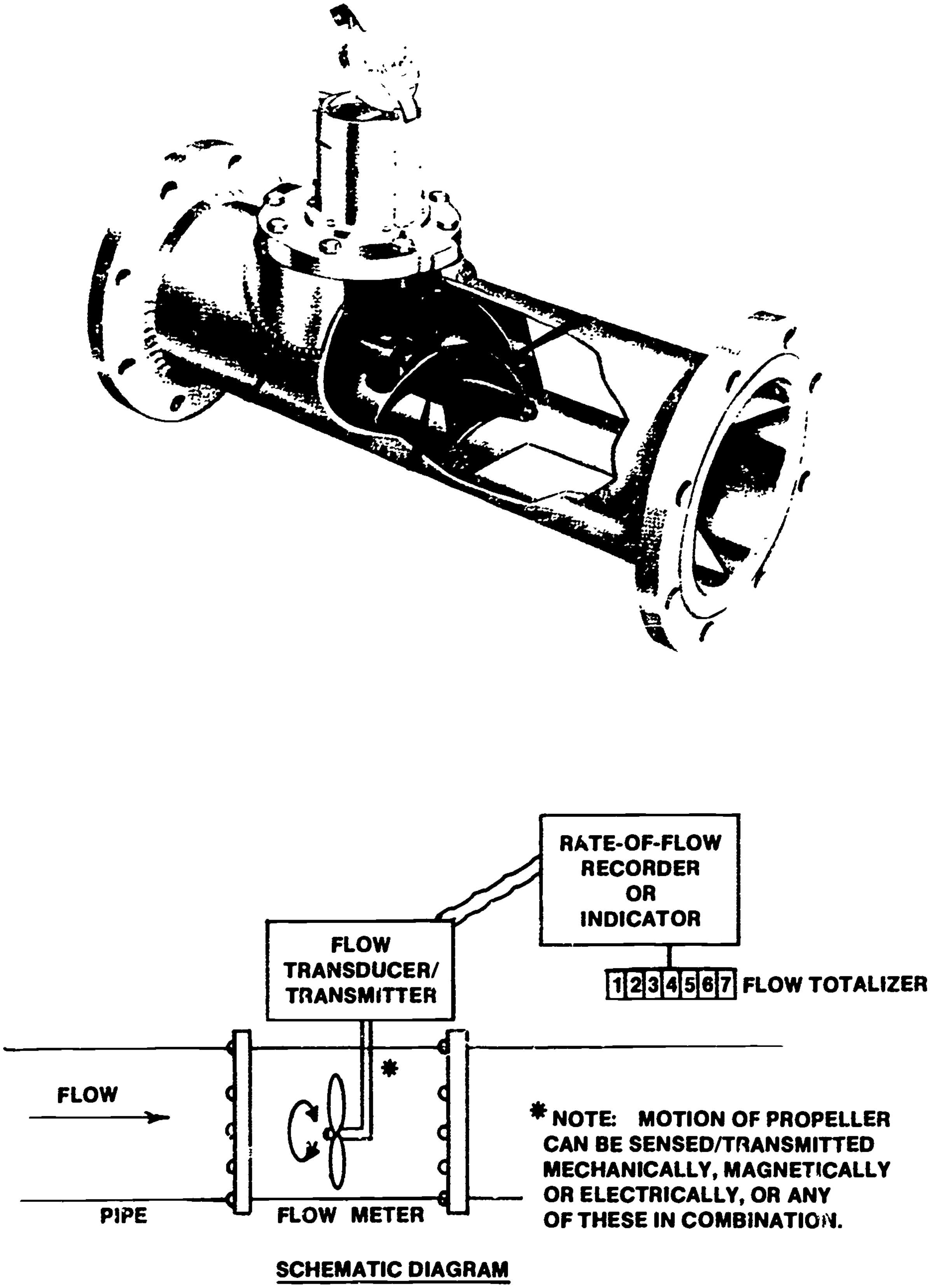
VELOCITY-SENSING DEVICES measure water speed within a pipeline. This can be done by sensing the rate of rotation of a special impeller (Figure 19.15) placed within the flowing stream; the rate of flow is directly proportional to impeller RPM (within certain limits). Since normal water velocities in pipes and channels are well under 100 feet per second (about 8 mph or 3 m/sec), the impeller turns rather slowly. This rotary motion drives a train of gears which finally indicates *RATE* of flow as a speedometer-type readout. *TOTAL* flow appears as the cumulative number, similar to the odometer (total mileage) on your car.

Rotation of the velocity-sensing element is not always transferred by gears, but may be picked up as a magnetic or electric signal (pulses) by the instrument system. Nor is velocity always sensed mechanically; it may also be detected or measured purely electrically (the thermister type) or hydraulically (the pitot tube), but the principle of equating water velocity with rate of flow within a constant flow-area is the same. Of course, all such flow meters are calibrated to read out in an appropriate unit of flow rate, rather than velocity units.



Service meter (*TOTAL* flow)

Fig. 19.14 Flow sensing device



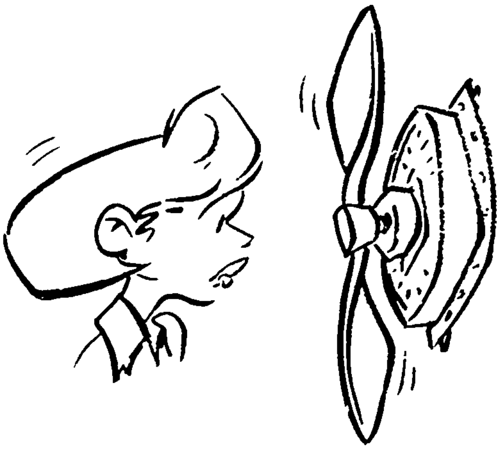
*NOTE: MOTION OF PROPELLER CAN BE SENSED/TRANSMITTED MECHANICALLY, MAGNETICALLY OR ELECTRICALLY, OR ANY OF THESE IN COMBINATION.

SCHEMATIC DIAGRAM

Fig. 19.15 Propeller (velocity) meter

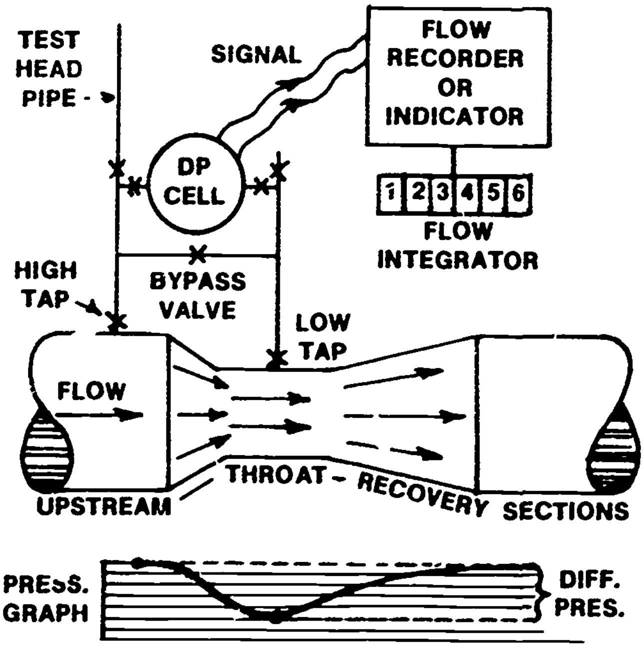
Typically, this type of flow element transmits its reading to a remote site as electrical pulses, although other devices can be used in order to convert to any standard electrical or pneumatic signal.

Preventive maintenance of impeller-type flow meters centers around regular lubrication of rotating parts. Propeller meters, as they are called, have a long history of reliability and acceptable accuracy in waterworks practice. When propeller meters become old, they become susceptible to under-registration (read low) due to bearing wear and gear-train friction. Accordingly, annual tear-down for inspection is indicated. An over-registration is a physical impossibility as far as the operating principle goes, but a partially full pipeline, wrong gears installed, or a malfunctioning transmitter can cause high readings.

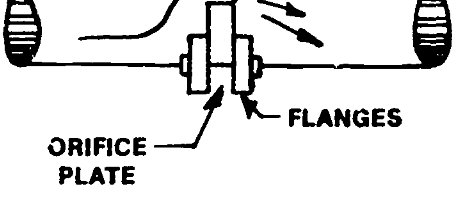


DIFFERENTIAL-PRESSURE SENSING DEVICES (Figures 19.16 and 19.17), also called venturi or just differential meters, depend for their operation upon a basic principle of hydraulics. When a liquid is forced to go faster in a pipe or tube, its internal pressure drops. If a carefully sized restriction is placed within the pipe or flow channel, the flowing water must speed up to get through it. In doing so, its pressure drops a little; and, it always drops the same amount for the same flow. This small pressure drop, the differential, is the difference between the water pressure before the restriction and within the restriction. This difference is proportional to the rate of flow. The difference in pressure is measured very precisely by the instrumentation associated with the certain flow-tube or venturi installed. Typically, only a difference of a few psi is required. This small value of pressure difference is often described in inches of water (head).

Measuring flow by this method removes a little hydraulic energy from the water. However, the classical venturi tube, with its carefully tapered form, allows recovery of well over 95 percent of the original pressure throughout its range of flows. Other ways of constricting the flow do not allow such high recoveries of pressure, nor the accuracy possible with modern venturi flow tubes. The Dall tube is a shortened form of the venturi, with acceptable accuracies for many in-plant purposes (filter wash-water flows).



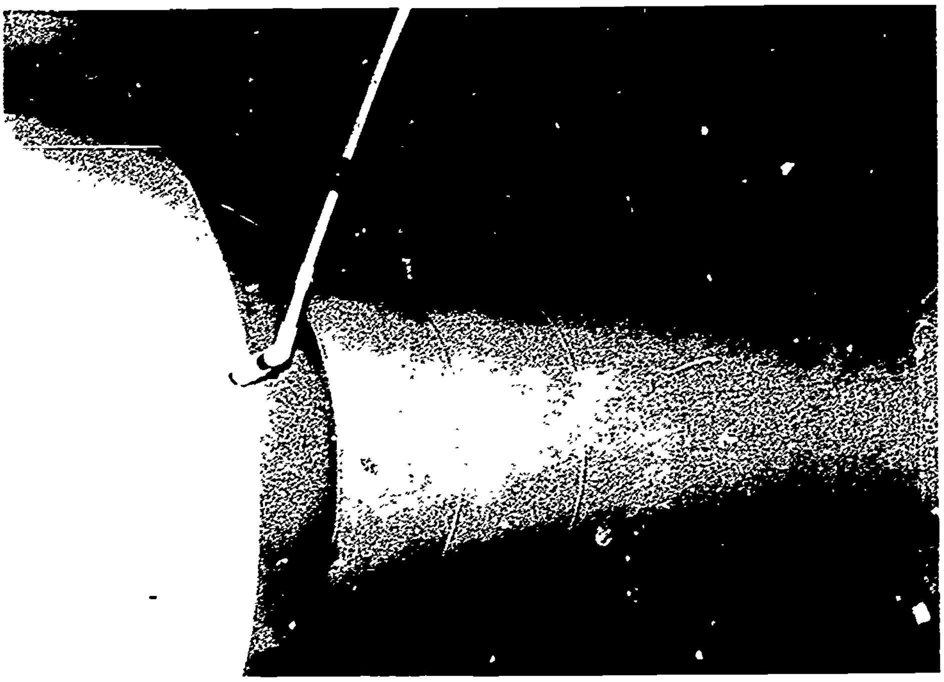
Venturi system (flow rate)



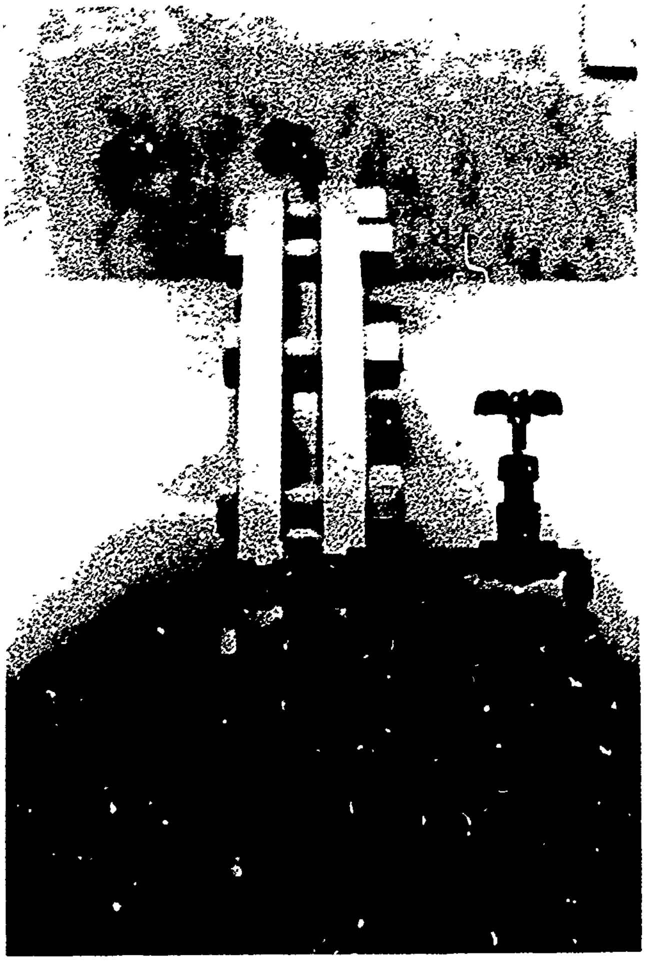
Orifice plate installation (flow rate)

Fig. 19.16 Schematic diagrams of differential pressure flow metering

The orifice plate (Figures 19.16 and 19.17) is inserted between flanges in a pipe and is a stainless steel plate with a calculated size hole (orifice) in it. The pressure drop is sensed right at the orifice, or immediately downstream to



54-inch Venturi tube



24-inch Orifice plate

Fig. 19.17 Photos of differential pressure flow meters yield a comparatively rough flow indication This drop in pressure is permanent; that is, a permanent pressure loss occurs with orifice plate installations.

Differential devices require little if any preventive maintenance by the operator since there are no real moving parts Occasionally, flushing of the hydraulic sensing lines is good practice. This flushing should only be done by a qualified person. When dealing with an instrument sensitive to small fractions of a psi, opening the wrong valve can damage the internal parts Also, if an instrument containing mercury is used, this toxic (and expensive) metal can easily be blown out of the device and *INTO THE WATER PIPELINE!* Thus, all valve manipulations must be understood and done deliberately after careful planning.

In nearly all cases, the instrumentation associated with the larger flow tubes is transmitted to a remote readout station. Local readout is also provided (sometimes inside the case only), for purposes of calibration. Differential meter flow transmitters may be electrical or pneumatic types (with signal transmitted proportional to the square root of the differential pressure).

Venturi meters have been in use for many decades and can produce very close accuracies year after year. Older flow tubes are quite long physically (to yield maximum accuracy and pressure recovery). Newer units are much shorter but have even better accuracy. With no moving parts, the venturi-type meter is not subject to mechanical failure as is the propeller meter. Flow tubes, however, must be kept clean and without obstructions upstream and downstream to provide designed accuracy.

These flow meter types all provide rate of flow indication. The rate of flow is continuously totalized, usually at the readout instrument, as the total flow up to that point in time (recorded in gallons or cubic feet).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381.

19.2H What are two types of flow readings?

19.2I List the two main types of (larger) flow measurement devices.

19.2J Smaller service meters are what type of flow meter?

19.2K How do velocity-sensing devices measure flows?

19.2L How are flows measured with venturi meters?

19.24 Chemical Feed Rate

Chemical feed rate indicators are usually a necessary part of the particular chemical feed system and thus are usually not considered instrumentation as such. For example, a dry feeder for lime or dry polymer may be provided with an indicator for feed rate in units of weight per time, such as lbs/hr or grams/minute. In a fluid (liquid or gas) feeder, the indication of quantity/time, such as gallons/hour or pounds/day may be provided by use of a rotameter (Figure 19.13).

19.25 Process Instrumentation

Process instrumentation provides for continuous checking of physical or chemical indicators of water quality in a treatment plant. These instruments do not include laboratory instruments (unless set up to measure sample water continuously), although the operating principles are usually quite similar. The process variables of turbidity and pH are always monitored closely in a modern water treatment plant (Figure 19.18). Very frequently chlorine residuals are also continuously measured and controlled. Usually these three variables are measured at several locations. For example, turbidity of raw, settled, and filtered water is frequently measured Additionally, other indicators of water quality may be sensed on a continuous basis such as fluoride, electrical conductivity (for TDS), water hardness and alkalinity, and temperature. In every case, the instrumentation is specific as to operating principle, standardization procedures, preventive maintenance, and operational checks. The manufacturer's technical manual sets forth routine procedures to check and operate the equipment.

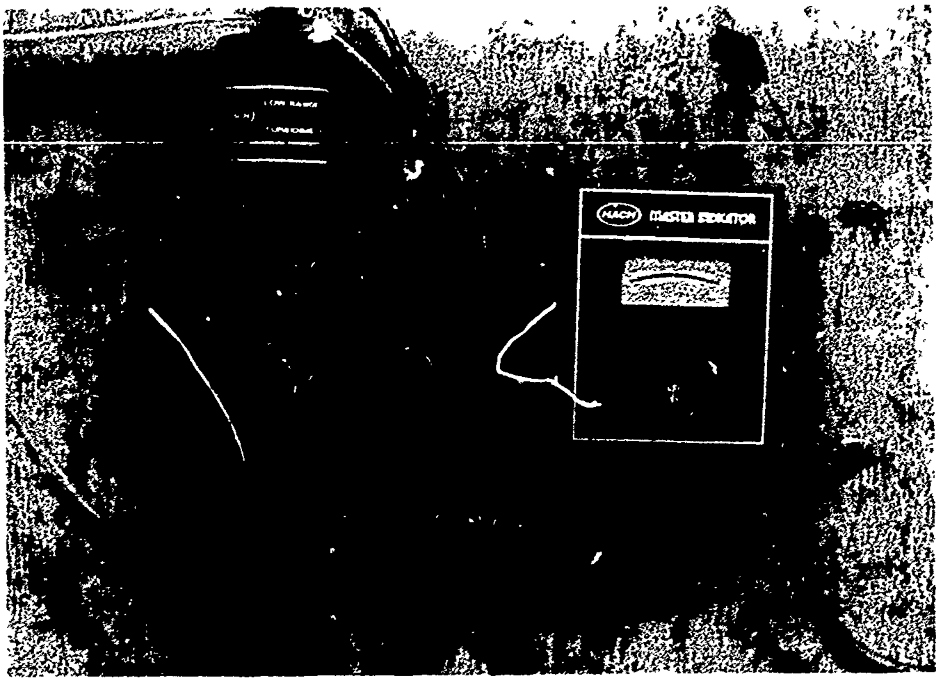
Operators must realize that most process instrumentation is quite sensitive and thus requires careful handling and special training to service. No adjustments should be made without a true understanding of the device. Generally speaking, this category of instrumentation must be maintained by the water agency's instrument specialist or the factory representative rather than by an operator (unless specially instructed)

19.26 Signal Transmitters/Transducers

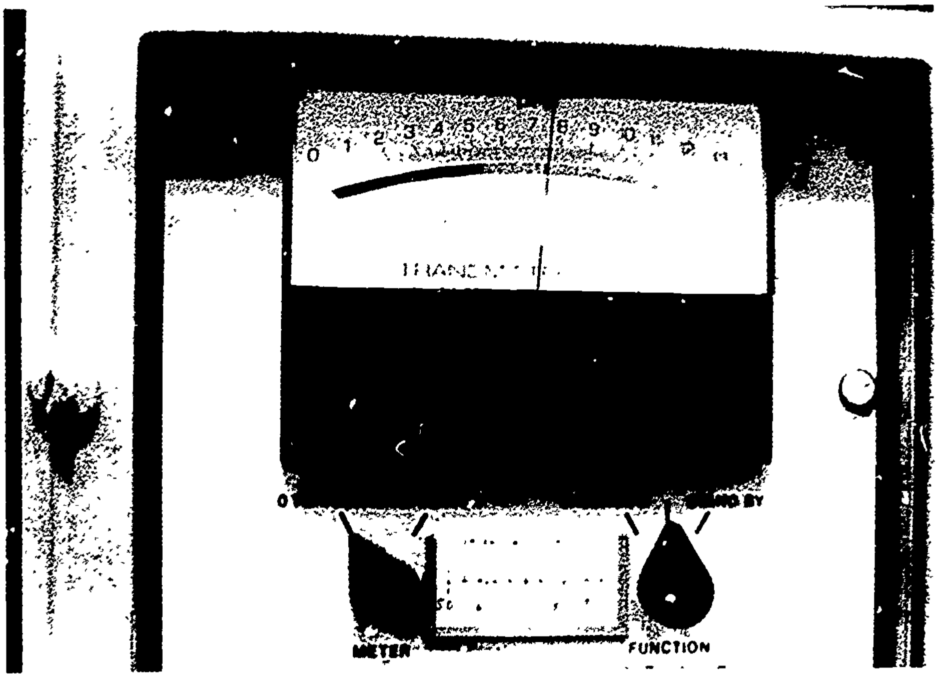
Common practice measures a variable at one location and provides a readout of the value at a remote location, such as a main panel board Except in the case of a blind transmitter, a local indication is provided at the field site as well as being available at the remote site. Associated with the remote (panel) readout system quite often are alarm set-points, an integrator, or a controller (though any of these may exist at the measuring site also). Usually a recorder is found only on a panel board along with all other recorders remote from the sensor in the field. These system components will be discussed further in Section 19.3, "Categories of Instrumentation."

In order to transmit a measured value to a remote location for readout, it is necessary to generate a signal proportional to the value measured. This signal is then transmitted to a receiver which provides a reading based upon the signal. Also, a controller may use the signal to control the measured variable.

Presently, two general systems for transmission of signals, electrical and pneumatic, are used in waterworks, as well as in most other industrial situations. Electricity, of course, requires wiring (though radio transmission or microwave are possible). Pneumatic systems require small-diameter tubing (usually ¼ inch or 6 mm) between transmitter and receiver. When the transmitter is quite far removed from the receiving station, a special terminology is used for the electrical link between the two; this is called telemetry. The wiring used is telephone lines, leased from the local telephone company, or owned by the water agency. Telemetry will be discussed separately in Section 19.33, "Telemetry," since the signals are usually a special type.

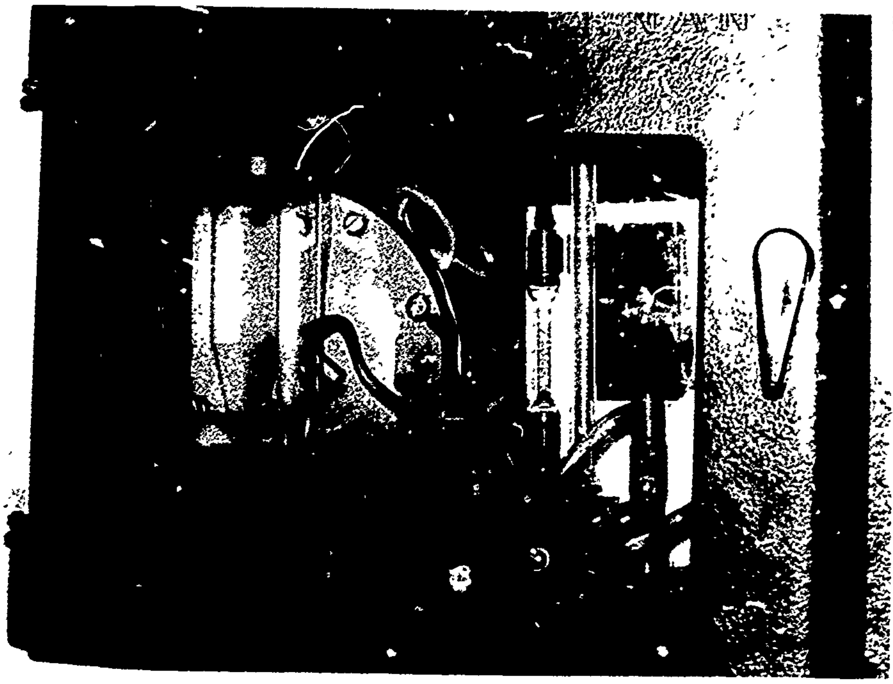


Turbidimeter



pH meter

Fig. 19.18 Water treatment plant instrumentation (Continued on the next page)



Chlorine residual analyzer

Fig. 19.18 Water treatment plant instrumentation (Continued from previous page)

Electric signals used within a water treatment plant are either voltage (1 to 5 volts D.C.), current (4 to 20 milliamps D C), or pulse types. Milliamp signals (4 to 20 ma) are the most common electrical signals for most instrumentation and control systems in recent years. In any of these, a low voltage is applied so no severe shock hazard exists (though shorting signal wires may still destroy electrical components). Signal transmission is limited to several hundred feet, with signal strength usually set up for the specific connecting lines.

A power supply to generate the required electrical energy may be at the transmitter, the receiver, or at another location. The transmitter may be an integral part of the measurement sensor/transducer, or separately housed. In any case, the transmitter adjusts the signal to a corresponding value of the measured variable, and the receiver in turn converts this signal to a visible indication which is the readout.

Pneumatic signal systems are restricted to comparatively short distances. Components include a compressor to provide air under pressure, as well as the necessary air filters and an air dryer. The precision of signal transmission by pneumatics is comparable to electrical signals so both systems are found about equally in waterworks.

Compressed air presents no shock hazard and most plants must have compressors available for other purposes. Also, pneumatic systems seem to be more understandable to operating personnel and thus easier to keep functioning as desired. As with electrical signal circuits, the transmitter and receivers perform as their names imply. Pneumatic controllers, and all other types of equipment, are as available as their electrical counterparts. Pneumatic signals are generated by causing pressures from 3 to 15 psi (20 to 100 kPa or 0 2 to 1.1 kg/sq cm), proportional to the variable, in almost every installation, with 9 psi (62 kPa or 0.65 kg/sq cm) then representing a 50 percent signal.

Preventive maintenance of pneumatic components centers around ensuring a clean, dry air supply at all times which requires alert operators.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 381.

19.2M How are chemical feed rates measured?

19 2N What process variables are commonly monitored and/or controlled by instruments?

19.2O By what means can values measured at one site be read out at a remote location?

19.2P What are the two general systems used to transmit measurement signals?

End of Lesson 1 of 2 Lessons
on
INSTRUMENTATION

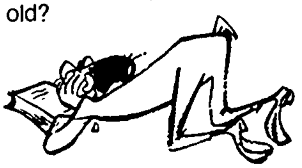
DISCUSSION AND REVIEW QUESTIONS

Chapter 19. INSTRUMENTATION

(Lesson 1 of 2 Lessons)

Write the answers to these questions in your notebook before continuing.

1. Why should operators understand measurement and control systems?
2. How can measurement and control systems make an operator's job easier?
3. What is the difference between precision and accuracy?
4. Why should a screwdriver not be used to test an electrical circuit?
5. What precautions should an operator take before entering a vault?
6. How can water levels be measured?
7. What problems can develop with propeller meters when they become old?



CHAPTER 19. INSTRUMENTATION

(Lesson 2 of 2 Lessons)

19.3 CATEGORIES OF INSTRUMENTATION

19.30 Measuring Elements

Measuring (or primary) elements are those devices which make the actual measurement of the variable. Transducers are usually associated with sensors to convert the sensor's signal to another magnified action producing a more useable indication. If remote transmission of the value is required, a transmitter may become part of the transducer. An illustrative example of these three components is the typical venturi meter: (1) the flow tube is the primary element, (2) the differential-pressure device ("D.P. cell") the transducer, and (3) the signal producing components are the transmitter. An understanding of the separate functions of each section of the "flow meter" is important to the proper understanding of equipment problems.

19.31 Panel Instruments (See Figure 19.1, page 343)

19.310 Indicators

The components of measurement and control systems found on the water plant's main panel board are generally thought of as the plant instrumentation. These components are important to the operator, and hence to plant operation itself, because they display the variable directly. These panel devices can produce alarm signals to indicate if a variable is outside its range of expected values. In addition, the controllers are often installed on (or behind) the main panel along with the operating buttons and switches for the plant's equipment.

However, in this age of cybernetics (a fancy term for instrumentation), you can easily be lulled into an overdependence on automation to operate the plant processes more or less blindly. You must realize that there is no substitute for critical evaluation and informed judgment in the "trusting" of instrument systems as they relate to important plant functions. You must not rely solely upon the readings of any single instrument to ensure proper plant operation, but must consult other instruments and closely watch the other indicators of plant operation. Even the most sophisticated and expensive instrument systems require constant maintenance work by specialists and do malfunction at times

19.311 Indicators/Recorders

The major components found on the plant's main panel are indicators and recorders. Indicators give a visual presentation of a variable's value, either as an analog or as a digital display (Figures 19.19 and 19.20). The analog display uses some manner of pointer (or other indicator) against a scale. A digital display is a direct numerical readout. Recorders, which can also serve as indicators, give a permanent record of how the variable changes with time by way of a moving chart Whereas there are usually several indicators out in the plant or field, recorders are usually housed at a central location in the plant. We will discuss both indicators and recorders in the following paragraphs.

Since there are two types of signal transmission available, panel indicators may be of the electric or the pneumatic type. The digital readout is a relatively recent development, with both advantages and disadvantages. Digitals may be read more quickly and precisely from a longer distance, and can respond virtually instantly to variable changes. But analog indicators are cheaper, more rugged, and may not even require electrical power (the pneumatic type), an advantage during a power failure.

Another advantage of the electric or pneumatic analogs or gages is that a wrong indication (value) is more recognizable than with a digital system, and also is more easily repaired by the operator.

For example, the pointer on a flow meter gage may merely be stuck, as evidenced by a perfectly constant reading. With a digital reading there is no practical way for the operator to see whether a problem actually does exist, nor is there any way for the operator to attempt a repair, such as freeing a pointer. Erratic or unreliable operation, while always a problem, seems to be worse when digitals are involved since there is "no way out" for the operator. You often can't tell if the problem is real, and you can't do anything to "get-by-'til 8 A.M." as is often required on a night shift.

With all-electronic instrumentation, as advantageous as it may seem from a technical and economic standpoint, the operator has little recourse in case of malfunction of critical instrumentation. Temporary power failures, tripped panel circuit breakers, voltage surges (lightning) resulting in blown fuses, and problems of excessive heat can all result in electronic instrument problems. However, electromechanical or pneumatic instruments may keep operating, or recover operation, readily after such power or heat problems. Electronic systems may require the services of an instrument technician, or even the factory technician, to become fully operable again. Accordingly, the operator should insist upon some input into the design phase of instrument systems to ensure that the plant is still operable during power outages, hot weather, and other contingencies. Standby power generators and/or batteries are used to keep plants operating during power outages.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.3A What is the purpose of indicators?

19.3B Describe an analog display.

19.3C Where are recorders usually found at a water treatment plant?

19 3D What factors can cause electronic instrument problems?

19.312 Recorders

Recorders are indicators designed to show how the value of the variable has changed with time (Figure 19.20). Usually this is done by attaching a pen (or stylus) to the indicating arm, which then marks or scribes the value of the variable onto a continuously moving chart. The chart is marked on a horizontal or circular scale in time units. Some models of recorders reverse the scales by indicating time on the vertical and variable on the horizontal scales.

The chart is driven along at a precise speed under the pen, to correspond with the time markings on the chart. Chart speeds range from several inches to a fraction of an inch per

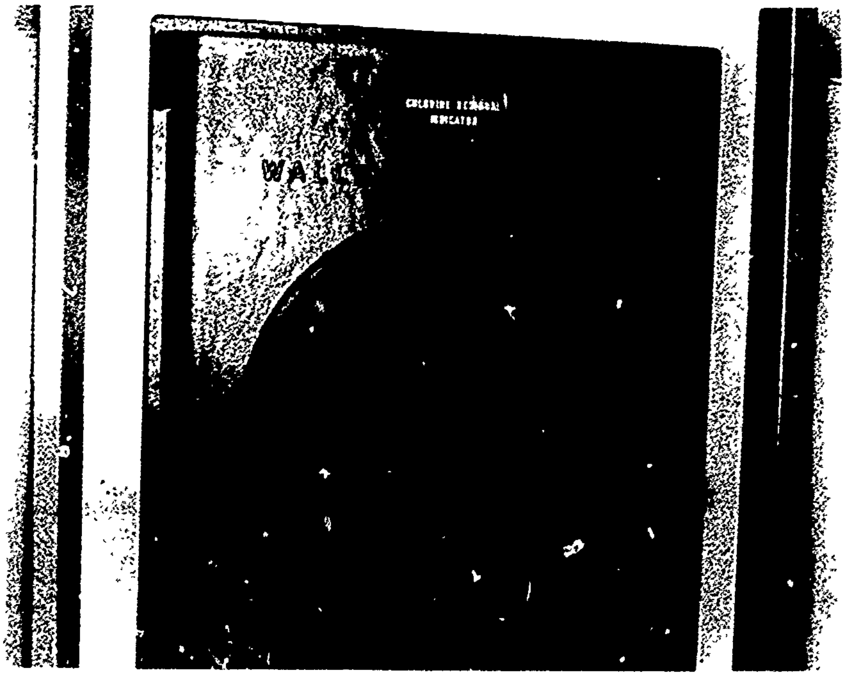


Fig. 19.19 Analog chlorine residual indicator

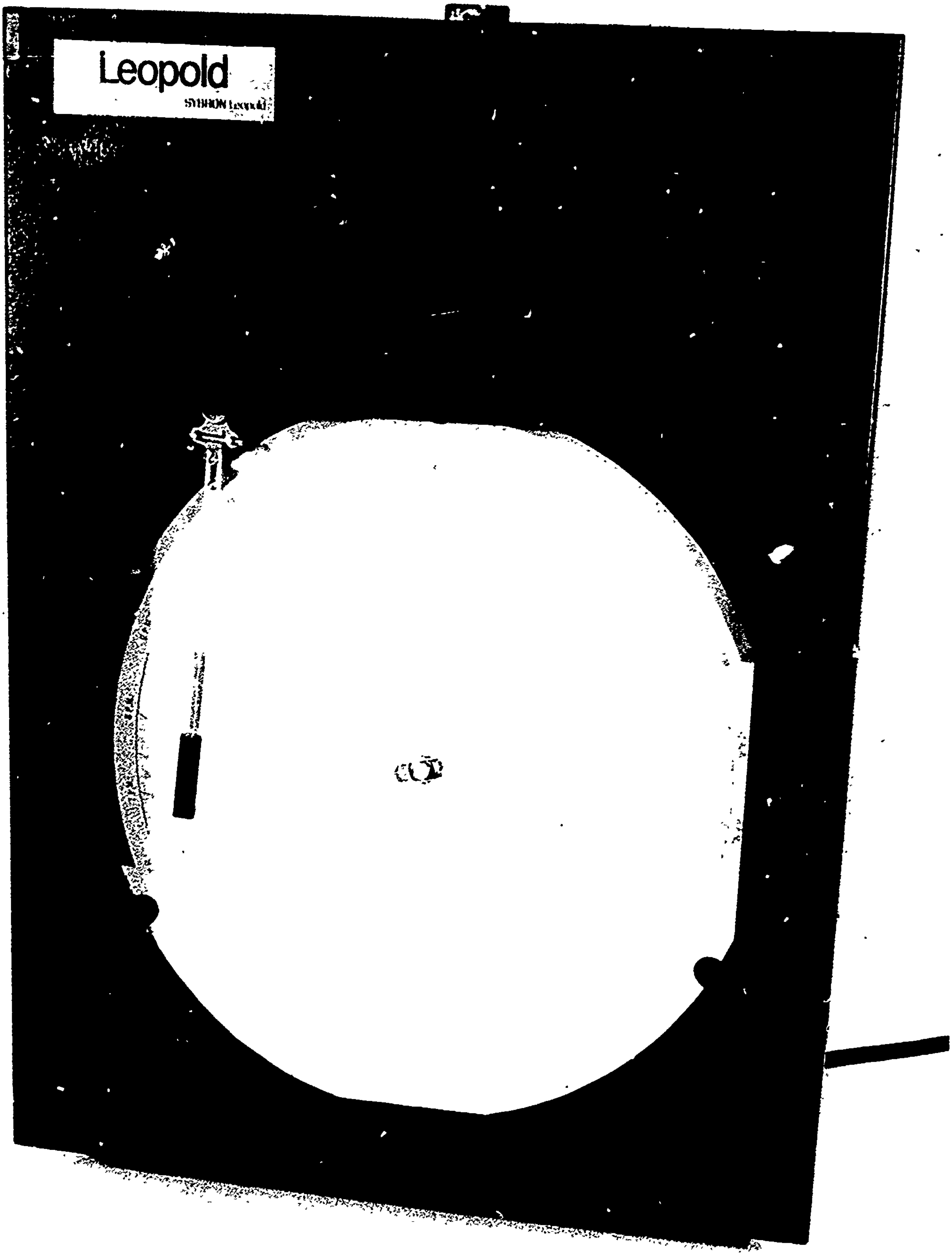
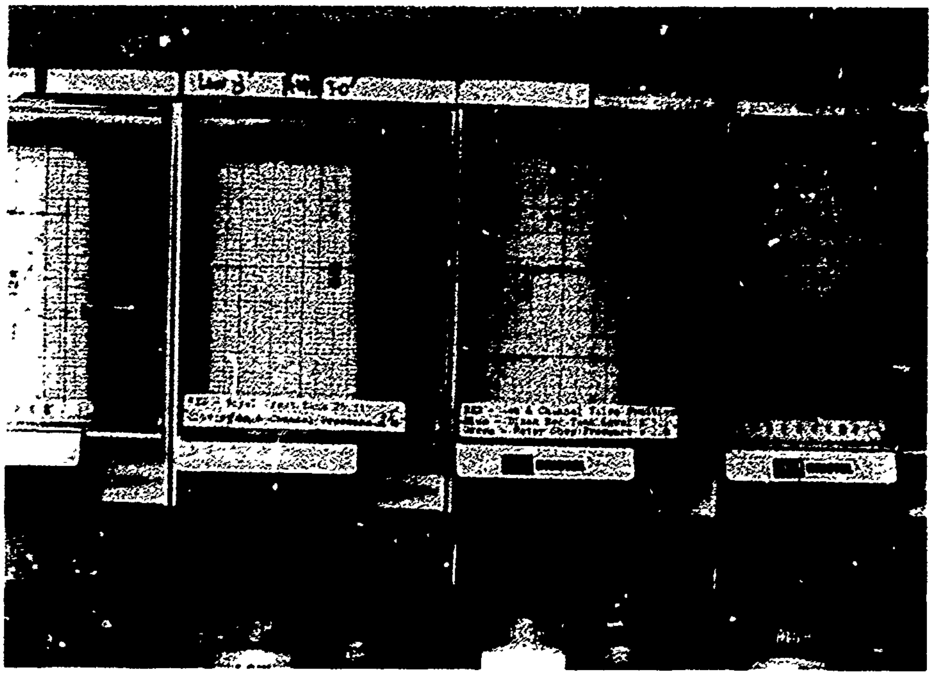


Fig. 19.20 Digital indicator/recorder combination (24-hour circular chart)

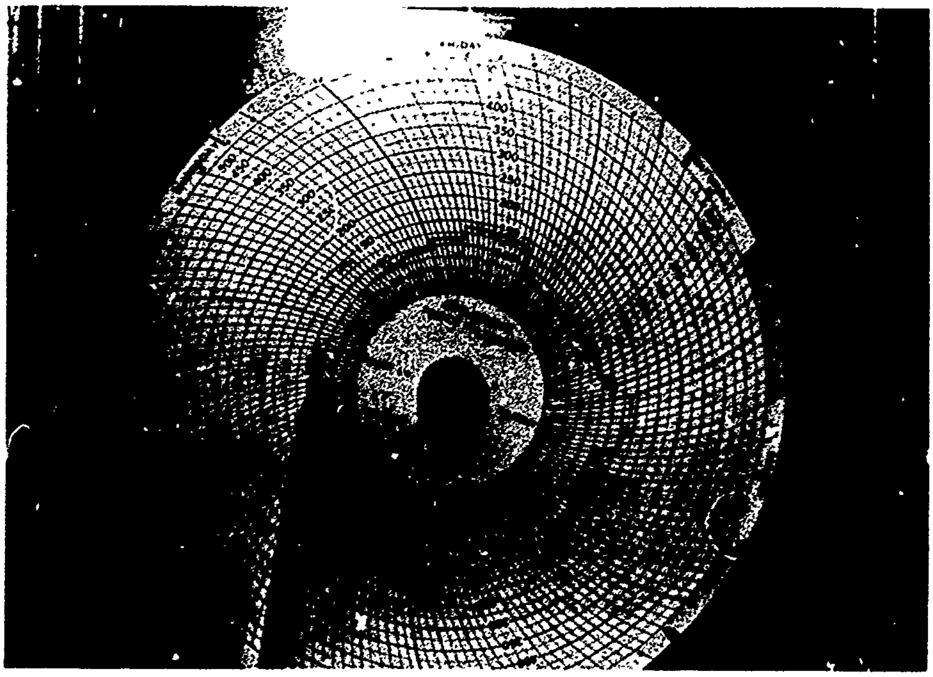
(Permission of Leopold Company, Division of Sybron Corporation) minute, with the pen and drying time of the ink specific to a given range of speeds.

There are two main types of recorder charts and recorders: the horizontal strip-chart type and the circular type. The horizontal strip-chart carries its chart on a roll or as folded stock, with typically several months' supply of chart available. Several hours of charted data are usually visible or easily available for the operator to read. On a circular recorder, the chart makes one revolution every day, week, or month, and the record of the entire elapsed time period is visible at any time.

Changing of charts is usually the operator's duty, and is easier with circular recorders, though not that difficult with most strip-chart units.



Strip-chart recorders



Seven-day circular-chart recorder

Fig. 19.21 Recorders, strip chart and circular chart

Recorders may be electric or pneumatic. Pneumatic models frequently have electric chart drives. Purely mechanical units, useful at a remote, unpowered pressure gaging station, have hand-wound chart drives and are of the circular-chart type. Other models are battery powered. Recorders are most commonly described by the nominal size of the strip-chart width or circular-chart diameter (for example, a 4-inch (100 mm) strip-chart, or a 10-inch (250 mm) circular-chart recorder). Figures 19.20 and 19.21 present various popular models of indicators and recorders.

19.313 Totalizers

The rate of flow as a variable is a time-rate: that is, it involves time directly, such as in gallons per minute, or million gallons per day, or cubic feet per second. Flow rate units become units of volume with the passage of time. For example, flow in gallons per minute accumulates as total gallons during an hour or day. The process of calculating and presenting an on-going, running total of flow volumes passing through a meter is termed "integration" or totalizing.

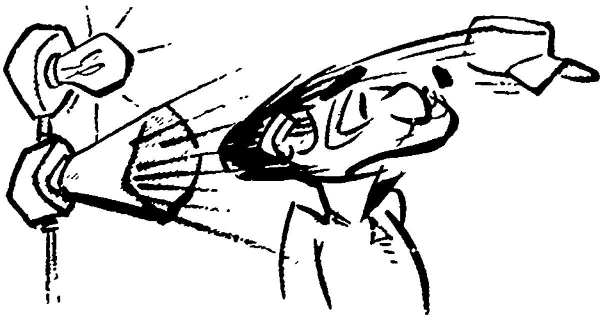
An integrator, also called a totalizer, continually adds up gallons or cubic feet as a cumulative total up to that point in time. Virtually all flow indicators and recorders are equipped with totalizers, though sometimes as separate units (Figures 19.20 and 19.21). Many flow meters *ONLY* measure the total quantity of fluid passing through it; the domestic service meter (common water meter) is an example of this type of flow meter.

Large quantities of water (or liquid chemical) are commonly measured in units of hundreds or thousands of gallons or cubic feet. This is simply a shorthand means of expressing the measurement. On the face of a totalizer you will find a multiplier such as × 100 or × 1000. This indicates that the reading is to be multiplied by this (or another) factor to yield the full amount of gallons or cubic feet. If the readout uses a large unit, such as "mil gal," a decimal will appear between appropriate numbers on the display, or a fractional multiplier (× 0.001, for example) will appear on the face of the totalizer.

Every operator should personally be able to *CALCULATE* total flow for a time period in order to verify that the integrator is actually producing the correct value. Accuracy to one or two parts in a hundred (±1 or 2 percent) is usually acceptable in a totalizer. There are methods to integrate (add up) the area under the flow-rate curve on a recorder chart, to check total flow for long-term accuracy calculations.

19.314 Alarms

Alarms are visual and/or audible signals that a variable is out of bounds or that a condition exists in the plant requiring the operator's attention. For noncritical conditions, the glow of a small lamp or light on (or outside of) an indicating instrument is sufficient notice. For more important variables or conditions, an attention-getting annunciator panel (Figure 19.22) with flashing lights and an unmistakable and penetrating alarm horn is commonly used.



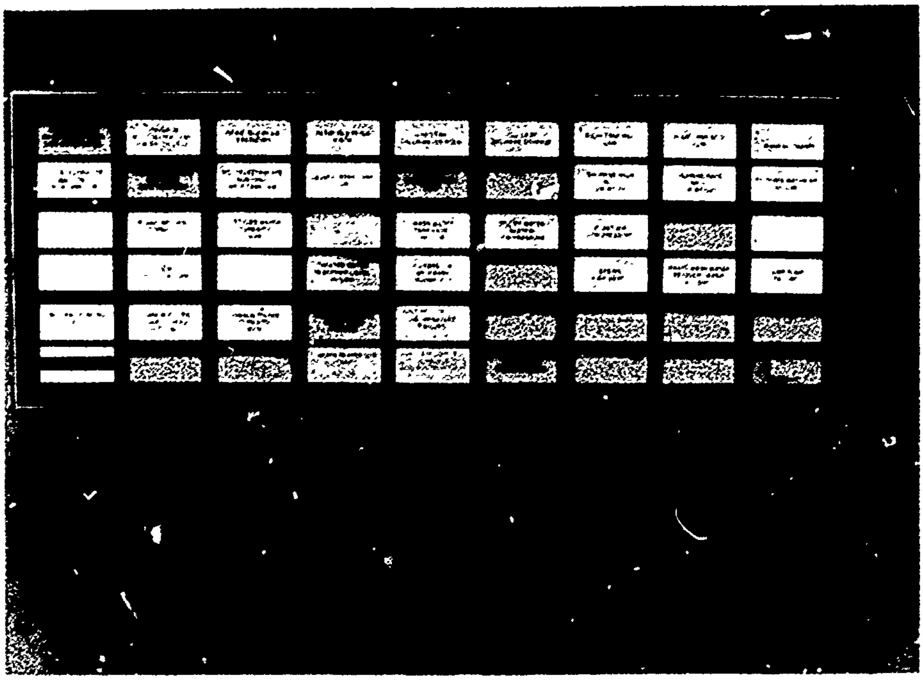


Fig. 19.22 Annunciator (alarm) panel (each rectangle represents a monitored location)

Annunciator panels all have "acknowledge" and "reset" features to allow the operator to squelch the alarm sound (leaving the visible indication alone) and to reset the system after the alarm condition is corrected. The alarm contacts (switches) activating the system commonly use the same instrument as the variables presented on the main panel, or are wired in from remote alarm sensors in the plant or field. The operator is usually responsible for setting these alarm contacts and the operator must use judgment as to the actual limits of the particular variables that will ensure meeting proper operational goals. Each system is different so no attempt will be made here to instruct operating personnel in alarm re-setting procedures.

Sometimes, operators fail to reset alarm limits as conditions and judgments change in the plant. It is not uncommon to see the annunciator panel "lit up," with the operator ignoring all the alarm conditions as the normal status quo! *SUCH PRACTICE IS NOT ADVISED BECAUSE A TRUE ALARM CONDITION REQUIRING IMMEDIATE OPERATOR ATTENTION MAY BE LOST IN THE RESULTING GENERAL INDIFFERENCE TO THE ALARM SYSTEM.* For some operators, acknowledging an alarm sound to get rid of the noise is second nature, without due attention to each and every activating condition. Alarm contact limits should always be reset (or deactivated) as necessary to assure that the operator is as attentive to the alarm system as possible to prevent real emergencies.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.3E What is the purpose of recorders?

19.3F What are the two types of charts used on recorders?

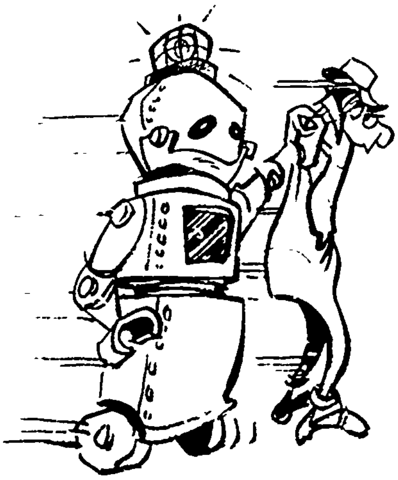
19.3G How are charts driven in remote locations where there is no electricity available?

19.3H List two types of warnings that are produced by alarms.

19.32 Automatic Controller

Section 19.0 explains the nature of control systems, especially as they are used in waterworks operations. Indications of proper and improper control need to be recognized even though actual adjustment of the controller should be left to a qualified instrument technician. By shifting to the manual mode, you can bypass the operation of any controller, whether electric, pneumatic, or even hydraulic. Learn how to shift all controllers to manual operation. This will allow you to take over control of a critical system when necessary in an emergency, as well as at any other time it suits your purposes. For example, you could quickly correct a "cycling" or "sluggish" recorder indication rather than waiting for the controller to correct the condition in time, if it does at all.

A controller, while admittedly "superhuman" in some of its abilities, is still limited. It can only do what it has been programmed to do. You as the operator can exercise *JUDGMENT* based on your experience and observations, so do not hesitate to intervene if a controller is not exercising control within sensible limits. Of course, you must be *SURE* of your conclusions, and competent to take over control if you decide to operate manually.



To repeat a few of the more important operational control considerations, remember that "on-off" control is quite different in operation than proportional control. Both methods may exercise close control of a variable; however, proportional control may be better suited to the purpose. Attempting to set up an "on-off" control system to maintain a variable within too close a tolerance may result in rapid on-off operation of equipment. Such operation can damage both the equipment and the switching devices. Therefore, do not attempt to set a level controller, for instance, to cycle the pump or valve more often than actually necessary for plant operation.

In the case of a proportional controller, it too may begin to cycle its final control element (pump or valve) through a wide range if any of the internal settings, namely proportional band or reset, are adjusted so as to gain closer control of the variable than is reasonable. Accordingly, it may be better to accommodate to a small offset (difference between setpoint and control point), than risk an upset in control by attempting too much control.

19.33 Pump Controllers

Control of pumping systems can be achieved by an automatic controller which determines the output of a variable-speed pump, or by an on-off type of controller starting/stopping the pump(s) according to a level, pressure, or flow measurement. The control of a variable-speed system was discussed earlier in the description of the automatic (proportional) control method, so this section will restrict comments to on-off pump control.

Usually an on-off pump control system responds to level changes in a tank or a reservoir of some type. Water level can be sensed directly or by pressure change at the pump site. The pump is turned off or on as tank level rises above or falls below pre-determined level or pressure limits. Control is rather simple in this case.

However, such systems may include several extra features to ensure fail-safe operation. To prevent the pump from running after a loss of signal, electrical circuitry should be designed so the pump will turn *OFF* on an *OPEN* signal circuit, and *ON* only with a *CLOSED* circuit. Ideally, the sensor can distinguish between an open or closed remote level/pressure contact and an open or shorted telemetry line. Larger pump systems will usually have a low-pressure cut-off switch on the suction side to prevent the pump from running when no water is available, such as with a dry wet well or a closed suction valve.

Pumps may also be protected against overheating, caused by continuing to pump into a closed discharge situation, by a high-pressure cut-off switch on the discharge piping. Both the high- and low-pressure switches may shut off the pump through a time delay circuit, so that short-term pressure surges can be tolerated within the pump piping. Usually the low- or high-pressure switches also key an alarm to notify the operator of the condition. For remote stations, the plant's main panel may include indicator lights to show the pump's operating condition. Figure 19.23 shows a typical pump control circuitry.

Pump control panels (Figure 19.24) may also include automatic or manual sequencers. This provision allows the total pump operating time required for the particular system to be distributed equally among all the pumps at a pump station. A manual switch for a two-pump station, for example, will read "1-2" in one position and "2-1" in the other position. In the first position, pump #1 is the "lead" pump (which runs most of the time) and #2 the "lag" pump (which runs less). When the operator changes the switch to "2-1," the lead-lag order of pump operation is reversed, as it should be periodically, to keep the running time (as read on the elapsed time (E.T.) meters, or as estimated) of both pumps to about the same number of total hours. In a station with multiple pumping units, an automatic sequencer regularly changes the order of the pumps' startup to maintain similar operating times for all pumps.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.3I Under what conditions might an operator decide to bypass a proportional-type controller? How could this be done?

19.3J What basic principle should guide you in programming the frequency of operation of an "on-off" control?

19.3K How can pumps be prevented from running upon loss of signal?

19.3L How can you ensure that all pumps in a pump station operate for roughly equal lengths of time?

19.34 Telemetering Links (Phone Lines)

Remote monitoring or controlling of water distribution system operational variables, such as level, pressure, and flow, may require the use of long signal transmission lines. These lines may be wires (two being required for each circuit) owned by the water agency or telephone lines leased from the local telephone company (Figure 19.25). This lease line arrangement is being used by many utility agencies. In most cases, a transmitter generates an audio frequency or tone on the line. For example, a frequency of 1000 *Hz*[2] produces a medium high-pitched hum on the tone channel (line). Each variable to be transmitted and received has its own tone. This helps limit the number of phone lines needed to and from the remote sites. A very limited number of different tones can be sent over the same phone lines and then be unscrambled by their individual receivers. A remote sensing and control station can send tone signals to the water plant and simultaneously receive tone signals to effect control at the same site. An example would be a flow/pressure/level sensing station across town, with a control valve or pump there under remote manual control. The term "telemetry" is used to denote such use of remote signaling to monitor and/or control remote station operation. The term "supervisory control" applies to the remote control feature exercised through telemetry systems.

With or without use of tone equipment (which mainly serves to allow multiple signals on single phone lines), the actual signal is of the pulse-duration or the pulse-frequency type in virtually every application in waterworks.[3] Pulse-duration, also called pulse-width or time-duration depending on the brand of equipment, functions by creating a 15 second (sometimes less) regular signal cycle within the transmitter. The value of the variable transmitted occupies more or less of this basic time cycle; a 50-percent signal would produce a 7½-second tone (during the remaining 7½ seconds the circuit would be silent). Each manufacturer has selected some standard, usable portion of the 15 second cycle. For example, one company uses only 9 seconds (from 3 seconds to 12 seconds) of the time to proportion 0 to 100 percent of the variable's value. If the panel indicator shows that the depth of water in a remote tank can range from 0 to 9 feet, a tone lasting 6 seconds (67 percent signal) out of the possible 9 seconds, would cause the indicator to show a depth of water of 6 feet. In any case, the corresponding receiver is set up to accept and relay the proper signal to the indicating/controlling instrumentation. This form of signal telemetry is very popular, being easy to understand, requiring no sophisticated instrumentation to check or calibrate, and being virtually insensitive to improper signals originating in the telephone lines or at the phone company. A limitation of this form of signal (time-duration) is when it is used for the "pacing" of chemical feeders, especially coagulants. During a low flow period, alum feeders will be feeding alum intermittently which will produce very poor coagulation/flocculation results. A loss of signal or interference causes the indicator to go to zero or to maximum scale. If you have the opportunity, ask the instrumentation service person to allow you to listen to a tone channel, or better, to a phone line carrying several channels.

From an operational standpoint, there isn't much you can do if you "lose a channel," no matter how important it is to plant operations. Fuse replacement can be tried, then a call

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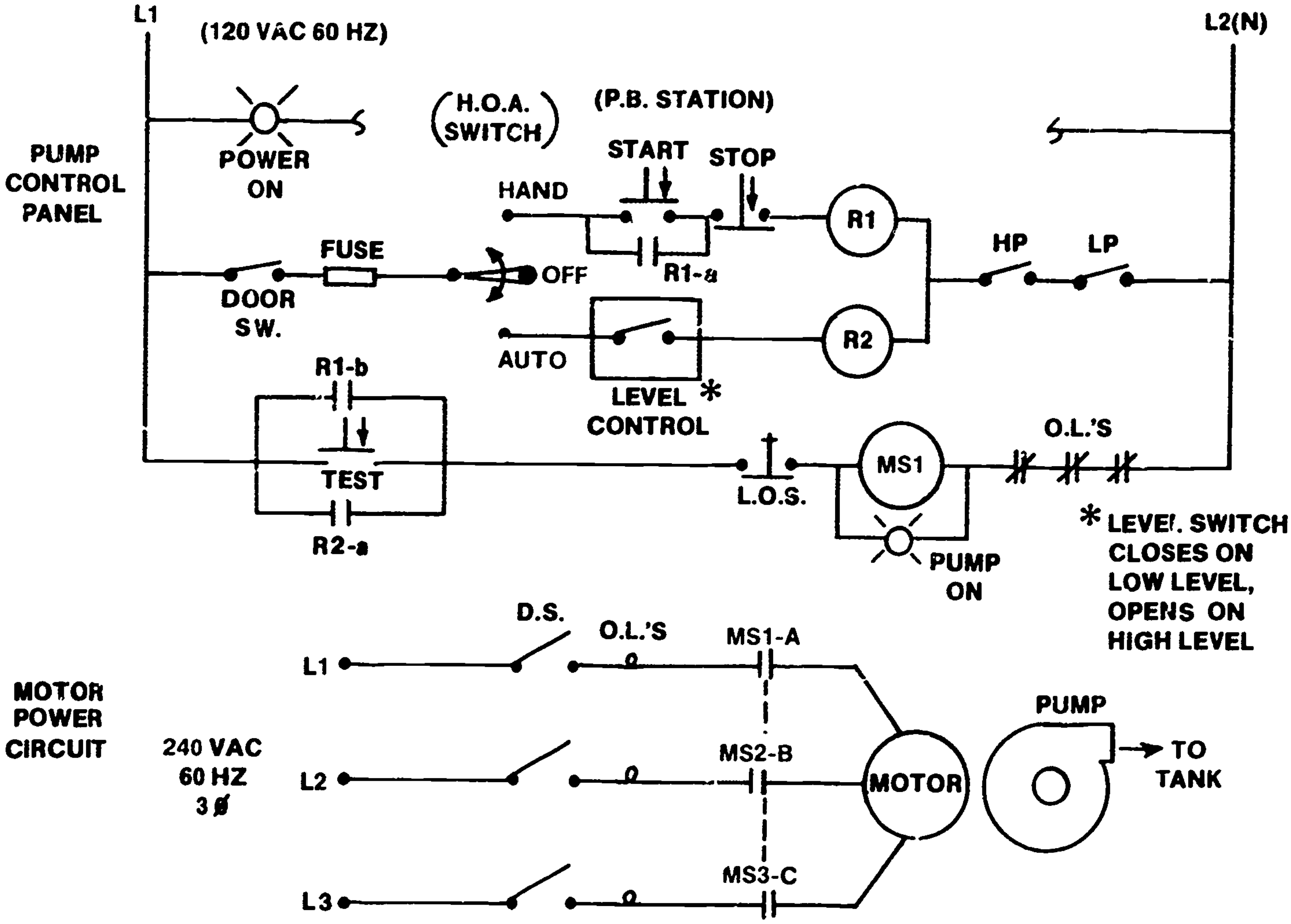
[2] *Hz or Hertz (HURTS). The number of complete electromagnetic cycles or waves in one second of an electrical or electronic circuit. Also called the frequency of the current. Abbreviated Hz.*

[3] *Some short-distance signals operate only by sensing opening or closing of an electrical contact, completely analogous to a local (in-plant) level or pressure switch.*



REFER TO FIG. 19.4, page 346, FOR LEGEND OF TERMS AND SYMBOLS

Fig. 19.23 Pump control station diagram (on-off control) (simplified double-line schematic)

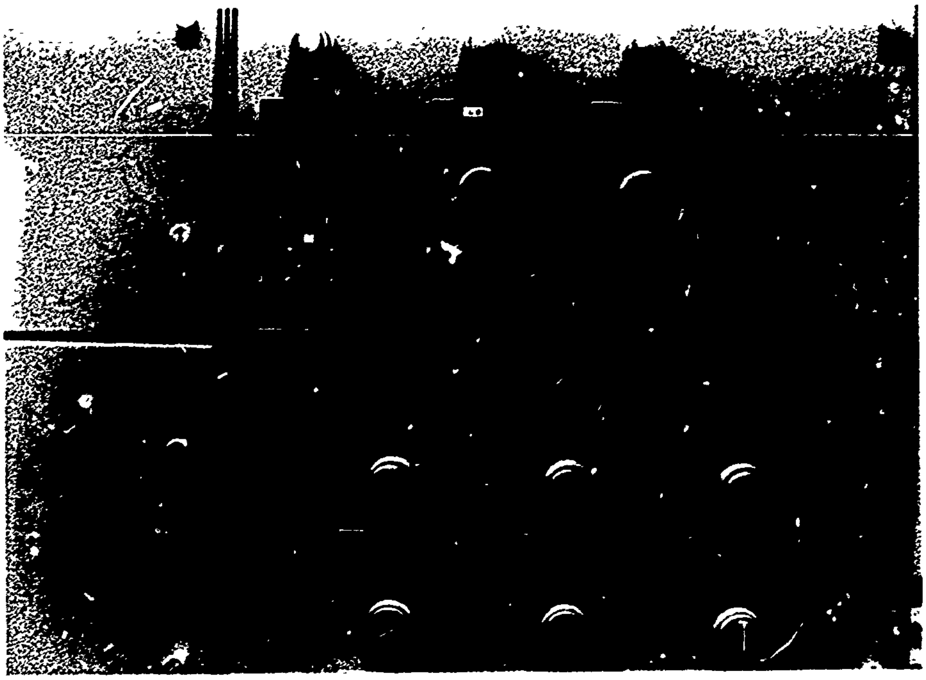
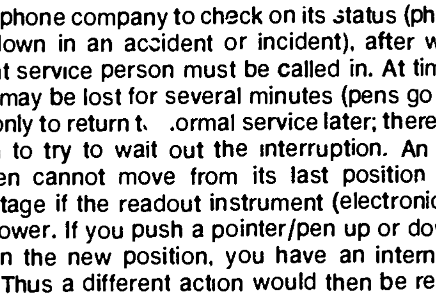


Fig. 19.24 Photo of pump control station

to the telephone company to check on its status (phone lines may be down in an accident or incident), after which the instrument service person must be called in. At times, tone channels may be lost for several minutes (pens go to top or bottom), only to return to normal service later; therefore, you may wish to try to wait out the interruption. An indicator pointer/pen cannot move from its last position during a power outage if the readout instrument (electronic) has no internal power. If you push a pointer/pen up or down and it remains in the new position, you have an internal power problem. Thus a different action would then be required of the operator, not related to a telemetry problem.

19.35 Air Supply Systems

Pneumatic instrumentation depends upon a constant source of clean, dry, pressurized air for reliable operation. Given a quality air supply, pneumatics can operate seemingly forever without significant problems. Without a quality air supply, operational problems can be frequent. The operator of a plant is usually assigned the task of ensuring that the "instrument air" is available and dry, though rarely are operators told how to accomplish this (it being assumed evidently that clean air will "be there" automatically).



The plant's instrument air supply system consists of a compressor with its controls, master air pressure regulator, air filter and air dryer, as well as the individual pressure regulator/filters in the line at each pneumatic instrument (Figure 19.26). Only the instrument air is filtered and dried; the plant air usually does not require such measures since it is being used only for pneumatic tools.

As air passes through a compressor, it not only picks up oil but the air's moisture content is concentrated by the compression process. Special measures must be taken to remove both of these liquids. You can remove oil by filtering the air through special oil-absorbent elements. A process called *DESICCATION*[4] can be used to remove the water. This is simply a matter of either passing the moisture-laden air through desiccant columns, which regenerate their absorption capacity periodically through heating, or of refrigerating the instrument air. The refrigeration method is based upon the principle that cold air can hold comparatively little moisture within it. You must recognize that the capacity of any of these systems of oil or water removal is limited to amounts of liquid encountered under normal conditions.

If the compressor is so worn as to pass more oil than usual, the oil separation process may permit large amounts of oil to pass into the air supply. If the air storage tank contains excessive liquid water (due to irregular or improper drainage), the air drying system may not handle the excess moisture. Learn enough about the instrument air system to be able to open the drain valves, cycle the desiccator, or bypass the tank, in order to prevent instrumentation problems due to an oily, moisture-saturated air supply.

Operators should regularly crack the regulator/filter drain valves at the site of the plant instruments. An unusual quantity of liquid drainage may indicate an overloading or

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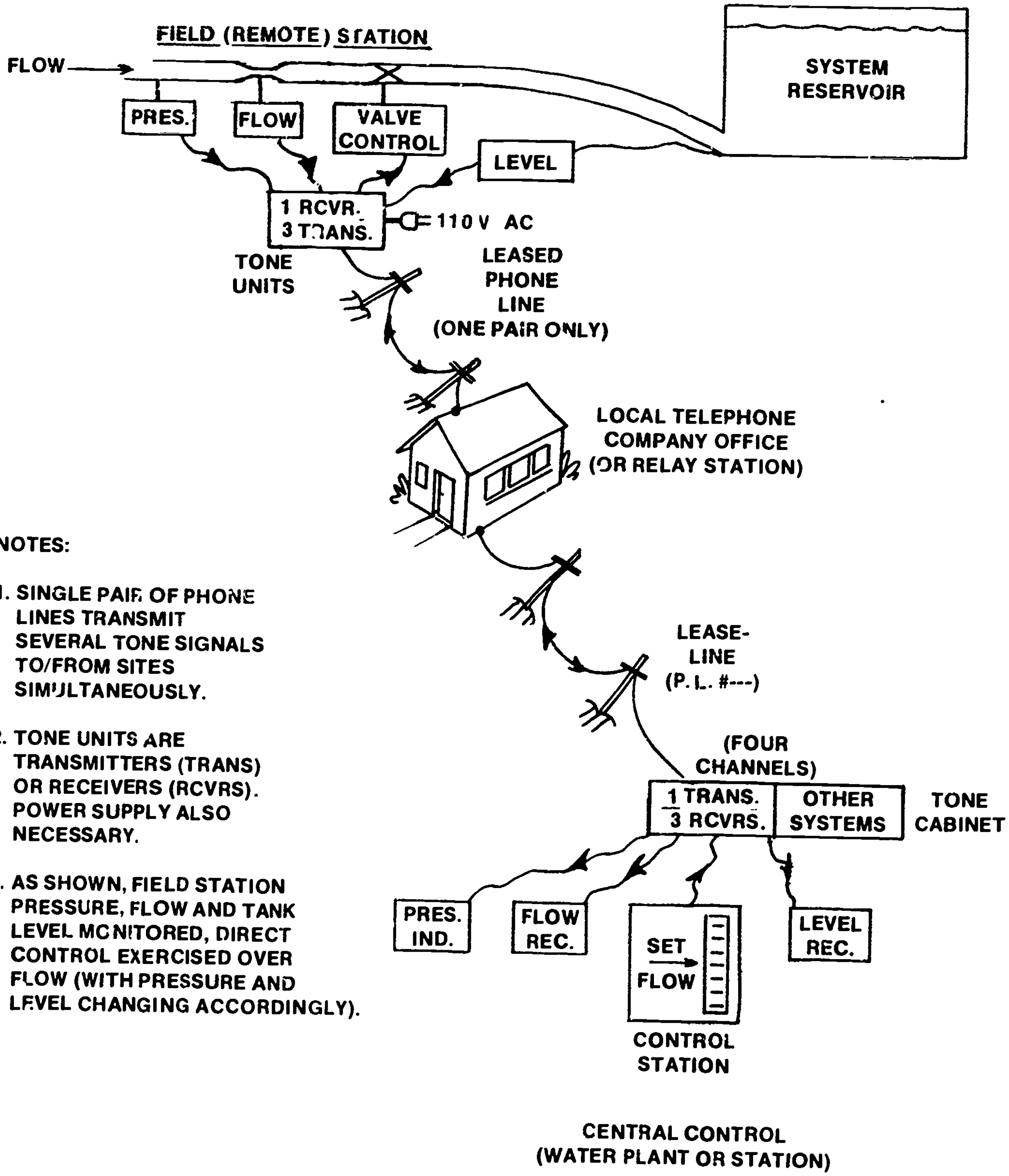
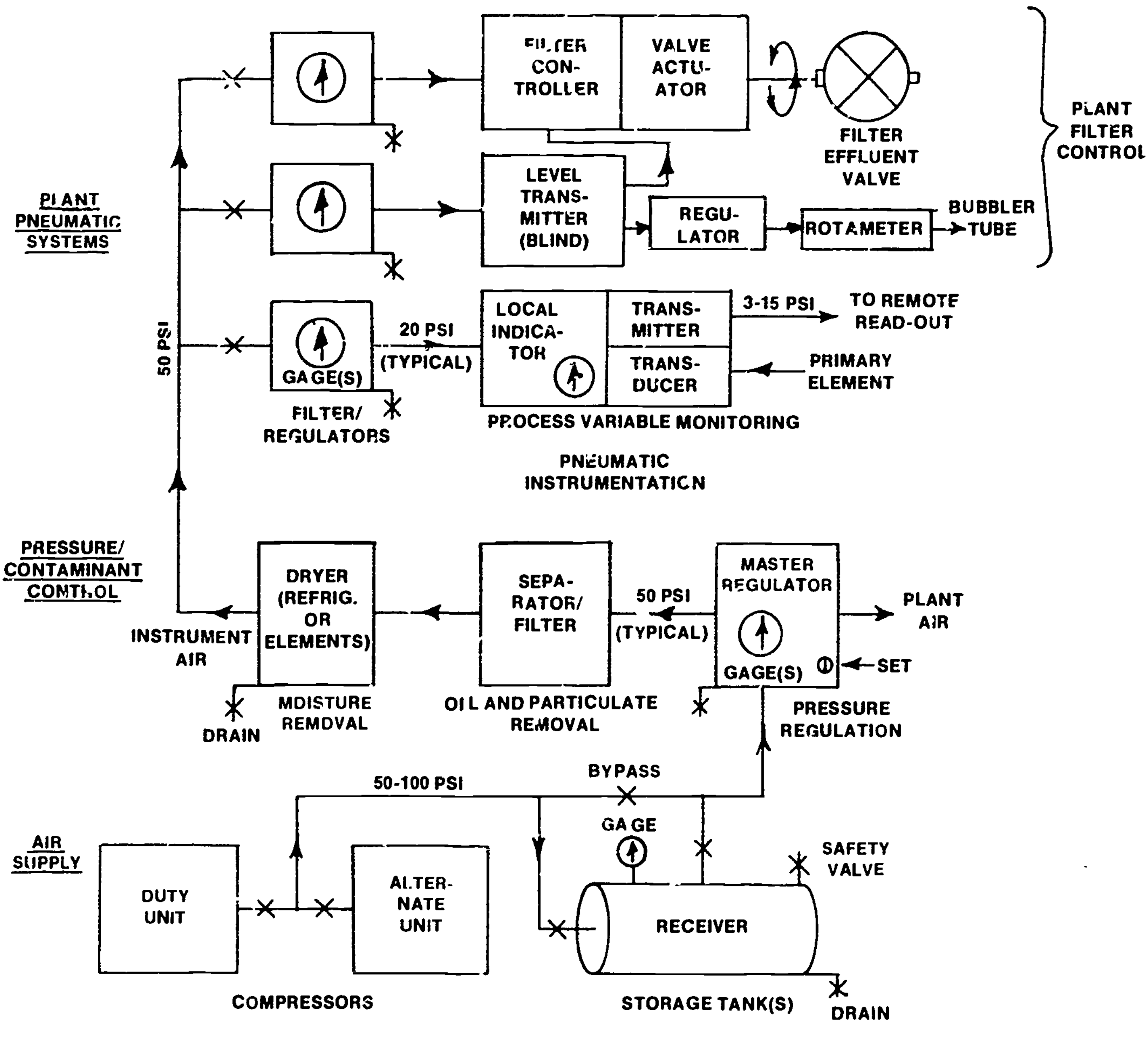
[4] *Desiccation (DESS-uh-KAY-shun). A process used to thoroughly dry air, to remove virtually all moisture from air.*



NOTES:

1. SINGLE PAIR OF PHONE LINES TRANSMIT SEVERAL TONE SIGNALS TO/FROM SITES SIMULTANEOUSLY.
2. TONE UNITS ARE TRANSMITTERS (TRANS) OR RECEIVERS (RCVRS). POWER SUPPLY ALSO NECESSARY.
3. AS SHOWN, FIELD STATION PRESSURE, FLOW AND TANK LEVEL MONITORED, DIRECT CONTROL EXERCISED OVER FLOW (WITH PRESSURE AND LEVEL CHANGING ACCORDINGLY).

Fig. 19.25 Diagram of telemetry system (monitoring and supervisory control)



NOTES:

1. COMPRESSOR AND TANK OFTEN AN INTEGRAL UNIT.
2. MOST CRITICAL COMPONENTS HAVE ALTERNATE/STANDBY UNITS.
3. SOME DRAINS MAY BE AUTOMATIC TYPE.

Fig. 19.26 Instrument air system functional diagram (simplified, not all valves and piping shown) failure in the instrument air filter/drying parts. Also, pneumatic indicators/recorders should be watched for erratic pointer/pen movements which may well be indicative of air quality or supply problems.

The seriousness of temporary plant or compressor station power failures can be lessened if you temporarily turn off all non-essential usages of compressed air in the plant. The air storage tank is usually sized so that there is enough clean, dry air on hand to last for several hours, if conserved. Knowing this, you may be able to wait out a power failure without undue drastic action by observing remaining available pressure at the air supply.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.3M How are signals transmitted over long distances, such as from a water storage reservoir to pumps at a water treatment plant?

19.3N What happens to a remote indicator when a signal is lost?

19.3O What are the essential qualities of the air supply needed for reliable operation of pneumatic instrumentation pressure systems?

19.3P How are moisture and oil removed from instrument air?

19.36 Laboratory Instruments

This category of instrumentation includes those analytical units usually found in larger water treatment plant laboratories. Turbidimeters, colorimeters and comparators, pH, conductivity (TDS), dissolved oxygen (D.O.), and temperature indicators fit in this classification of instruments (Figure 19.27). We have already seen that process models of each of these units monitor these same variables out in the plant. Operators rarely are required to do anything more than make periodic readings from lab instruments, though standardizing the particular instrument is often required before the determination of a sample's turbidity or color is made. Preventive, and certainly corrective, maintenance (if any) is handled by the chemist, factory rep, or instrument technician since each unit is quite specialized and complex. Some of these countertop instruments or devices are quite delicate and replacement parts, such as turbidimeter tubes or pH electrodes, are quite expensive. Moreover, the use of many of these instruments requires the regular handling of laboratory glassware and other breakable items. The operator who, through carelessness, lack of knowledge, or simple hurrying, consistently breaks glassware or "finds the pH meter broken" does not become popular with the chemist, supervisor, nor the other operators. The byword in the lab is *WORK WITH CAUTION.* Protect valuable and essential equipment and instrumentation.

19.37 Test and Calibration Equipment

In most larger water plant operations, the plant operating staff have little occasion to use testing and calibration meters and devices on the plant instrumentation systems. A trained technician will usually be responsible for maintaining such systems. There are, however, some general considerations the operator should understand concerning the testing and calibration of plant measuring and control systems. With this basic knowledge, you may be able to discuss needed repairs or adjustments with an instrument technician and perhaps actually assist with that work. A greater understanding of your plant's instrument systems may also enable you to analyze instrument problems as they bear upon continued plant operation, to handle emergency situations created by instrument failure, and finally your skills in instrument testing and calibration equipment may result in a job promotion and/or pay raise.

The most useful piece of test equipment is the V-O-M, that is the Volt-Ohm-Milliammeter, commonly called the "multimeter" (Figure 19.28). To use this instrument you will need a workable understanding of electricity, but once you learn to use it, the V-O-M has potential for universal usage in instrument and general electrical work. Local colleges and other educational institutions may offer courses in basic electricity which undoubtedly include practice with a V-O-M. You, as a professional plant/system operator, are unlikely to find technical training of greater practical value than this type of course or program. Your future use of test and calibration equipment in general certainly should be preceded by instruction in the fundamentals of electricity.

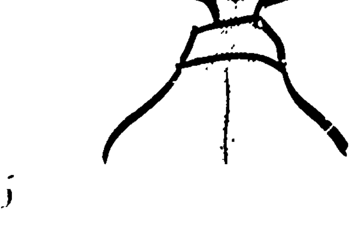
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.3Q Why should an operator be especially careful when working in a laboratory?

19.3R Why should an operator become familiar with the testing and calibration of plant measuring and control systems?

19.3S What is a V-O-M?



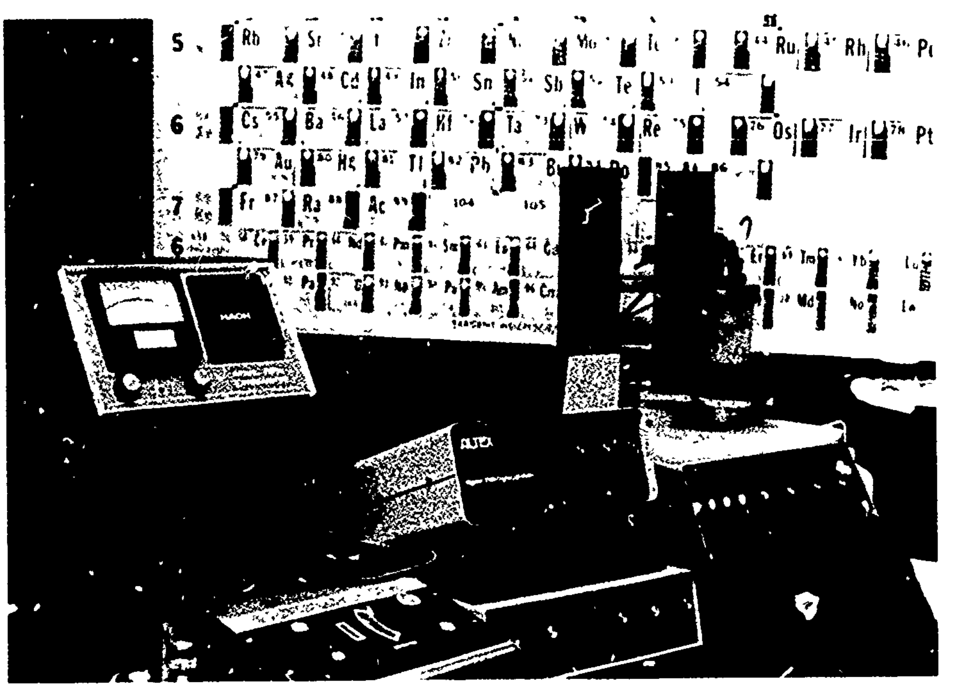


Fig. 19.27 Water laboratory instruments

19.4 OPERATION AND PREVENTIVE MAINTENANCE

19.40 Proper Care of Instruments

Usually instrumentation systems are remarkably reliable year after year, assuming proper application, setup, operation and maintenance. Measurement systems may be found still in service at some utilities up to 50 years after installation To a certain extent, good design and application account for such long service life, but most important is the careful operation and regular maintenance of the instrument's parts or components. The key to such proper "O & M" is the operator's practical understanding of the system. Operators must know how to (1) recognize properly functioning instruments, so as to prevent prolonged and damaging malfunction, (2) shut down and prepare devices for seasonal or prolonged nonoperation, and (3) perform preventive (and minor corrective) maintenance tasks to ensure proper operation in the long term. By contrast, a sensitive instrumentation system can be quite easily ruined in short order with neglect of *ANY ONE* of the three principles listed

Operators should be familiar with the "Technical Manual" (also called the "Instruction Book" or "Operating Manual") of each piece of equipment and instrument encountered in a plant. Each manual will have a section devoted to the operation of some component of a measuring or control system (though frequently not for the entire system). Detailed descriptions of maintenance tasks and operating checks will usually be found in the same section of the manual. Depending upon the general type of instrument (electro-mechanical, pneumatic, or electronic), the suggested frequency of the operation and maintenance/checking tasks can range from none to monthly. Accordingly, this section of the course only addresses itself to those general tasks an operator might be expected to perform to operate and maintain instrumentation systems. These general tasks can be summed up from the *OPERATIONS STANDPOINT AS LEARNING AND CONSTANT ATTENTION TO WHAT CONSTITUTES NORMAL FUNCTION, AND FROM A MAINTENANCE STANDPOINT, ENSURING PROPER AND CONTINUING PROTECTION AND CARE OF EACH COMPONENT.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382

19.4A List the three principles which are the keys to proper instrument O & M.

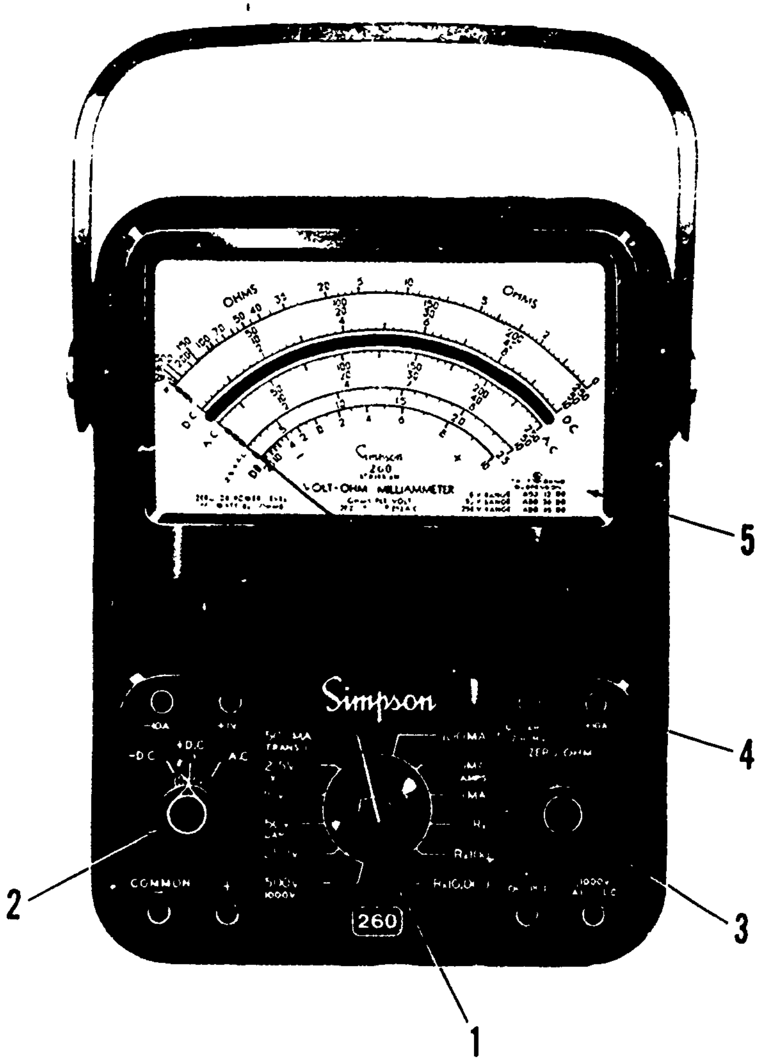
19.4B What generally is expected of an operator of instrumentation systems from (1) an operations standpoint and (2) a maintenance standpoint?

19.41 Indications of Proper Function

The usual pattern of day-to-day operation of every measuring and control system in a plant should become so familiar to all operators that they almost unconsciously sense any significant change. This will be especially evident and true for systems with recorders where the pen trace is visible. An operator should watch indicators and controllers for their characteristic actions. With analog instruments, each pen or pointer may display its own unique characteristics (though some may be virtually the same). Thus, the pen for "Flow Recorder A" may normally scribe out a one-eight-inch (3 mm) wide track due to inherent sensitivity or flow variations, whereas "Level Recorder B" may normally produce a trace as steady as a rock (Figure 19.29). However, if the flow pen is noticed as steady one day, or the level indication widens due to a quiver, then the operator should suspect a problem. In this regard, signs of possible improper function (though not *NECESSARILY* so) include (Figure 19.29):

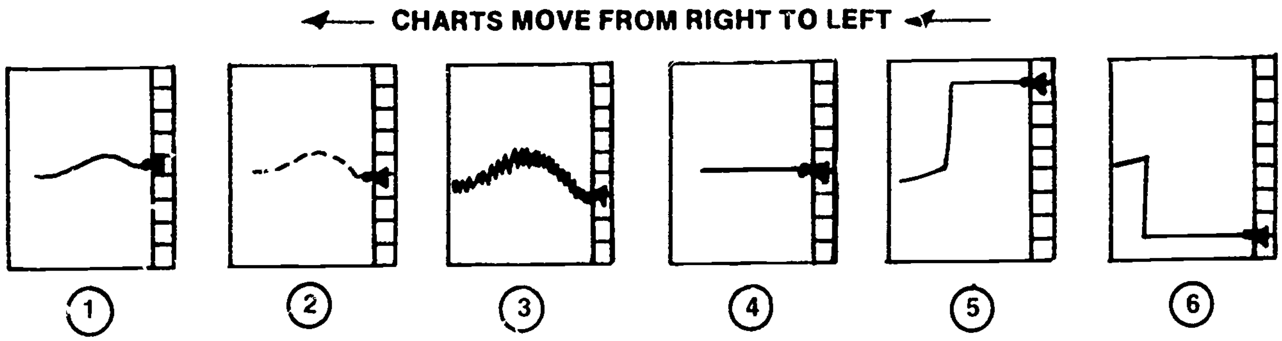
Controls, Jacks and Indicator

1. Range Switch:	Has 12-positions. May be turned in either direction. There are 5-voltage positions, 4-direct current positions, and three resistance positions used to select desired ranges.
2. Function Switch:	Has 3-positions: −D.C., +D.C., and A.C. To measure DC voltage, current or resistance, the function switch is set to −D.C., or +D.C. according to the polarity of the applied current or voltage. Turning this switch reverses the test lead connections without removing the leads from the circuit under test.
3. ZERO OHMS:	This control is used to compensate for variation in the voltage of the internal batteries
4. Circuit Jacks:	There are 8-jacks, two in each corner of the sub-panel. They provide an electrical connection to the test leads.
5. Meter:	4-1/2" indicating instrument. Has a scale for each function and range.



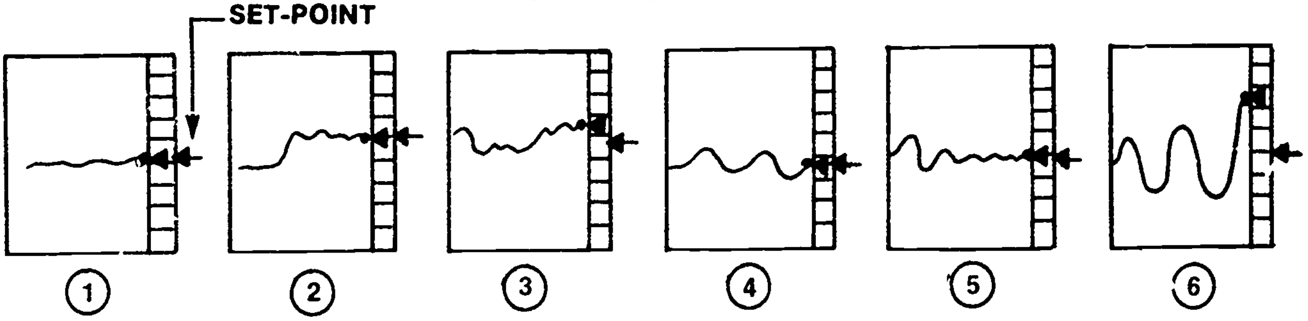
Front Panel Controls, Jacks and Indicator

MEASURING/MONITORING SYSTEMS



1 Normal function: Ink trace dark and steady, variable within expected range.
2. Pen skips. Pen dirty, dry, or not on chart; clean pen/tubing, re-ink, check contact.
3. Wide trace: "Noisy" system, too sensitive; causes inking problems, can be adjusted out.
4. Flat trace (upscale): OK if usual for system, otherwise check sensor or process.
5. Trace to max. scale: Instrumentation problem (sudden or constant 100% unlikely).
6. Trace to min. scale: Process or sensor off, also may be signal loss.

CONTROL SYSTEMS



1 Normal control: Pen trace steady, process or set-point changes controlled well.
2. Normal control: Small oscillations normal with process or set-point change.
3. Abnormal control: Excessive departure from set-point, "sloppy" controller.
4 Cycling or hunting: Unstable control, controller settings need adjustment.
5. Damped oscillations: Process upset, control OK if acceptable for process.
6. Worsening oscillations: System out of control due to process or set-point change, service required. Do not use "auto," switch to "manual" control.

Fig. 19.29 Indications of proper and abnormal function
(systems with strip-chart recorders; circular chart indications are similar)

1. Very flat or steady pen trace is the system working at all, or is the variable really that constant?);
2. Excessive pen/pointer quiver (causes undue wear on parts, can usually be adjusted out); and
3. Constant or periodic hunting, or spikes, in a pen/pointer (improper adjustment, control or other problem).

Additionally, it is not uncommon for a pointer or pen to become stuck at some position on its scale, usually at the extreme limits of movement. Pens are particularly prone to sticking, getting hung-up on the chart edge or in a tear or hole. Therefore, operators should become observant not only of unusual pointer/pen movement, but unusual *LACK* of movement by indicators and recorders. In the case of recorders, you may *LIGHTLY TAP* an instrument to check on the pointer/pen motion. If a gentle tap does not cause slight movement, a problem may well exist. Anyone hitting or shaking a delicate instrument hard, however, in an attempt to check it out, only reveals a lack of training in this area.

At times, firmly pushing an instrument into its case, or closing the door completely, may close the interlock switch and switch the system on, as designed. However, jamming the device into its case, or slamming a door is *NEVER* considered proper action. If a device still doesn't begin to work, check the power connection and instrument fuse(s), if any.

For pneumatic systems, an unnoticed failure of the instrument air supply is the most common reason for an inoperable instrument. Such a failure of the air supply extends the inoperable situation to all pneumatic systems in the plant. Complete functional loss of a single pneumatic instrument is rather rare, but erratic operation is not uncommon, due to previously mentioned water or oil in the air supply.

One of the surest indications of a serious electrical problem in instrument or power circuits is, of course, smoke and/or a burning odor. Such signs of a problem should never be ignored. Smoke/odor means heat, and no device can operate long at unduly high temperatures. Any electrical equipment which begins to show signs of excessive heating must be shut down immediately, regardless of how critical it is to plant operation. Overheated equipment will very likely fail soon anyway, with the damage being aggravated by continued usage. Fuses and circuit breakers are not always designed to de-energize circuits before damage occurs, and cannot be relied upon to do so.

Finally, operators frequently forget to reset an individual alarm, either after an actual occurrence or after a system test. This is especially prevalent when an annunciator panel is allowed to operate day after day with lit-up alarm indicators (contrary to good practice) and one more light is not easily noticeable. Also, when a plant operator must be away from the main duty station, the system may be set so the audible part of the alarm system is temporarily squelched. When the operator returns, the audible alarm system may inadvertently not be reset. In both instances (individual or collective loss of audible alarm) the consequences of such inattention can be serious. Therefore, get in the habit of checking and re-setting your annunciator system often.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.4C List three possible signs of an improperly functioning flow recorder.

19.4D Where or how are recording pens most likely to become stuck or "hung-up?"

19.4E What is a common reason for nonoperation of pneumatic systems?

19.4F What is an indication of a serious problem in an electrical instrument or power circuit?

19.42 Startup/Shutdown Considerations

The startup and periodic (seasonal) or prolonged shutdown of instrumentation equipment requires very little extra work by the operator. Startup is limited mainly to undoing or reversing the shutdown measures taken.

When shutting down any pressure, flow or level measuring system, valve off the access of water to the measuring element. Exercise particular care, as explained previously, regarding the *ORDER* in which the valves are manipulated for any flow-tube installation. Also, the power source of some instruments may be shut off, unless the judgment is made that keeping an instrument case warm (and thus dry) is in order. In such cases, constantly moving parts, such as chart drives, should be turned off. With an electrical panel room containing instrumentation, it is good practice to leave some power components on (such as a power transformer) to provide space heat for moisture control. In a known moist environment, sealed instrument cases may be protected for a while with a container of *DESICCANT*[5] ("indicating silica gel" which is blue if O.K. and pink when the moisture-absorbent capacity is exhausted).

Though preventing the access of insects and rodents into any area appears difficult, general cleanliness seems to help considerably. Rodenticides are available to control mice; this is good preventive maintenance practice in any electrical space. Mice will chew off wire and transformer insulation, and may urinate on other insulator material, leading to serious damage.

Nest-building activities of some birds can also be a problem. Screening buildings and equipment against entry by birds has become a design practice of necessity. Insects and spiders are not known to cause specific functional problems, but startup and operation of systems invaded by ants, bees, or spiders should await cleanup of each such component of the system. All of these pests can bite or sting, so take care!

With pneumatic instrumentation, it is desirable to purge each device with dry air before shutdown. This measure helps rid the individual parts of residual oil and moisture to minimize internal corrosion while standing idle. As before,

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[5] *Desiccant (DESS-uh-kant) A drying agent which is capable of removing or absorbing moisture from the atmosphere in a small enclosure.*

periodic blow-off of air receivers and filters keeps these liquids out of the instruments to a large degree. Before shutdown, however, extra attention should be paid to instrument air quality for purging. Before startup each filter/receiver should again be purged.

Finally, pay attention to the pens and chart drives of recorders upon shutdown. Ink containers (capsules) may be removed if deemed necessary, and chart drives turned off. A dry pen bearing against one track (such as zero) of a chart for weeks on end is an invitation to startup problems. Reinking and chart replacement at startup is an easy matter if the proper shutdown procedures were followed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.4G How can moisture be controlled in an instrument?

19.4H Why should pneumatic instrumentation be purged before shutdown?

19.43 Maintenance Procedures and Records

Preventive maintenance means that attention is given periodically to equipment in order to *PREVENT* future malfunctions. Corrective maintenance involves actual, significant repairs which are beyond the scope of this work and responsibility of the operator (in most cases). Routine operational checks are part of all P.M. (preventive maintenance) programs in that a potential problem may be discovered and thereby corrected before it becomes serious.

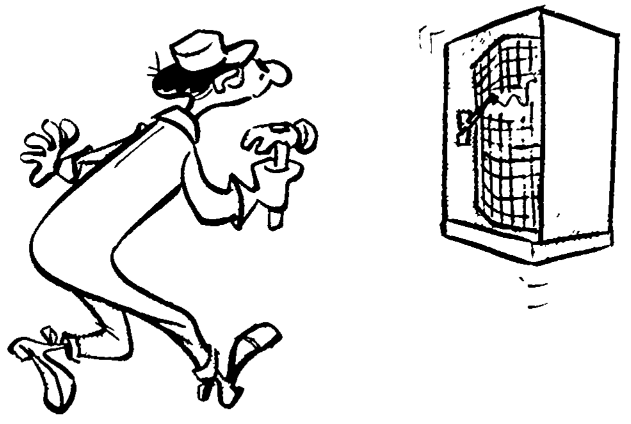
P.M. duties for instrumentation should be included in the plant's general P.M. program. If your plant has no formal, routine P.M. program, it should have! Such a program must be set up "on paper." That is, the regular duties required are printed on forms or cards which the operator (or technician) uses as a reminder, guide, and record of P.M. tasks performed. Without such explicit measures, experience shows that preventive maintenance will almost surely be put off indefinitely. Eventually, the press of critical corrective maintenance (often due to lack of preventive maintenance!) and even equipment replacement projects may well eliminate forever any hope of a regular P.M. program. The fact that instrumentation is usually very reliable (being of quality design) may keep it running long after non-maintained pumps and other equipment have failed. Nevertheless, instrumentation does require proper attention periodically to maximize its effective life. P.M. tasks and checks on modern instrument systems are quite minimal (even virtually non-existent on some), so there are no valid reasons for failing to ever perform these tasks.

19.44 Operational Checks

Operational checks are most efficiently performed by always observing each system for its continuing signs of normal operation. However, some measuring systems may be cycled within their range of action as a check on the responsiveness of components. For instance, if a pressure-sensing system indicates only one pressure for months on end, and some doubt arises as to whether it's working or not, the operator may bleed off a little pressure at the primary element to produce a small fluctuation. Or, if a flow has appeared constant for an overly long period, the bypass valve in the D.P. (Differential Pressure) cell piping[6] may be cracked open briefly to cause a drop in reading. Be sure you crack the bypass valve. If you open the wrong valve the pressure may be excessive and be beyond the range of the D.P. cell which could cause some problems. A float suspected of being stuck (very constant level indication) may be freed by jiggling its cable, or other measures taken to cause a slight fluctuation in the reading.

Whenever an operator or a technician disturbs normal operation during checking or for any reason, operating personnel must be informed — ideally *PRIOR TO* the disturbance. If a recorder trace is altered from its usual pattern in the process, the person causing the upset should initial the chart appropriately, with time noted. Some plants require operators to mark or date each chart at midnight (or noon) of each day for easy filing and retrieval.

In the case where a pen/pointer is thought to be stuck mechanically, that is, it does not respond at all to simulated or actual change in the measured variable, it is normally permissible to open an instrument's case and try to move the pointer/pen, *BUT ONLY TO THE MINIMUM* extent possible to establish its freedom. Further deflection may well bend or break the device's linkage. A "dead pen" often is due only to loss of power or air to the readout mechanism. Any hard or repeated striking of an instrument to make it work identifies the striker as ignorant of good operational practice and can ruin the equipment. Insertion of tools into an instrument case in a random "fix-it" attempt could damage the instrument. Generally speaking, any extensive operating check of instrumentation should be performed by the instrument technician during routine P.M. program activities.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 382.

19.4I Why should regular preventive maintenance duties be printed on forms or cards?

19.4J How are operational checks performed on instrument equipment?

19.4K What should be done if a recorder trace is altered from its usual pattern during the process of checking an instrument?

19.45 Preventive Maintenance

The technical manual for each item of instrumentation in your plant should be available so you can refer to it for O & M purposes. When a manual cannot be located, contact the

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[6] *There is no similar easy way to check a propeller meter's response.*

manufacturer of the unit. Be sure to give all relevant serial/model numbers in your request for the manual. Request two manuals, one to use and one to put in reserve. All equipment manuals should be kept in one protected location, and signed out as needed. Become familiar with the sections of these manuals related to O & M, and follow their procedures and recommendations closely.

A good practice is to have on hand any supplies and spare parts which are or may be necessary for instrument operation (such as charts) or service (such as pens and pen cleaner) Some technical manuals contain a list of recommended spare parts which you could use as a guide. Try to obtain these supplies/parts for your equipment. A new pen on hand for a critical recorder can be a lifesaver at times.

Since P/M. measures can be so diverse for different types, brands, and ages of instrumentation, only the few general considerations applicable to all will be covered in this section.

1. Protect all instrumentation from moisture (except as needed by design), vibration, mechanical shock, vandalism (a very real problem in the field) and unauthorized access.
2. Keep instrument components clean on the outside, and closed/sealed against inside contamination. This specifically includes spider webs and rodent wastes.
3. *DON'T* presume to lubricate, adjust, fix, calibrate, free-up, or modify any component of a system arbitrarily. If you are not qualified to take any of these measures, then don't do it.
4. *DO* keep record pens and charts functioning as designed by frequent checking and service, bleed pneumatic systems regularly as instructed, ensure continuity of power for electrical devices, and don't neglect routine analytical instrument cleanings (such as turbidimeters) and standardizing duties as required by your own plant's established procedures.

As a final note, it is a good idea to get to know and cooperate fully with your plant's instrument service person. Good communication between this person and the operating staff can only result in a better all-around operation. If your agency is too small to staff such a specialist (most are), it may be a good idea to enter into an instrumentation service contract with an established company or possibly even with the manufacturers of the majority of the components. With rare exceptions, general maintenance persons (even journeyman electricians) are not qualified to perform extensive maintenance on modern instrumentation. Be sure that someone takes good care of your instruments and they will take good care of you

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 383.

19.4L How can the technical manual for an instrument be obtained if the only copy in a plant is lost?

19.4M What instrument supplies and spare parts should always be available at your plant?

19.5 ADDITIONAL READING

1. *TEXAS MANUAL*, Chapter 14, "Instrumentation."
2. *AUTOMATION AND INSTRUMENTATION* (M2). Obtain from Computer Services, American Water Works Association, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 30002. Price to members, $18.00; nonmembers, $23.00

End of Lesson 2 of 2 Lessons on INSTRUMENTATION

DISCUSSION AND REVIEW QUESTIONS

Chapter 19. INSTRUMENTATION

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 383. The question numbering continues from Lesson 1.

8 What are the advantages and limitations of analog versus digital indicators?

9 Why is it poor practice to ignore many of the lamps that are "lit up" (alarm conditions) on an annunciator panel?

10 How should the constantly "lit up" lamps (alarm conditions) on an annunciator panel be handled?

11 What controls are available to protect pumps from damage?

12 What problems are created by oil and moisture in instrument air, and how can these contaminants be removed?

13. Why should plant measuring and control systems be regularly tested and periodically calibrated?

14 What could cause erratic operation of pneumatic instruments?

15. Why should insects and rodents be kept out of instruments?

16 How could you tell if a float might be stuck and how would you determine if it was actually stuck?

SUGGESTED ANSWERS

Chapter 19 INSTRUMENTATION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 343.

19.0A Measurement instruments can be considered an extension of your human senses because they can perform the same duties as your eyes and ears can directly.

19.0B Water treatment processes and equipment that could be monitored or controlled by measurement and control systems include influent and effluent flows, basin levels, pump operation, chemical feeders and filter valves.

19.0C An advantage of instruments over our senses is that instruments provide quantities or measurable information, whereas only qualitative information is available from our senses.

19.0D The analog readout of an instrument has a pointer (or other indicating means) that reads against a dial or scale.

Answers to questions on page 345.

19.0E An on-off type "controller" controls the automatic starting-stopping of a pump or a chemical feeder motor.

19.0F Examples of "proportional control" in waterworks operations include: (1) chlorine residual analyzer/controller; (2) chemical feed, flow paced (open loop); (3) pressure- or flow-regulating valves; (4) continuous level control of filter basins; (5) variable-speed pumping system for flow control.

19.0G The motor control station provides for on-off operation of electric motors.

Answers to questions on page 347.

19.1A The general principles for safe performance on the job are to *ALWAYS* avoid unsafe acts and correct unsafe conditions.

19 1B Electrical shock can cause death by asphyxiation and/or burning.

19.1C An electrical "explosion" could shower you with molten metal, startle you into a bumped head or elbow, or cause a bad fall.

Answers to questions on page 348.

19.1D Operators should be especially careful when working around powered automatic mechanical equipment because the equipment could start unexpectedly and cause serious injury.

19.1E The purpose of an electrical lock-out device is to positively prevent the operation of an electrical circuit, or to de-energize the circuit temporarily.

19 1F If electrical current flows through your upper body, electrical shock could harm your heart and/or your head.

19.1G Thin rubber or plastic gloves can be worn to reduce markedly your chances of electrical shock.

Answers to questions on page 349.

19 2A A sensor is the primary element that measures a variable. The sensor is often a transducer of some type that converts energy of one kind into some other form to produce a readout or signal.

19.2B Pressure is measured by the movement of a flexible element or a mechanically deformable device subjected to the force of the pressure being measured.

19.2C Some sensors are fitted with surging and overrange protection to limit the effect of pressure spikes or water hammer on the sensor.

Answers to questions on page 355.

19 2D Liquid level sensors include floats, displacers, probes, pressure sensors, and bubbler tubes.

19.2E A signal can be generated by a float element by attaching the float to a steel tape or cable that is wrapped around a drum or pulley. The level sensed is transmitted as a signal (electrical) proportional to the rotation (position) of the pulley or drum.

19.2F Probes are used instead of mechanical systems to measure liquid levels in sealed or pressurized tanks, or with chemically-active liquids.

19.2G A bubbler measures the level of a liquid by sensing (measuring) air pressure necessary to cause bubbles to just flow out the end of the tube.

Answers to questions on page 360.

19.2H The two types of flow readings are (1) rate of flow and (2) total flow (volume).

19 2I The two main types of larger flow measurement devices are (1) velocity sensing and (2) differential-pressure sensing. Magnetic and ultrasonic devices are also used.

19.2J Smaller service meters are one of the positive-displacement types of total flow meters.

19.2K Velocity-sensing devices measure flows by sensing the rate of rotation of a special impeller placed within the flowing system.

19.2L Flows are measured with venturi meters by sensing the pressure differential between the water pressure before the restriction in the meter or tube, and the pressure within the restriction.

Answers to questions on page 362.

19.2M Chemical feed rates are measured on a weight or volumetric basis if the chemical is in a dry solid form. If chemical is in liquid form, a volumetric flow device such as a rotameter may be used.

19.2N Process variables commonly measured and/or controlled by instruments include turbidity, pH, chlorine residual, fluoride, electrical conductivity, hardness, alkalinity and temperature.

19.2O Values measured at one site are transmitted by a signal to a receiver at a remote location.

19.2P The two general systems used to transmit measurement signals are electrical and pneumatic systems.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 364.

19.3A The purpose of indicators is to give a visual presentation of a variable's value, either as an analog or as a digital display.

19.3B An analog display uses some type of pointer (or other indicator) against a scale.

19.3C Recorders are usually found in a central location at a water treatment plant.

19.3D Factors that can cause electronic instrument problems include temporary power failures, tripped panel circuit breakers, voltage surges (or lightning) resulting in blown fuses, and excessive heat.

Answers to questions on page 368.

19.3E Recorders are indicators designed to show how the value of the variable has changed with time.

19.3F Recorder charts may be circular or strip types.

19.3G In remote locations where no electricity is available, charts are driven by hand-wound drives or batteries.

19.3H Alarms may produce either visual and/or audible signals.

Answers to questions on page 369.

19.3I An operator might bypass a proportional-type controller in an emergency or when, in the judgment of the operator, the controller is not exercising control within sensible limits. To bypass a controller, switch to the manual mode of operation.

19.3J "On-off" controls should be programmed to operate or cycle associated equipment on and off no more often than actually necessary for plant or system operation.

19.3K Pumps can be prevented from running upon loss of signal by electrical circuitry designed so the pump will turn *OFF* on an *OPEN* signal circuit and *ON* only with a *CLOSED* circuit.

19.3L Pumps in a pump station can be operated for similar lengths of time by the use of manual or automatic "sequencers" which switch different pumps to the "lead" pump position and the other(s) to the "lag" position periodically.

Answers to questions on page 374.

19.3M Signals are transmitted over long distances by the use of signal transmission lines. These lines may be wires owned by the water agency, or telephone lines leased from the local telephone agency. Radio or microwave transmission is sometimes used.

19.3N A loss of signal causes the indicator to go to zero or to maximum scale, depending on type of signal.

19.3O Pneumatic instrumentation pressure systems must have a constant source of clean, dry, pressurized air for reliable operation.

19.3P Oil is removed by filtration through special oil-absorbent elements, and a dryer desiccator or refrigeration is used to remove moisture from instrument air.

Answers to questions on page 374.

19.3Q Care must be exercised when working in the laboratory so as not to break the sensitive instruments, delicate equipment, or fragile glassware.

19.3R Operators should become familiar with the testing and calibration of plant measuring and control systems in order to assist instrument technicians, and to better understand the plant's instrumentation system. Also, development of skills in instrument testing and calibration equipment may result in a job promotion and/or pay raise.

19.3S V-O-M stands for **Volt-Ohm-Milliammeter**, commonly referred to as a multi-meter.

Answers to questions on page 375.

19.4A The three principles which are the keys to proper instrument O & M are:

1. Recognizing properly functioning instruments, so as to prevent prolonged and damaging malfunctions,
2. Shutting down and preparing devices for seasons or prolonged nonoperation, and
3. Performing preventive (and minor corrective) maintenance tasks to ensure proper operation in the long term.

19.4B General tasks expected of operators of instrumentation systems can be summed up (1) from an operations standpoint as learning and constant attention to what constitutes normal function, and (2) from a maintenance standpoint, as ensuring proper and continuing protection and care of each component.

Answers to questions on page 378.

19.4C Three signs that a flow recorder may not be functioning properly are:

1. Very flat or steady pen trace (is the system working at all, or is the variable really that constant?);
2. Excessive pen/pointer quiver (causes undue wear on parts, can usually be adjusted out); and
3. Constant or periodic hunting, or spikes, in a pen/pointer (improper adjustment, control or other problem).

19.4D Recording pens are most likely to become stuck or "hung-up" on the chart edge or in a tear or hole.

19.4E A common reason for nonoperation of a pneumatic system is the failure of the instrument air supply caused by water and oil.

19.4F An indication of a serious problem in an electrical instrument or power cicuit is the presence of smoke and/or a burning odor.

Answers to questions on page 379.

19.4G Moisture can be controlled in instruments by a space-heat source (such as a power transformer) or by inserting a container of desiccant into its case.

19.4H Pneumatic instrumentation should be purged with dry air before shutdown to rid the individual parts of residual oil and moisture and to minimize internal corrosion.

Answers to questions on page 379.

19.4I Regular preventive maintenance duties should be printed on forms or cards for use by operators as a reminder, guide and record of preventive maintenance.

19.4J Operational checks are performed by always observing each system for its continuing signs of normal operation, and cycling some indicators by certain testing methods.

19.4K If a recorder trace is altered from its usual pattern during the process of checking an instrument, the operator causing the upset should initial the chart appropriately, with the time noted.

Answers to questions on page 380.

19.4L To obtain a technical manual for an instrument, write to the manufacturer. Be sure to provide all relevant serial/model numbers in your request to the manufacturer for a manual.

19.4M Instrument supplies and spare parts that should always be available include charts, pens, pen cleaners and ink, and any other parts necessary for instrument operation or service.

OBJECTIVE TEST

Chapter 19. INSTRUMENTATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Accuracy of an instrument relates to the closeness of a measurement to the actual value.
   1. True
   2. False

2. A digital readout display provides a direct, numerical reading.
   1. True
   2. False

3. A motor control station provides for the on-off operation of an electric motor.
   1. True
   2. False

4. The pressing down of a relay armature within an electrical panel may cause an electrical "explosion" to shower you with molten metal.
   1. True
   2. False

5. A danger may exist around powered mechanical equipment even when the exposed rotating or meshing elements have "guards" fitted in compliance with safety regulations.
   1. True
   2. False

6. Power tools are often used to calibrate instruments.
   1. True
   2. False

7. Falls are a leading cause of lost-time accidents.
   1. True
   2. False

8. A measured variable is that quantity which is sensed and quantified by a primary element or sensor.
   1. True
   2. False

9. Pressure is sensed by mechanically immovable elements.
   1. True
   2. False

10. Use of a bubbler tube is a very precise method of measuring water levels.
    1. True
    2. False

11. When propeller meters become old, they become susceptible to over registration (read high).
    1. True
    2. False

12. The permanent pressure loss through a venturi meter is greater than through an orifice plate.
    1. True
    2. False

13. Pneumatic signal systems are commonly used over very long distances.
    1. True
    2. False

14. Operators may safely rely solely upon the readings of instruments to ensure proper plant operation.
    1. True
    2. False

15. Alarms are visual and/or audible signals that a variable is out of bounds.
    1. True
    2. False

16. Several different tone signals can be sent over the same pair of phone lines.
    1. True
    2. False

17. A remote sensing and control station can send tone signals to the water plant and simultaneously receive tone signals to effect control at the site over the same lines.
    1. True
    2. False

18. "Pneumatics" may operate for many years without significant problems if they have a quality air supply.
    1. True
    2. False

19. "Plant air" must be filtered and dried, as with "instrument air."
    1. True
    2. False

20. If a gentle tap on an instrument causes a slight pen movement, the instrument is functioning properly.
    1. True
    2. False

MULTIPLE CHOICE

21. Objectives of this chapter include how to
    1. Determine location and cause of measurement and control system failures.
    2. Dismantle an automatic controller and repair it.
    3. Safely enter a vault without any ventilation system.
    4. Test an electrical circuit with a screwdriver.
    5. Use power tools in wet environments.

22. Operators should be able to
    1. Drain an air line.
    2. Free a stuck pen.
    3. Repair a turbidimeter.
    4. Replace a fuse.
    5. Restore proper control of a controller.

23. ______ refers to how closely an instrument measures the actual value of the process variable being measured.
    1. Accuracy
    2. Calibration
    3. Precision
    4. Repeatability
    5. Standardization

24. Examples of proportional control encountered by waterworks operators include
    1. Chemical feed, flow paced.
    2. Chlorine residual analyzer/controller.
    3. Continuous level control of filter basins.
    4. Flow regulating valves
    5. Pressure regulating valves.

25. ______ is the circulating action between the sensor which measures a process variable and the controller which controls or adjusts the process variable.
    1. Control loop
    2. Control system
    3. Feedback
    4. Linearity
    5. Telemetry

26 Which of the following items are safety provisions that may be used on electrical equipment?
    1. Insulating covers
    2. Lockouts
    3. Safety switches
    4. Torque ratings
    5. Warning labels

27. When working on instruments while standing on a ladder, you should
    1. Carry tools on an electrician's belt.
    2. Leave tools on the ladder steps when not working.
    3. Use a non-conductive type of ladder.
    4. Wear a hard hat.
    5. Wear thin rubber or plastic gloves.

28. Pressure is measured or sensed by
    1. Bourdon tubes.
    2. Bellows.
    3. Diaphragms.
    4. Pistons.
    5. Propellers.

29. ______ are used to measure the level of water.
    1. Bubblers
    2. Displacers
    3. Electrical probes
    4. Floats
    5. Stilling wells

30. Velocity may be sensed ______.
    1. Chemically
    2. Electrically
    3. Hydraulically
    4. Mechanically
    5. Naturally

31. Flow measuring devices include
    1. Impellers.
    2. Orifice plates.
    3. Propellers.
    4. Rotameters.
    5. Venturis.

32. Which of the following process variables are usually monitored continuously by instrumentation in a modern water treatment plant?
    1. Chlorine residual
    2. Coliforms
    3. Iron and manganese
    4. pH
    5. Turbidity

33. Advantages of digital panel indicators include
    1. Cheaper than analog.
    2. Erroneous values easily recognized.
    3. Quickly read.
    4. Respond virtually instantly to variable change.
    5. Rugged.

34. Causes of electronic instrument problems include
    1. Dirty instrument air.
    2. Excessive heat.
    3. Temporary power failure.
    4. Tripped panel circuit breakers.
    5. Voltage surges.

35. Controls available to protect pumps from damage include
    1. High-pressure cut-off switches.
    2. Lock-out switches.
    3. Low-pressure cut-off switches.
    4. Sensors that detect open or closed signal circuits.
    5. Warning tags.

36. Reliable operation of pneumatic instrumentation pressure system requires
    1. Clean air.
    2. Dry air.
    3. Pressurized air.
    4. Properly lubricated air.
    5. Uninterrupted power.

37. Essential parts of a plant's instrument air supply system include
    1. Air filters.
    2. Air dryers.
    3. Compressors.
    4. Compressor controls.
    5. Master air pressure regulators.

38. Erratic performance by pneumatic instruments may be caused by
    1. Carbon dioxide in the air supply.
    2. Excessive temperature of air supply.
    3. Oil in air supply.
    4. Over-pressurized air supply.
    5. Water in air supply.

39. An operator should be alert for which of the pen movements that could indicate a potential problem?
    1. Constant hunting
    2. Periodic spikes
    3. Quivering pen movement
    4. Similar cycles
    5. Very flat pen trace

40. Recording pens may get stuck on or in
    1. Chart edges.
    2. Chart ends.
    3. Holes.
    4. Ink.
    5. Tears.

End of Objective Test

CHAPTER 20

SAFETY

by

Joe Monscvitz

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Chapter 20. Safety

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OBJECTIVES

Chapter 20. Safety

Following completion of Chapter 20, you should be able to:

1. List the responsibilities of all persons and agencies involved in waterworks safety,
2. Identify and safely handle hazardous chemicals,
3. Recognize fire hazards and properly extinguish various types of fires,
4. Safely maintain waterworks equipment and facilities,
5. Properly operate and maintain vehicles,
6. Recognize electrical hazards,
7. Safely perform duties in a laboratory, and
8. Protect other operators and yourself while working in and around waterworks facilities.

GLOSSARY

Chapter 20. SAFETY

DECIBEL (DES-uh-bull) DECIBEL

A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average level at which sound causes pain to humans.

OLFACTORY FATIGUE (ol-FAK-tore-ee) OLFACTORY FATIGUE

A condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor.

OSHA OSHA

The Williams-Steiger Occupational Safety and Health Act of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

TAILGATE SAFETY MEETING TAILGATE SAFETY MEETING

The term *TAILGATE* comes from the safety meetings regularly held by the construction industry around the tailgate of a truck.

CHAPTER 20. SAFETY

(Lesson 1 of 4 Lessons)

20.0 RESPONSIBILITIES

20.00 Everyone Is Responsible for Safety

Waterworks utilities, regardless of size, must have a safety program if they are to realize a low frequency of accident occurrence. A safety program also provides a means of comparing frequency, disability and severity with other utilities. The utility should identify causes, provide training, have means of reporting, and hold supervisors responsible for the program implementation. Each utility should have a safety officer or supervisor evaluate every accident, offer recommendations, and keep and apply statistics. The effectiveness of any safety program will depend upon how the utility holds its supervisors responsible. If the utility holds only the safety officer or the employees responsible, the program will fail. The supervisors are key in any organization. If they disregard safety measures, essential parts of the program will not work. The results will be an overall poor safety record. After all, the first line supervisor is where the work is being performed, and some may take advantage of an unsafe situation in order to get the job completed. The organization must discipline such supervisors and make them aware of their responsibility for their own and their operators' safety.

Safety is good business both for the operator and the agency. For a good safety record to be accomplished, all individuals must be educated and must believe in the program. All individuals involved must have the conviction that accidents can be prevented. The operations should be studied to determine the safe way of performing each job. Safety pays, both in monetary savings and in happiness of the operating staff.

20.01 Regulatory Agencies

There are many state and federal agencies involved in ensuring safe working conditions. The one law that has had the greatest impact has been the Occupational Safety and Health Act of 1970 (OSHA), Public Law 91-596, which took effect on December 29, 1970. This legislation affects more than 75,000,000 employees and has been the basis for most of the current state laws covering employees. Also, many state regulatory agencies enforce the OSHA requirements.

The OSHA regulations provide for safety inspections, penalties, recordkeeping and variances. Supervisors must understand the OSHA Act and must furnish each operator with the rules of conduct in order to comply with occupational safety and health standards. The intent of the regulations is to create a place of employment which is free from recognized hazards that could cause serious physical harm or death to an operator.

Civil and criminal penalties are allowed under the OSHA Law, depending upon the size of the business and the seriousness of the violation. A routine violation could cost an employer or supervisor up to $1,000 for each violation. A serious, willful or repeated violation could cause the employer or supervisor to be assessed a penalty of not more than $10,000 for each violation. Penalties are assessed against the supervisor responsible for the injured operator. Operators should become familiar with the OSHA regulations as they apply to their organizations. They must correct violations and prevent others from occurring.

20.02 Utilities

Water utilities must make safety a part of management's responsibility. Each utility should start and maintain a safety program by holding its supervisors responsible for the effectiveness of the program. The utilities must have a reporting system to keep records; they may be required to submit reports to state and federal agencies. Even if the utility does not submit reports to other agencies, it should keep and review such reports on its own, as a means of reducing hazards to the operators.

Each utility should develop policy statements on safety, giving its objective concerning the operator's welfare (Table 20.1). The statement should be brief, but express the utility's recognition of the need for safety to stimulate efficiency, improve service, improve morale and to maintain good public relations. The policy should recognize the human factor (the unsafe act) as the most significant cause of accidents, and thereby emphasize the operator's responsibility to perform the job safely. The policy should be one of providing the operators with proper equipment and safe working conditions. Finally, it is essential that the policy reinforce the supervisory responsibility to maintain safe work practices

This policy statement should be made by every utility regardless of size. The statement should be written and given to each operator and all other employees and reinforced by the supervisory staff. Without such an objective, the utility cannot hope to gain the loyalty and respect of its operators, nor can it achieve efficient plant operation. The utility must hold everyone responsible for safety and designate a specific individual to be responsible for an active, ongoing safety program.

TABLE 20.1 SAFETY POLICY STATEMENT

LAS VEGAS VALLEY WATER DISTRICT
SAFETY STATEMENT WORK RULE #920

The District recognizes its responsibility for providing the safest working conditions for its employees and customers. This responsibility is met by means of a safety program which will be applied through the development of safety awareness among the employees, the use of up-to-date safety equipment, and the continual inspection of conditions and practices by all levels of supervision.

It is the responsibility of every employee to develop safe working habits. The development of proper attitudes toward safety is the only method to improve safe working habits. Therefore, training sessions play a large part in the safety program. The District wants to protect all employees and the public from injury and accidents. To accomplish this goal, the safety program will involve everyone, and it will require the active participation and cooperation of all to make it operate effectively.

Safety training sessions are conducted for all District employees and employees are expected to perform in a safe manner Negligent or unsafe conduct by an employee will subject the employee to disciplinary action.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 438.

20.0A What should be the duties of a safety officer?

20.0B Who should be responsible for the implementation of a safety program?

20.0C Who enforces the OSHA requirements?

20.0D What should be included in a utility's policy statement on safety?

20.03 Supervisors

The success of any safety program will depend upon how the supervisors of the utility view their responsibility. The supervisor who has the responsibility for directing work activities must be safety conscious. This supervisor controls the operators' general environment and work habits and influences whether or not the operators comply with safety regulations. The supervisor is in the best position to counsel, instruct and review the operators' working methods and thereby effectively ensure compliance with all aspects of the utility's safety program.

The problem, however, is one of the supervisor accepting this responsibility. The supervisor who wishes to complete the job and go on to the next one without taking time to be concerned about working conditions, the welfare of operators, or considering any aspects of safety is a poor supervisor. Only after an accident occurs will a careless supervisor question the need for a work program based on safety. At this point, however, it is too late, and the supervisor may be tempted to simply cover up past mistakes. As sometimes happens, the supervisor may even be partially or fully responsible for the accident by causing unsafe acts to take place, by requiring work to be performed in haste, by disregarding an unsafe work environment or by overlooking or failing to consider any number of safety hazards. This negligent supervisor could be fined, sentenced to a jail term, or even be barred from working in the profession.

All utilities should make their supervisors bear the greatest responsibility for safety and hold them accountable for planning, implementing and controlling the safety program. If most accidents are caused and do not just happen, then it is the supervisor who can help prevent most accidents.

Equally important are the officials above the supervisor. These officials include commissioners, managers, public works directors, chief engineers, superintendents and chief operators. The person in responsible charge for the entire agency or operation must believe in the safety program. This person must budget, promote, support and enforce the safety program by vocal and visible examples and actions. The top person's support is absolutely essential for an effective safety program.

20.04 Operators

Each operator also shares in the responsibility for an effective safety program. After all, operators have the most to gain since they are the most likely victims of accidents. A review of accident causes shows that the accident victim often has not acted responsibly. In some way the victim has not complied with the safety regulations, has not been fully aware of the working conditions, has not been concerned about fellow employees, or just has not accepted any responsibility for the utility's safety program.

Each operator must accept, at least in part, responsibility for fellow operators, for the utility's equipment, for the operator's own welfare, and even for seeing that the supervisor complies with established safety regulations. As pointed out above, the operator has the most to gain. If the operator accepts and uses unsafe equipment, it is the operator who is in danger if something goes wrong. If the operator fails to protect the other operators, it is the operator who must make up the work lost because of injury. If operators fail to consider their own welfare, it is they who suffer the pain of any injury, the loss of income, and maybe even the loss of life.

The operator must accept responsibility for an active role in the safety program by becoming aware of the utility's safety policy and conforming to established regulations *THE OPERATOR SHOULD ALWAYS CALL TO THE SUPERVISOR'S ATTENTION UNSAFE CONDITIONS*, environment, equipment or other concerns operators may have about the work they are performing. Safety should be an essential part of the operator's responsibility.

20.05 First Aid

By definition, first aid means emergency treatment for injury or sudden illness, before regular medical treatment is available. Everyone in an organization should be able to give some degree of prompt treatment and attention to an injury.

First aid training in the basic principles and practices of life-saving steps that can be taken in the early stages of an injury are available through the local Red Cross, Heart Association, local fire departments and other organizations. Such training should periodically be reinforced, so that the operator has a complete understanding of water safety, cardio-pulmonary resuscitation (CPR) and other life-saving techniques. All operators need training in first aid, but it is especially important for those who regularly work with electrical equipment or must handle chlorine and other dangerous chemicals.

First aid has little to do with preventing accidents, but it has an important bearing upon the survival of the injured patient. A well-equipped first aid chest or kit is essential for proper treatment. The kit should be inspected regularly by the safety officer to assure that supplies are available when needed. First aid kits should be prominently displayed throughout the treatment plant and in company vehicles. Special consideration must be given to the most hazardous areas of the plant such as shops, laboratories, and chemical handling facilities.

Regardless of size, each utility should establish standard operating procedures (SOP) for first aid treatment of injured personnel. All new operators should be instructed in the utility's first aid program.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 438.

20.0E How could a supervisor be responsible for an accident?

20.0F What types of safety-related responsibilities must each operator accept?

20.0G What is first aid?

20.0H First aid training is most important for operators involved in what types of activities?

20.06 Reporting

The mainstay of a safety program is the method of reporting and keeping of statistics. These records are needed regardless of size of the utility, as they provide a means of identifying accident frequencies and causes as well as the personnel involved. The records can be looked upon as the operator's safety report card. Therefore, it becomes the responsibility of each injured operator to fill out the utility's accident report.

All injuries should be reported, even if they are minor in nature, so as to establish a record in case the injury develops into a serious injury, it may be difficult at a later date to prove the accident did occur on the job and have the utility accept the responsibility for costs. The responsibility for reporting accidents affects several levels of personnel. First, of course, is the injured person. Next, it is the responsibility of the supervisor, and finally, the

Responsibility of Management to review the causes and take steps to prevent such accidents from happening in the future.

Accident report forms may be very simple. However, they must record all details required by law and all data needed for statistical purposes. The forms shown here in Figures 20.1 and 20.2 are examples for you to consider for use in your plant. The report must show the name of the injured, employee number, division, time of accident, nature of injury, cause of accident, first aid administered, and remarks for items not covered elsewhere. There should be a review process by foreman, supervisor, safety officer, and management. *RECOMMENDATIONS ARE NEEDED AS WELL AS A FOLLOW-UP REVIEW TO BE SURE THAT PROPER ACTION HAS BEEN TAKEN TO PREVENT RECURRENCE.* In addition to reports needed by the utility, there are other reports that may be required by state or federal agencies. For example, vehicle accident reports must be submitted to local police departments. If a member of the public is injured, additional forms are needed because of possible subsequent claims for damages. If the accident is one of occupational injury, causing lost time, other reports may be required. Follow-up investigations to identify causes and responsibility may require the development of other specific types of record forms.

In the preparation of accident reports, it is the operator's responsibility to correctly fill out each form, giving complete details. The supervisor must be sure no information is overlooked which may be helpful in preventing recurrence.

The Safety Officer must review the reports and determine corrective actions and make recommendations.

In day-to-day actions, operators, supervisors and management often overlook opportunities to counsel individual operators in safety matters. Then, when an accident occurs, they are not inclined to look too closely at accident reports. First, the accident is a series of embarrassments, to the injured person, to the supervisor and to management. Therefore, there is a reluctance to give detailed consideration to accident reports. However, if a safety program is to function well, it will require a thorough effort on the part of the operator, supervisor and management in accepting their responsibility for the accident and making a greater effort through good reporting to prevent future similar accidents. Accident reports must be analyzed, discussed, and the real cause of the accident identified and corrected.

Emphasis on the prevention of future accidents cannot be overstressed. We must identify the causes of accidents and implement whatever measures are necessary to protect operators from becoming injured.

Date ____________

Name of injured employee ____________ Employee # ________ Area ________

Date of accident ________ Time ______ Employee's Occupation ________

Location of accident ____________ Nature of injury ____________

Name of doctor ____________ Address ____________

Name of hospital ____________ Address ____________

Witnesses (name & address) ____________

PHYSICAL CAUSES

Indicate below by an "X" whether in your opinion, the accident was caused by:

___ Improper guarding
___ Defective substances or equipment
___ Hazardous arrangement
___ Improper illumination
___ Improper dress or apparel
___ No mechanical cause
___ Working methods
___ Lack of knowledge or skill
___ Wrong attitude
___ Physical defect
___
___
___ Not listed (describe briefly) ____________

UNSAFE ACTS

Sometimes the injured person is not directly associated with the causes of an accident. Using an "X" to represent the injured worker and an "O" to represent any other person involved, indicate whether, in your opinion, the accident was caused by:

___ Operating without authority
___ Failure to secure or warn
___ Working at unsafe speed
___ Make safety device inoperative
___ Unsafe equipment or hands instead of equip.
___ No unsafe act
___ Unsafe loading, placement & etc.
___ Took unsafe position
___ Worked on moving equipment
___ Teased, abused, distracted & etc.
___ Did not use safe clothing or personal protective equipment.
___ Not listed (describe briefly) ____________

What job was the employee doing? ____________

What specific action caused the accident? ____________

What steps will be taken to prevent recurrence? ____________

Date of Report ________ Immediate Supervisor ____________

REVIEWING AUTHORITY

Comments: ____________ Safety Officer	Comments: ____________ Department Director Date

Fig. 20.1 Supervisor's accident report

INJURED: COMPLETE THIS SECTION

Name ______ Age ______ Sex ______

Address ______ Marital Status ______

Title ______ Dept Assigned ______

Place of Accident ______

Street or Intersection ______

Date ______ Hour ______ A.M. ______ P.M. ______

Type of Job You Were Doing When Injured

Object Which Directly Injured You

Part of Body Injured

How Did Accident Happen? (Be specific and give details; use back of sheet if necessary).

Did You Report Accident or Exposure at Once? (Explain "No")	Yes ☐ No ☐
Did You Report Accident or Exposure to Supervisor? Give Name	Yes ☐ No ☐
Were There Witnesses to Accident or Exposure? Give Names	Yes ☐ No ☐
Did You See a Doctor? (If Yes, Give Name) ______	Yes ☐ No ☐
Are You Going to See a Doctor? (Give Name) ______	Yes ☐ No ☐

Date ______ Signature ______

SUPERVISOR: COMPLETE THIS SECTION — (Return to Personnel as soon as Possible)

Was an Investigation of Unsafe Conditions and/or Unsafe Acts Made? If Yes, Please Submit Copy.	Yes ☐ No ☐
Was Injured Intoxicated or Misconducting Himself at Time of Accident? (Explain "Yes")	Yes ☐ No ☐

Date Disability Commenced ______ Last Day Wages Earned ______ Date Back on Job ______

Date Report Completed ______ 19___ Signed By ______

Title ______

Distribution - Canary - Department Head. Pink - Supervisor. White - Personnel

Fig. 20.2 Accident report

20.07 Training

If a safety program is to ever work well, management will have to accept responsibility for the following three components of training:

1. Safety education of all employees,
2. Reinforced education in safety, and
3. Safety education in the use of tools and equipment.

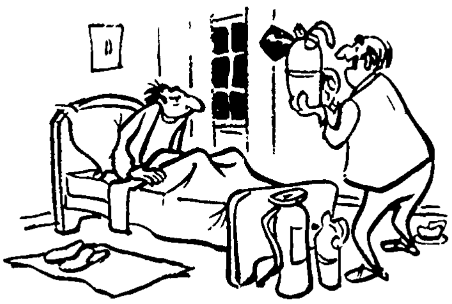
Or to put it another way, the three most important controlling factors in safety are education, education and education.

Responsibility for overall training must be that of upper management. A program that will educate operators and then reinforce this education in safety must be planned systematically and promoted on a continuous basis. There are many avenues to achieving this goal.

The safety education program should start with the new operator. Even before employment, verify the operator's past record and qualifications and review the pre-employment physical examination. In the new operator's orientation, include instruction in the importance of safety at your utility or plant. Also discuss the matter of proper reporting of accidents as well as the organization's policies and practices. Give new operators copies of all safety SOP's and direct their attention to parts that directly involve them. Ask the safety officer to give a talk about utility policy, safety reports and past accidents, and to orient the new operator toward the importance of safety to operators and to the organization.

The next consideration must be one of training the new operator in how to perform assigned work. Most supervisors think in terms of On-the-Job Training (OJT). However, OJT is not a good way of preventing accidents with an inexperienced operator. The idea is all right if the operator comes to the organization trained in how to perform the work, such as a treatment operator from another plant. Then you only need to explain your safety program and how your policies affect the new operator. For a new operator who is inexperienced in water treatment or in utility operation, the supervisor must give detailed consideration to the operator's welfare. In this instance, the training should include not only a safety talk, but the foreman (supervisor) must train the inexperienced operator in all aspects of treatment plant safety. This training includes instruction in the handling of chemicals, the dangers of electrical apparatus, fire hazards, and proper maintenance of equipment to prevent accidents. Special instructions will also be needed for specific work environments such as manholes, gases (chlorine and hydrogen sulfide (H_2S)), water safety, and any specific hazards that are unique to your facility. The new operator must be checked out on any equipment personnel may operate such as vehicles, forklifts, valve operators, and radios. All new operators should be subjected to a safety orientation program during the first few days of their employment, and an overall training program in the first few months.

The next step in safety education is reinforcement. Even if the operator is well trained, mistakes can occur; therefore, the education must be continual. Many organizations use the "tailgate" method as a means of maintaining the operator's interest in safety. The program should be conducted by the first line supervisor. Schedule the informal tailgate meeting for a suitable location, keep it short, avoid distractions and be sure that everyone can hear. Hand out literature, if available. Tailgate talks should communicate to the operator specific considerations, new problems, and accident information. These topics should be published. One resource for such meetings can be those operators who have been involved in an accident. Although it is sometimes embarrassing to the injured, the victim is now the expert on how the accident occurred, what could have been done to prevent it, and how it felt to have the injury. Encourage all operators, new and old, to participate in tailgate safety sessions.



Use safety posters to reinforce safety training and to make operators aware of the location of dangerous areas or show the importance of good work habits. Such posters are available through the National Safety Council's catalog.[1] Awards for good safety records are another means of keeping operators aware of the importance of safety. The awards could be given to individuals in recognition of a good safety record. Publicity about the awards may provide an incentive to the operators and demonstrates the organization's determination to maintain a good safety record. The awards may include: AWWA's water drop pins, certificates, and/or plaques showing number of years without an accident. Consider publishing a utility newsletter on safety tips or giving details concerning accidents that may be helpful to other operators in the organization. Awards may be given to the organization in recognition of its effort in preventing accidents or for its overall safety program. A suggestion program concerning safety will promote and reinforce the program and give recognition to the best suggestions. The goal of all these efforts is to reinforce concerns for the safety of all operators. If safety, as an idea, is present, then accidents can be prevented.

Education of the operator in the use of tools and equipment is necessary. As pointed out above, OJT is not the answer to a good safety record. A good safety record will be achieved only with good work habits and safe equipment. If the operator is trained in the proper use of equipment (hand tools or vehicles), the operator is less likely to misuse them. However, if the supervisor finds an operator misusing tools or equipment, then it is the supervisor's responsibility to reprimand the operator as a means of reinforcing utility policies. The careless operator who misuses equipment is a hazard to other operators. Careless operators will also be the cause of a poor safety record in the operator's division or department.

An important part of every job should be the consideration of its safety aspects by the supervisor. The supervisor should instruct the foreman or operators about any dangers involved in job assignments. If a job is particularly dangerous, then the supervisor must bring that fact to everyone's attention and clarify utility policy in regard to unsafe acts and conditions.

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[1] *Write or call your local safety council or National Safety Council, 444 N. Michigan Avenue, Chicago, Illinois 60611, phone toll free "hot line" (800) 621-8051 (not applicable within Illinois).*

If the operator is unsure of how to perform a job, then it is the operator's responsibility to ask for the training needed. Each operator must think, act, and promote safety if the organization is to achieve a good safety record Training is the key to achieving this objective and training is everyone's responsibility — management, the supervisors, foremen and operators

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 438.

20.0I What is the mainstay of a safety program?

20.0J Why should you report even a minor injury?

20.0K Why should a safety officer review an accident report form?

20.0L A new inexperienced operator must receive instruction on what aspects of treatment plant safety?

20.0M What should an operator do if unsure of how to perform a job?

20.08 Measuring

To be complete, a safety program must also include some means of identifying, measuring and analyzing the effects of the program. The systematic classification of accidents, injuries, and lost time is the responsibility of the safety officer This person should use an analytical method which would refer to types and classes of accidents. Reports should be prepared using statistics showing lost time, costs, type of injuries and other data based on a specific time interval. Such data calls attention to the effectiveness of the program and promotes awareness of the types of accidents that are happening. Management can use this information to decide where the emphasis should be placed to avoid accidents. However, statistical data are of little value if a report is prepared and then set on the bookshelf or placed in a supervisor's desk drawer. The data must be distributed and read by all operating and maintenance personnel

As an example, injuries can be classified as fractures, burns, bites, eye injuries, cuts and bruises. Causes can be referred to as heat, machinery, falling, handling, chemicals, unsafe acts, and miscellaneous. Cost can be considered as lost time, lost dollars, lost production, contaminated water or any other means of showing the effects of the accidents.

Good analytical reporting will provide a great deal of detail without a lot of paper to read and comprehend. Keep the method of reporting simple and easy to understand by all operators, so they can identify with the causes and be aware of how to prevent the accident happening to themselves and/or other operators. Table 20.2 gives one method of showing injury and cause in terms of operator-days lost.

TABLE 20.2 SUMMARY OF TYPES AND CAUSES OF INJURIES

	CAUSE OF INJURY										
Type of Injury	Unsafe Act	Chemical	Falls	Handling Objects	Heat	Machinery	Falling Objects	Stepping	Striking	Miscellaneous	TOTAL
Lacerations											
Sprains											
Eye Injuries											
Bites											
Cuts											
Bruises											
Contusions											
Miscellaneous											

There are many other methods of analyzing data. Table 20.2 could be rearranged by using cost in dollars rather than operator-days lost. Not all accidents mean time lost, but there can be other cost factors. The data analysis should also indicate if the accidents involve vehicles, company personnel, the public, company equipment, loss of chemical, or other factors. Results also should show direct cost and indirect cost to the agency, operator and the public.

Once the statistical data have been compiled, someone must be responsible for reviewing it in order to take preventive actions. Frequently such responsibility rests with the safety committee. In fact, safety committees may operate at several levels, for example management committee, working committee, or an accident review board. In any event, the committee must be active, be serious and be reinforced by management.

Another means of measuring safety is by calculating the injury frequency rate for an indication of the effectiveness of your safety program. Multiply the number of disabling injuries by one million and divide by the total number of employee-hours worked. The number of injuries per year is multiplied by one million in order to obtain injury frequency rate values or numbers which are easy to use. In our example problems we obtained numbers between one and one thousand.

$$\text{Injury Frequency Rate} = \frac{(\text{Number of Disabling Injuries/year})(1{,}000{,}000)}{\text{Number of Hours Worked/year}}$$

These calculations indicate a frequency rate per year, which is the usual means of showing such data. Not that this calculation accounts only for disabling injuries. You may wish to show all injuries, but the calculations are much the same.

EXAMPLE 1

A rural water company employs 36 operators who work in many small towns throughout a three-state area. The operators suffered four injuries in one year while working 74,880 hours. Calculate the injury frequency rate.

Known		Unknown
Number of Operators	= 36	Injury Frequency Rate
Number of Injuries	= 4/yr	
Number of Hours Worked	= 74,880 yr	

Calculate the injury frequency rate.

$$\text{Injury Frequency Rate} = \frac{(\text{Number of Disabling Injuries/year})\,(1{,}000{,}000)}{\text{Number of Hours Worked/year}}$$

$$= \frac{(4/\text{yr})\,(1{,}000{,}000)}{74{,}880/\text{yr}}$$

$$= 53\ 4$$

EXAMPLE 2

Of the four injuries suffered by the operators in Example 1, one was a disabling injury. Calculate the injury frequency rate for the disabling injuries.

Known		Unknown
Number of Disabling Injuries	= 1 yr	Injury Frequency Rate
Number of Hours Worked	= 74,880 yr	

Calculate the injury frequency rate.

$$\underset{\text{(Disabling Injuries)}}{\text{Injury Frequency Rate}} = \frac{(\text{Number of Disabling Injuries/yr})\,(1{,}000{,}000)}{\text{Number of Hours Worked/yr}}$$

$$= \frac{(1/\text{yr})\,(1{,}000{,}000)}{74{,}880/\text{yr}}$$

$$= 13\ 4$$

Yet another consideration may be lost-time accidents. The safety officer's analysis may take into account many other considerations, but in any event, the method given here will provide a means of recording and measuring injuries in the treatment plant. In measuring lost-time injuries, a severity rate can be considered.

A severity rate is based on one lost hour for every million operator-hours worked. The rate is found by multiplying the number of hours lost by one million and dividing by the total number of operator-hours worked.

$$\text{Injury Severity Rate} = \frac{(\text{Number of Hours Lost/yr})\,(1{,}000{,}000)}{\text{Number of Hours Worked/yr}}$$

EXAMPLE 3

The water company described in Examples 1 and 2 experienced 40 operator-hours lost due to injuries while the operators worked 74,880 hours. Calculate the injury severity rate

Known		Unknown
Number of Hours Lost	= 40 hrs/yr	Injury Severity Rate
Number of Hours Worked	= 74,880 hrs/yr	

Calculate the injury severity rate.

$$\text{Injury Severity Rate} = \frac{(\text{Number of Hours Lost/yr})\,(1{,}000{,}000)}{\text{Number of Hours Worked/yr}}$$

$$= \frac{(40\ \text{hrs/yr})\,(1{,}000{,}000)}{74{,}880\ \text{hrs/yr}}$$

$$= 534$$

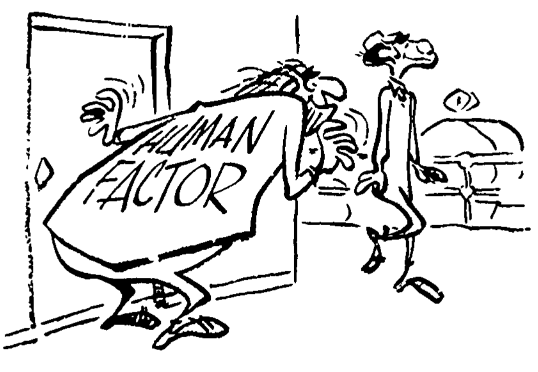
Notice that all these data points are based on a one year time interval which makes them suitable for use by the safety officer in preparing an annual report

20.09 Human Factors

First, you may ask, what is a human factor? Well, it is not too often that a safety text considers human factors as part of the safety program. However, if these factors are understood and emphasis is given to their practical application, then many accidents can be prevented. Human Factors Engineering is the specialized study of technology relating to the design of operator-machine interface. That is to say, it examines ways in which machinery might be designed or altered to make it easier to use, safer, and more efficient for the operator. We hear a lot about making computers more user friendly, but human factor engineering is just as important to everyday operation of other machinery in the everyday plant.

Many accidents occur because the operator forgets the human factors. The ultimate responsibility for accidents due to human factors belongs to the management group. However, this does not relieve the operator of the responsibility to point out the human factors as they relate to safety. After all, it is the operator using the equipment who can best tell if it meets all the needs for an inter-relationship between operator and machine.

The first step in the prevention of accidents takes place in the plant design. Even with excellent designs, accidents can and do happen. However, every step possible must be taken during design to assure a maximum effort of providing a safe plant environment. Most often the operator has little to do with design, and therefore needs to understand human factors engineering so as to be able to evaluate these factors as the plant is being operated. As newer plants become automated, this type of understanding may even be more important.



Other contributing human factors are the operator's mental and physical characteristics. The operator's decision-making abilities and general behavior (response time, sense of alarm, and perception of problems and danger) are all important factors. Ideally, tools and machines should function as intuitive extensions of the operator's natural senses and actions. Any factors disrupting this flow of action can cause an accident. Therefore, be on the lookout for such factors. When you find a system that cannot be acted upon by inspection, change it. You may prevent an accident. If the everyday behavior of an operator is inappropriate with regard to a specific job, reconsider the assignment to prevent an accident.

The human factor in safety is the responsibility of design engineers, supervisors and operators. However, the operator who is doing the work will have a greater understanding of the operator-machine interface. For this reason, the operator is the appropriate person to evaluate the means of reducing the human factor's contribution to the cause of accidents, thereby improving the plant's safety record.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 438.

20.0N Statistical accident reports should contain what types of accident data?

20.0O How can injuries be classified?

20.0P How can causes of injuries be classified?

20.0Q How can costs of accidents be classified?

End of Lesson 1 of 4 Lessons
on
SAFETY

DISCUSSION AND REVIEW QUESTIONS

Chapter 20. SAFETY

(Lesson 1 of 4 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. Why must waterworks utilities have a safety program?
2. How can a good safety record be accomplished?
3. What is the intent of the OSHA regulations?
4. Why should water utilities establish a reporting system that supplies data for a permanent record?
5. Why do operators have the most to gain from an effective safety program?
6. Who should review accident report forms?
7. What topics should be included in a safety officer's talk to new operators?
8. What are the purposes of "tailgate" talks?

Chapter 20. SAFETY

(Lesson 2 of 4 Lessons)

20.1 CHEMICAL HANDLING

20.10 Safe Handling of Chemicals

The water treatment plant operator handles a wide variety of chemicals depending on the type of plant. In a simple well system, chlorine may be the only chemical used. In more complicated plants, there may be chlorine, other gases, sulfuric acid, lime, alum, powdered activated carbon and anhydrous ammonia. All of these chemicals fall into groups: acids, hydroxides, gases, salts, organics and solvents. Each group requires you, the operator, to have a good understanding of all types of chemicals. You must know how to handle the many problems associated with each of these elements or compounds. For example, you must know how to store chemicals, understand the fire problem, the tendency to "arch"[2] in a storage bin, how to feed dry, how to feed liquid, and how to make up solutions. All of these factors and many more problems may cause an unsafe condition. Overheating gas containers, dust problems with powdered carbon, burns caused by acid, reactivity of each chemical under a variety of conditions that may cause fire and explosion are other safety hazards. You will need to know the usable limits because of toxicity, the protective equipment required for each chemical, each chemical's antidote, and how to control fires caused by each chemical. Although you may not regularly handle all of the chemicals listed here, you may come into contact with them from time to time. Try at least to learn all of the characteristics of the chemicals you will use regularly. For example, learn the boiling point, explosive limits, reactivity, flammability, first aid used for each chemical, and other characteristics that may prove helpful in preventing a safety hazard. Study the chemistry of each chemical used in the plant in order to have a safe plant in which to work. In the following discussions we shall concentrate on the characteristics of each compound and point out its hazards, reactivity and the information needed to avoid conditions that may cause a safety problem.

20.11 Acids

Acids are used extensively in water treatment. For example, hydrofluoric acid in fluoride addition or hydrochloric acid in cleaning. Table 20.3 lists many of the acids used in water treatment and gives their characteristics. This quick reference gives you a guide for learning some of each acid's limitations and its reactivity with other compounds.

The antidote to all acids is neutralization. However, one must be careful in how this is peformed. Most often large amounts of water will serve the purpose, but if the acid is ingested (swallowed), then lime water or milk of magnesia may be needed. If vapors are inhaled, first aid usually consists of providing fresh air, artificially restoring breathing (CPR), or supplying oxygen. In general, acids are neutralized by a base or alkaline substance. Baking soda is often used to neutralize acids on skin because it is not harmful on contact with your skin. To understand these reactions, you will need to know some acid-base chemistry. The knowledge of acid-base chemistry and fast reactions on your part may reduce the safety hazards involved in handling acids in water treatment.

20.110 Acetic Acid (Glacial)

This chemical is stable when stored and handled properly. However, it may react violently with certain compounds such as ammonium nitrate, potassium hydroxide and other alkaline materials. Strong oxidizing glacial acetic acid is a combustible material. Fires involving the acid may be extinguished with water, dry chemical or carbon dioxide. Under such conditions as adding water, the diluted acid may produce hydrogen gas when it comes in contact with metals. When the chemical is involved in a fire situation, self-contained breathing apparatus must be used to protect the

TABLE 20.3 ACIDS USED IN WATER TREATMENT

Name, Formula	Common Name	Available Forms	Specific Gravity	Flammability	Color	Odor	Containers
Acetic Acid, CH_3COOH	Ethanoic Acid	Solution	1.05	N/A	Clear	Sharp, pungent	Carboys, drums
Hydrofluosilicic, H_2SiF_6	Fluosilicic Acid	Solution	1.4634	N/A	Clear	Pungent fumes	Drums, trucks R.R. tank cars
Hydrogen Fluoride, HF	Hydrofluoric Acid	Liquid	0.987	N/A	Clear	Fumes, toxic	Drums, tank cars
Hydrochloric Acid, HCl	Muriatic Acid	Solution	1.16	N/A	Clear to Yellow	Pungent, suffocating	Drums, carboys
Nitric Acid, HNO_3	—	Liquid	1.5027	N/A	Colorless, yellowish	Toxic fumes in presence of light	Drums, carboys, bottles
Sulfuric Acid, H_2SO_4	Oil of Vitriol; Vitriol	Solution	(60-66° Bé) 1.841	N/A	Clear	Odorless	Bottles, carboys, drums, truck, tank cars

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[2] *Arch. To form a bridge or arch of hardened or caked chemical which will prevent the flow of the chemical.*

operator against suffocation and problems caused by corrosive vapors

Most people find inhalation of acetic acid vapors in concentrations over 50 ppm intolerable, resulting in nose and throat irritations. Repeated exposure to high concentrations may produce congestion of the larynx. Skin contact with concentrated acetic acid can produce deep burns, with skin destruction. High vapor concentration may blacken the skin and produce allergenic reactions and eye irritation. Possible permanent damage or immediate burns are caused to the eye if the acid comes into contact with the eye. If the acid is ingested, severe intestinal irritation will result as well as burns to the mouth and upper respiratory tract.

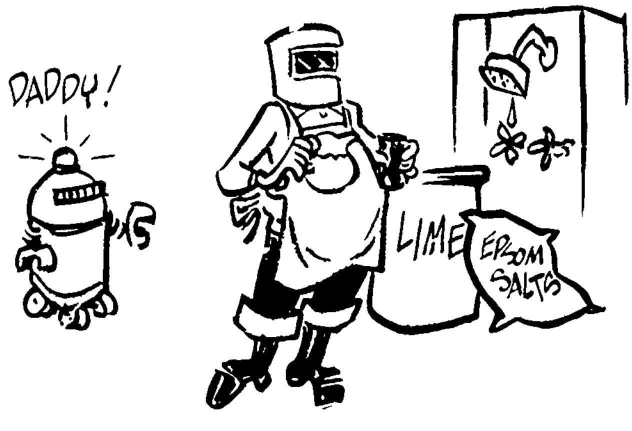
Operators should be protected by adequate exhaust facilities to ensure ventilation when working with acetic acid. At a minimum, exhaust hoods should have air velocity of 100 fpm (30 m/min). Wear rubber gloves and an apron to prevent skin contact. Wear splash-proof goggles or a face shield to prevent any eye contact. Gas-tight goggles may also be needed to prevent vapors from irritating your eyes. An eye wash station must be readily available where this chemical is being handled. Also, respiratory equipment should be available for emergency use Acetic acid can be handled safely by using adequate ventilation and safety equipment to prevent skin and eye contact. Remember also that acetic acid vapors can cause *OLFACTORY FATIGUE* (ol-FAK-tore-ee). This is a condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor. Acetic acid is detectable by your nose at 1 ppm, but documentation has shown operators tolerating up to 200 ppm.

If a leak or spill should occur, notify safety personnel and provide adequate ventilation. When cleaning up large spills, wear self-contained breathing apparatus and equipment to prevent contact with eyes and skin. To clean up spill areas and remove chemical residue, cover the area with sodium bicarbonate and flush away with an excess of water.

First aid for acetic acid exposure calls for removal of the victim to fresh air, rinsing the mouth and nasal passages with water and checking for inhalation problems. If the acid made contact with the eyes, immediately irrigate with water for at least 15 minutes. Obtain medical attention. For skin contact problems, wash with water immediately, if the acid was swallowed, give three glasses of milk or water and obtain medical attention quickly Acetic acid exposure, like all other acids, must be treated immediately to prevent damage to the victim.

20.111 Hydrofluosilicic Acid

This chemical is hazardous to handle under any conditions. Be extremely careful using this acid. The acid is colorless, transparent, fuming, corrosive and is a liquid. A pungent odor is created by the acid and contact causes skin irritation. When the acid vaporizes, it decomposes into hydrofluoric acid and silicon tetrafluoride. Hydrofluoric acid can attack glass. When handling the acid, always use complete protective equipment, rubber gloves, goggles or face shield, rubber apron, rubber boots and have lime slurry barrels, epsom salt solution and safety showers (Figure 20.3) available. Always provide adequate ventilation because its vapor can cause irritation to the respiratory system. Careful maintenance of protective equipment is essential because the fumes of the acid corrode or etch glass on the protective equipment.



First aid for eye contact is to thoroughly flush with water for 15 minutes and get medical aid as soon as possible. For skin contact, wash the affected areas with water For gross (large) contact, remove contaminated clothing under a safety shower and thoroughly wash entire body for 15 minutes or longer. In case of inhalation, remove operator to fresh air, restore breathing, if required, and get medical aid.

20.112 Hydrofluoric Acid

This acid is extremely poisonous, and produces terrible sores when allowed to come into contact with the skin. The acid is a clear, corrosive liquid that has a pungent odor. All of the precautions discussed for hydrofluosilicic acid apply to this acid also.

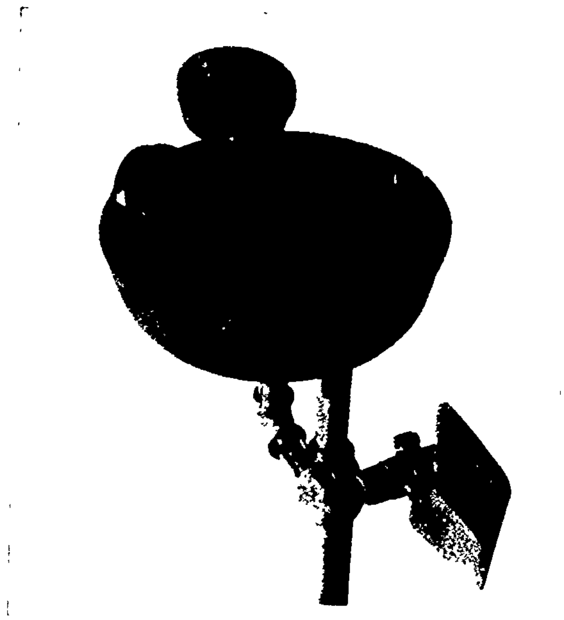
20.113 Hydrochloric Acid

This acid is used most often for cleaning in and around the treatment plant and is known as muriatic acid. The acid is also used very frequently in the laboratory. Hydrochloric acid is stable when properly contained and handled. This acid is one of the strong mineral acids and therefore, is highly reactive with metals and these oxides: hydrocarbon, amine, and carbonate compounds. The acid liberates significant levels of hydrogen chloride gas (HCl) because of its vapor pressure at room temperature and gives off large amounts of gas when heated. In reactions with most metals, hydrochloric acid will produce hydrogen gas.

Inhalation of HCl vapors or mists for long periods can cause damage to teeth and irritation to the nasal passages. Concentrations of 750 ppm or more will cause coughing, choking and produce severe damage of the mucous membranes of the respiratory tract. In concentrations of 1300 ppm, HCl is dangerous to life. Ingestion can cause burns of the mouth and digestive tract.

When handling HCl, provide adequate exhaust facilities to ensure ventilation and wear protective clothing and equipment to prevent body contact with the acid. Use rubber gloves, rubber apron, rubber boots and wear a long-sleeved shirt when handling hydrochloric acid To protect your eyes against splashing of the acid, you must wear safety goggles and/or a face shield. There should always be an eye wash station and safety shower located near areas where this acid is to be used.

First aid consists of thoroughly flushing the eyes with running water for 15 minutes and securing medical aid. If hydrochloric acid comes in contact with skin, wash the affected areas with water For gross contact remove clothing under the safety shower and continue showering for 15 minutes or longer. Should the acid be ingested, give lime

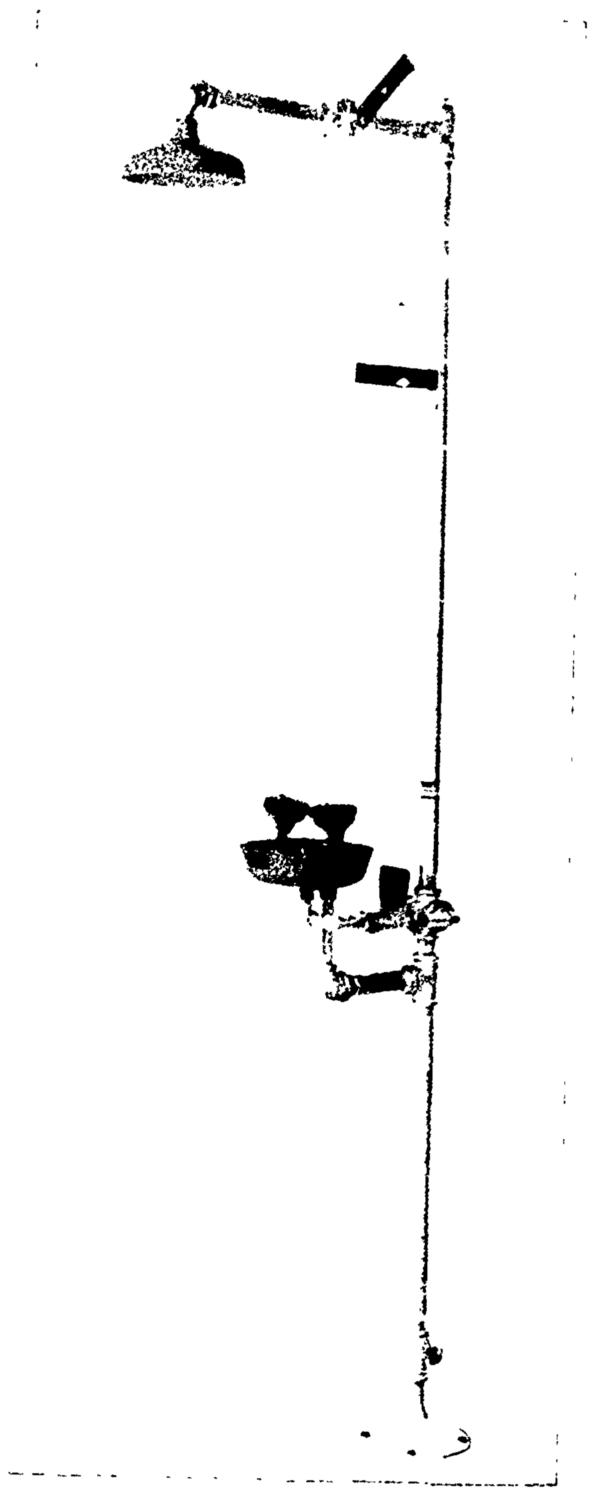


Model 01-0354-07—Face Wash. Yello-Bowl™, and Stainless Steel pipe and valve.

Specially Coated Corrosion-Proof Models
In addition to corrosion-resistant Stainless Steel, various coatings are available for protection against corrosive atmospheres at additional cost. The sprayed and baked epoxies as well as the new fluorocarbon coatings can be applied on all galvanized and stainless pipe and fittings. Specify type of coating required.

Plastic Models Available
All PVC plastic models for Face/Eye Washes as well as combination Shower-Face/Eye Wash assemblies. Ask your distributor for details.

Part #01-1128-06—
Shower and wash sign. Rugged plastic base, yellow and black contrast, 8" x 18".



Model 01-0502-19—Shower/Face Wash. Yello-Bowl™, Stainless Steel piping, fittings, and valves.

Fig. 20.3 Safety shower with face-eye wash
(Permission of Nevada Safety & Supply)

water, or water and milk of magnesia. Do not induce vomiting; get medical aid. In case of inhalation, remove the victim to fresh air, restore breathing if required, and get medical aid.

Store acid containers closed in a clean, cool, open and well-ventilated area. Keep out of the sun. Keep the acid away from oxidizing agents or alkaline materials. Provide emergency neutralization materials in use areas.

20.114 Nitric Acid

Like hydrochloric acid, nitric acid is one of the most commonly used acids in the water treatment laboratory and plant. The acid is a powerful oxidizing agent and attacks most metals. Nitric acid is stable when properly handled and placed into a proper container. The acid is one of the strong mineral acids, and is highly reactive with materials such as metals. When handling nitric acid, use protective clothing and equipment to prevent body contact with the liquid. Such equipment includes rubber gloves, rubber apron, and safety goggles or a face shield for eye protection against splashing of the acid. Nitric acid is a strong, poisonous and highly corrosive liquid and must be handled carefully. The acid forms toxic fumes in the presence of light; therefore, it should be kept out of the sun.

Like other acids, nitric acid should be stored in clean, cool, well-ventilated areas. The areas should have an acid-resistant floor and adequate drainage. Keep it away from oxidizing agents and alkaline materials. Protect containers from damage or breakage. Avoid contact with skin and provide emergency neutralization materials and safety equipment in use areas.

First aid for skin contact is to flush thoroughly with water for 15 minutes. Get medical aid if needed. This acid will cause burns, but these can be greatly reduced if the contact area is immediately flushed. For gross (large) contact, remove contaminated clothing under a safety shower. For eye contact, flush with water for 15 minutes and get medical aid. If acid is ingested, give lime water or water with milk of magnesia; get medical aid. For inhalation, remove to fresh air, restore breathing if required, and get medical aid.

20.115 Sulfuric Acid

This mineral acid is highly corrosive and will attack most metals. Sulfuric acid is also very reactive to the skin and must be handled with extreme care or you will suffer severe burns. Even when the acid is diluted, it is highly corrosive and must be contained in rubber, glass or plastic-lined equipment. The acid will decompose clothing and shoes. Sulfuric acid should not come in contact with potassium permanganate or similar compounds. Sulfuric acid reacts violently with water. *ALWAYS POUR ACID INTO WATER* while stirring to prevent the generation of steam and hot water which could boil over the container and cause serious acid burns.

As with other mineral acids, this material is stable when properly contained and handled. When you are handling sulfuric acid, you must use protective clothing and equipment to prevent body contact with the acid. Wear rubber gloves, safety goggles and/or a face shield for eye protection against splashing. Also wear a rubber apron, rubber boots, and long-sleeved shirt. The eye wash station and safety shower must be located nearby where the acid is being handled. The area should be well-ventilated, the acid should be stored in closed containers in a clean, cool, open area. The area should have an acid-resistant floor which is well drained. Keep away from oxidizing agents and alkaline materials and protect the containers from damage or breakage

Because the acid is highly corrosive and causes severe burns, first aid for sulfuric acid must be immediate to avoid substantial damage to human tissue. For eye contact, flush thoroughly with running water for 15 minutes, get medical aid — the first seconds are important. For skin contact, wash affected areas thoroughly with water. For gross (large) contact, remove contaminated clothing under the safety shower with prolonged washing for at least 15 minutes. In cases of ingestion, give lime water or water and milk of magnesia to drink; get medical aid. When working with sulfuric acid, avoid skin contact and always provide emergency neutralization materials and a safety shower near the work areas.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 438.

20.10A What does an operator need to know about chemicals used in a water treatment plant?

20.11A What should be done if an operator inhales acid vapors?

20.11B Acetic acid will react violently with which compounds?

20.11C Under what conditions can acetic acid be handled safely?

20.11D What protective equipment is necessary for handling hydrofluosilicic acid?

20.11E How can the inhalation of hydrochloric (HCl) vapors or mists cause damage to operators?

20.11F How should nitric acid be stored?

20.12 Bases

The bases that are used in water treatment are known as hydroxides From a functional standpoint they are used to raise pH. Most common bases are compounds of sodium, calcium and ammonium which are strong bases. However, there are other weak bases, such as silicate, carbonate and hypochlorite. But from the point of safety, both weak and strong bases must be given the same consideration when being handled Some are very toxic, and will attack human tissue very rapidly and cause burns. Explosive reactions will occur when bases come in contact with an acid and hazardous decomposition products are created under certain conditions. Bases must be neutralized with dilute acids. However, the operator must work carefully because under some conditions there may be other reactions, such as with hypochlorite compounds. Therefore, you should understand acid-base chemistry before handling any of the basic compounds used in water treatment Table 20.4 gives some of the common basic compounds used in water treatment. The following sections will discuss some of their characteristics and the precautions the operator must use to safely handle such compounds.

12.120 Ammonia

The operator may use one of two forms of ammonia, anhydrous or hydroxide. The first (anhydrous) is in a gas form and requires one type of consideration. The hydroxide is a liquid and requires another type of consideration. Anhydrous ammonia in the gaseous state is colorless, about 0.6 times as heavy as air. In a liquid state, ammonia is also colorless, 0.68 times as heavy as water and it vaporizes rapidly. The ammonia gas is capable of forming explosive mixtures with air. For your own safety, be aware of the possibility of suffocation since the gas can displace air which contains oxygen. Although the vapors are not poisonous, they can and will irritate the mucous membranes of the eyes, nose, throat and lungs. Irritation will be detected in concentrations of 5.0 ppm and when human tissue comes in contact with the liquid, it will cause severe burns.

When handling ammonia or working in an ammonia environment, respiratory protection is a requirement. For entry into emergency areas, use only a self-contained breathing apparatus. Install a good ventilation system to control vapors in the application room. Use protective clothing, rubber gloves, apron, boots and face and eye protection if you are going to work with ammonia for long periods.

Care must be used when storing or transporting containers Always keep cylinders with caps in place when not in use. Store cylinders in a cool, dry location away from heat and protect from direct sunlight. Storage near radiators, steam pipes or other sources of heat may raise the pressure to a dangerous point, whereas dampness may cause excessive corrosion. Do not store in the same room with chlorine. Always use lifting clamps or cradles. Avoid hoisting the cylinders using ropes, cables or slings and never drop the containers Control ammonia leaks. They can be detected by odor or by using a cloth swab soaked with hydrochloric acid. This will form a white cloud of ammonium chloride.

Ammonia gas will burn if it is blended with air in a mixture containing 15 to 28 percent ammonia by volume. Check cylinder valve stems for leaks; tighten the packing gland nut only with a special wrench provided for such purposes. If a serious leak in a cylinder cannot be controlled, place the container in a vat of water. Fifty-three pounds of ammonia will dissolve in 100 pounds of water at 68°F (20°C). *NEVER* neutralize liquid ammonia with an acid. The reaction generates a lot of heat which may speed up the release of ammonia gas.

First aid for skin contact with ammonia is to flush with large amounts of water for 5 to 10 minutes and get medical aid Remove contaminated clothing under a safety shower. For eye contact, flush thoroughly with water for 15 minutes immediately, and get medical aid. In the case of inhalation, remove to fresh air and restore breathing. If required, get medical aid. Nose and throat burns should be washed with water and rinsed with two percent boric acid solution. Urge the patient to drink large amounts of milk.

Ammonium hydroxide is an aqueous (watery) solution of anhydrous ammonia and is quite volatile (will evaporate) at atmospheric temperatures and pressures. This solution can cause local skin irritations A strong solution will cause human tissue destruction on contact with eyes, skin and mucous membranes of the respiratory system, so avoid contact with the compound. The solution will cause severe burns depending upon solution concentrations and length of contact time. The solution's vapor causes the same effects as the gas First aid should be the same as for anhydrous ammonia.

20.121 Calcium Hydroxide

Hydrated lime (calcium hydroxide) is one form of lime and quicklime (calcium oxide) is another form. The hydrated lime is the least troublesome of the two forms. The hydrated lime is less caustic and is therefore less irritating to the skin, but can cause injury to eyes. However, as a dust, it is just as hazardous as quicklime. Quicklime is a strong caustic and irritating to personnel exposed to the compound. When quicklime is mixed with water, a great deal of heat is generated which can cause explosions.

TABLE 20.4 BASES USED IN WATER TREATMENT

Name, Formula	Common Name	Available Forms	Spec. Grav. or Lbs/Cu Ft	Flammability	Color	Odor	Containers
Calcium Hydroxide and Oxide, $Ca(OH)_2$ or CaO	Hydrated Lime or Quick Lime	Dry Powder, Lump	50-70 lbs per cu ft	N/A	White	Dust	Bags, Bulk, Trucks
Sodium Hydroxide, $NaOH$	Caustic, Lye	Lump, Liquid, Flake	1.524	May Cause Flammable Condition	Opaque White	Toxic, Pungent	Drums, Bulk, Trucks
Sodium Silicate, Na_2SiO_2	Water Glass	Liquid	1.35-1.42	N/A	Opaque	N/A	Drums, Bulk, Trucks
Hypochlorite Compounds, $NaOCl$, $Ca(OCl)_2$	HTH	Powder	—	Explosive with Antifreeze	White	Toxic Cl_2, Pungent	Cans, Drums
Sodium Carbonate, Na_2CO_3	Soda Ash	Powder	23, 35, and 65 lbs/cu ft	N/A	White	Dust	Bags, Bulk, Trucks

Both quicklime and hydrated lime should be stored in cool, dry areas. Care must be taken to avoid mixtures of alum and quicklime, since quicklime tends to absorb the water that forms as alum crystallizes (water of crystallization) away from the alum. In a closed container this could lead to a violent explosion. Equal care should be taken to avoid mixtures of ferric sulfate and lime.

When handling both forms of lime, the operator should use chemical goggles and a suitable dust mask to protect the eyes and mucous membranes. Also wear proper clothing to protect the skin, because with long contact the lime can cause dermatitis or burns, particularly at perspiration points. Always shower after handling quicklime. All operators should wear a face shield when inspecting lime slakers. Hot lime suspension that splatters on the operator may cause severe burns of the eyes or skin. The hot mist coming from the slakers is also dangerous. The loss of water supply to a lime slaker can create explosive temperatures.

First aid for lime burns, which are like burns from other caustics, consists of alternatively washing with water and a mild acetic acid solution. One may also use large amounts of soap and water. For eye contact, wash immediately with large amounts of warm water and rinse with a boric acid solution. Get medical aid. For irritation of nose and throat because of exposure, see a physician.

20.122 Sodium Hydroxide (Caustic Soda)

Sodium hydroxide is available in pellet and flake forms. Caustic soda usually comes as a 50 percent solution of sodium hydroxide. This base is a strong caustic alkali and very hazardous to the operator. This compound is extremely reactive. Sodium hydroxide absorbs carbon dioxide from the air, reacting violently or explosively with acid and a number of organic compounds. Caustic soda 1) dissolves human skin, 2) when mixed with water causes heat, and 3) reacts with amphoteric metals (such as aluminum) generating hydrogen gas which is flammable and may explode if ignited. Sodium hydroxide can be dissolved in water and the solution used for the adjustment of pH because it is a liquid and easy to feed. This base is extensively used in water treatment. Because of its everyday use, you may forget just how hazardous this compound is and through neglect may injure yourself or another operator. Only trained and protected operators should undertake spill cleanup. The operator must act cautiously, dilute the spill with water and neutralize with a dilute acid, preferably acetic.

When handling caustic soda, control the mists with good ventilation. Protect your nose and throat with an approved respiratory system. For eye protection, you must wear chemical worker's goggles and/or a full face shield to protect your eyes. There must be an eye wash and safety shower at or near the work station for this chemical. Protect your body by being fully clothed, and by using impervious gloves, boots, apron and face shield.

Special precautions to be taken when handling or storing caustic soda include (1) prevent eye and skin contact, (2) do not breath dusts or mists, and (3) avoid storing this chemical next to strong acids. Dissolving sodium hydroxide in water or other substances generates excessive heat, causes splattering and mists. Solutions of sodium hydroxide are viscous and slippery.

First aid for the eyes consists of irrigating the eyes immediately and continuously with flowing water for at least 30 minutes. Prompt medical attention is essential. For skin burns, immediate and continuous, thorough washing in flowing water for 30 minutes is important to prevent damage to the skin Consult a physician if required. In case of inhalation, remove victim to fresh air, call physician, or transport injured person to a medical facility For ingestion, give large amounts of water or milk and immediately transport injured person to a medical facility, *DO NOT INDUCE VOMITING.*

You may also have occasion to use sodium hydroxide as flakes or pellets All of the precautions stated for liquid caustic also apply for the flake form

20.123 Sodium Silicate

This chemical is a liquid as used in water treatment. However, it is non-toxic, non-flammable, and non-explosive, but presents the same hazards to the eyes and skin as any other base compounds. Sodium silicate is a strong alkali and should be handled with care by using goggles or face shield, wearing gloves and protective clothing. The chemical will cause damage to the eyes and skin, but it is less dangerous than other alkaline compounds used in water treatment.

First aid for the eyes is to flush immediately and thoroughly with flowing water for at least 15 minutes. Get medical attention. If sodium silicate makes contact with skin, wash thoroughly with water, particularly if the solution is hot. Then wash the skin with a 10 percent solution of ammonium chloride or 10 percent acetic acid. For ingestion, give plenty of water and dilute vinegar, lemon or orange juice. Follow this with milk, white of eggs beaten with water or olive oil. Call a physician.

20.124 Hypochlorite

A number of hypochlorite compounds are commercially available for use in water treatment. If you understand the precautions for one such compound, you will know what steps must be taken with other hypochlorite compounds, such as calcium, sodium, or lithium. These chemicals may be used in either a liquid or dry form. There are several grades of hypochlorite compounds, but all are good oxidizers and are used for disinfection. When these compounds come into contact with organic materials, their decomposition releases heat very rapidly and produces oxygen and chlorine. Although hypochlorite compounds are non-flammable, they may cause fires when they come in contact with heat, acids, organic or other oxidizable substances.

All solutions of hypochlorite compounds attack the skin, eyes or other body tissues with which they come into contact. When handling hypochlorite, liquid or dry, use suitable protective clothing such as rubber gloves, aprons, goggles and/or a face shield. Be aware that many times these compounds are stored in containers and give off chlorine gas when opened. Store these compounds in a cool, dry, dark area.

First aid for eyes is to flush with plenty of water for at least 15 minutes and see a physician. If hypochlorite compounds come in contact with the skin, flush thoroughly with water for at least 15 minutes, and get medical attention as needed. In case of ingestion, wash out mouth thoroughly with water and give plenty of water to drink, and get medical attention. For inhalation, move the victim into fresh air and get medical attention.

Over-exposure to any of the hypochlorite compounds may produce severe burns, so avoid contact with these compounds. They are hazardous and can attack skin, eyes, mucous membranes and clothing.

20.125 Sodium Carbonate

Soda ash is a mild alkaline compound, but requires safety precautions to minimize hazards when handling the chemical. An adequate ventilation system is needed to control the dust generated by the compound. Wear protective gear, such as chemical safety goggles and/or a face shield, a well-fitting dust respirator and protective clothing to avoid skin contact. You should protect yourself by using a suitable cream or petroleum jelly on exposed skin surfaces, such as neck and hands. This compound's dust irritates the mucous membranes and prolonged exposure can cause sores in your nasal passage.

First aid for exposure to eyes (dust or solution) requires irrigation with water immediately for at least 15 minutes. Consult a physician if the exposure has been severe. For skin exposure, wash with large amounts of water; for contaminated clothing, wash before reusing. For inhalation or irritation of the respiratory tract, gargle or spray with warm water, and consult a physician as needed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439.

20.12A What are the two forms of ammonia used by operators?

20.12B How should ammonia be stored?

20.12C What are the two forms of lime used in water treatment plants?

20.12D What would you do if someone swallowed sodium hydroxide?

20 12E What would you do if sodium silicate came in contact with your skin?

20.13 Gases

There are a number of gases used in water treatment (Table 20 5) Most are supplied in steel drum containers, others must be generated on site. Some gases can be seen, others call the operator's attention by odor, and still others cannot be seen or detected by odor, yet are deadly. In this section we shall only discuss those which are supplied in containers that the operator must connect, disconnect, handle or store.

Exposure to the liquid form of these gases usually will cause damage to human tissue, such as skin burns, but the most important factor to remember is the displacement of oxygen. Most gases are heavier than air and remove air from a room by displacement. Therefore, it is very important to have the right type of ventilation and respiratory protection. Use only the self-contained breathing apparatus when working in emergency areas.

20.130 Chlorine (Cl_2)

Safety is of the utmost importance when handling chlorine. Do not treat chlorine cylinders roughly; never drop them or permit collision of two or more cylinders. Never hoist chlorine cylinders by the neck. Always use lifting clamps or cradles — do not use ropes, cables or chains. Store the cylinders in such a way that they cannot fall. Do not store chlorine cylinders below ground level and always keep the protective cap on the cylinder when it is not in use. Mark the empty containers and store them aside from full cylinders. Always store containers in an upright position in a clean, dry

TABLE 20.5 GASES USED IN WATER TREATMENT

Name, Formula	Common Name	Available Forms	Specific Gravity	Flammability	Color	Odor	Containers
Ammonia, NH_3	Ammonia	Liquid-Gas	0.04813 lbs/ cu ft @ 0°C	None	Colorless	Irritating	Cylinders, Tanks, Trucks
Chlorine, Cl_2	Liquid Chlorine	Liquid-Gas	1.468 @ 0°C	None	Greenish Yellow	Irritating	Cylinders, One Ton Units, Tank Cars
Carbon Dioxide, CO_2	Dry Ice	Liquid-Gas	0.914	None	Colorless	Odorless	Bulk Liquid Under Pressure
Sulfur Dioxide, SO_2	Sulfuric Acid Anhydride	Liquid-Gas	1.436 @ 0°C	None	Colorless	Suffocating, Pungent	Cylinders, One Ton Units, Tank Cars

location free of flammable materials. The storage area must be equipped with forced-exhaust ventilation with starting switches located on the outside of the storage room. Ventilation must provide at least one complete air change per minute. The temperature of the storage room should never be permitted to approach 140°F (60°C). Protect the chlorine cylinder from heat sources and never use an open flame on cylinders or pipes carrying chlorine. If chlorine is heated, the increase in temperature will cause an expansion of the gas which results in an increase in pressure inside of the cylinders or piping, resulting in rupture of the containers.

When working with chlorine, be equipped to control chlorine leaks which are most often found in the control valve. Repair kits are available for the 100- and 150-pound (45 and 68 kg) cylinders, as is emergency equipment for the one-ton (909 kg) tanks for controlling leaks. Each operator must be trained in the use of these emergency kits and must practice with the equipment at least once a year. Always check out even the slightest odor of chlorine; it may indicate a leak. Chlorine leaks only get worse. Small leaks can grow very rapidly causing serious problems that could have been easily solved as a small leak. There should always be two operators attending a chlorine leak, one to do the repairs and the other to act as safety observer. Some repairs require two operators to do the job (depends on leak and repair kit). Once again, use only the self-contained breathing apparatus when repairing a chlorine leak.

When connecting chlorine cylinders, be very careful with the threaded connections; never use two washers, use only one. If it does not work well, remove the washer and use another one. Do not reuse an old or used washer; always use a new washer. By taking this precaution, by cleaning the threads and washer, and by being careful with the thread setting, many chlorine leaks will be prevented. You *MUST* be aware whether you are using gas or liquid when connecting the container. On the one-ton (909 kg) tank, the top valve is for gas, the bottom valve is for liquid. If liquid chlorine is allowed into a gas feed system it will cause "freezing"[3] and shut down (plug) the system. Similarly, if liquid gets into the gas outlet, it will cause problems by "freezing." You must not panic in this situation. Do not do anything as foolish as adding heat by open flame or electrical heaters to clear a "frozen" (plugged) gas line. Get help from someone experienced with chlorine cylinders.

Never make repairs to the valve or chlorine container. Just stop the leak, perhaps by tightening the packing on the valve stem or placing the safety device onto the cylinder. Let the chlorine supplier repair the container. Never use a wrench longer than six inches (15 cm) to open the cylinder valve, making one complete turn of the valve stem in a counter-clockwise direction. The one turn will open the valve sufficiently for the maximum discharge. As a safety consideration, cylinders are equipped with fusible metal plugs which are designed to melt at 158 to 168°F (70 to 76°C). This will allow the cylinder contents to discharge and prevent rupturing of the tank. On 100- to 150-pound (45 to 68 kg) cylinders, the plug is located just below the valve seat. The one-ton (909 kg) tanks have six such plugs; three on each end. Should one of these plugs melt, permitting liquid chlorine to discharge, place the cylinder in a position with the leak at the top of the tank so that it permits the chlorine gas (rather than the liquid) to discharge. This action will reduce the amount of chlorine being discharged because the liquid will change to a gas to escape. In doing so, it will lower the temperature of the container, reducing the discharge rate.

All employees, maintenance personnel and operators who handle chlorine must have access to an approved chlorine gas mask (Figure 20.4) They must be instructed in the use and maintenance of this equipment. A monthly program should be conducted to familiarize and train each user of the safety equipment. Those employees who are to use the chlorine emergency equipment should practice with this equipment every six months while wearing a self-contained breathing apparatus. The emergency kit consists of clamps, gaskets, drift pins, hammers, wrenches, and other tools needed for repairing leaks. The operator may not be able to practice with all of the tools, but inspection and practice gives the operator an opportunity to do maintenance on the emergency equipment.

All operators working with chlorine should be familiar with methods of detecting chlorine leaks. When testing for leaks, use ammonia water on a small cloth or swab on a stick or use an aspirator containing ammonia water. This will form a white cloud of ammonia chlorine. Leaks should be repaired immediately. Do not apply the ammonia swab directly to the equipment surface. Also do not spray ammonia into a room full of chlorine because a white cloud will form and you won't be able to see anything.

Many plants are equipped with chlorine gas detectors. This equipment must be maintained weekly. If not properly maintained, it may not be operable when you need it. Change the electrolyte regularly, test the alarm and keep the detectors clean and in good repair.

Someone must be assigned the responsibility for maintenance of the self-breathing apparatus. That operator must keep records of the maintenance problems and of monthly drills using the gear. The assigned operator should check the masks for leaks, loose eyepieces, faulty tubing, or other worn or defective spots. If inspection indicates any defective parts, they should be discarded or repaired by a properly trained employee. Remember, in high concentrations of chlorine within a confined space where oxygen can be displaced, *DO NOT USE THE CANISTER TYPE OF MASK. NO CANISTER CAN PROVIDE OXYGEN.* Therefore, use only self-contained breathing apparatus or a hose-type mask supplied with air (Figure 20.5).

If you are caught in an area containing chlorine, do not panic, but leave immediately. Do not breathe or cough, and keep your head high until you are out of the affected area.

The first safety measure you can take when entering a chlorination room is to make sure the ventilating system is working. The ventilating system for the chlorination room should be working all the time. Doors of chlorination rooms should have panic bars as door openers so that in an emergency you will not have to search for the door opener. All safety equipment should be located outside of the chlorination room, but close enough so you can find the equipment when needed.

First aid for eyes exposed to liquid chlorine is immediate irrigation with flowing water for at least 30 minutes. Medical attention is essential. If the eyes are exposed to chlorine gas, immediately irrigate with flowing water for a period of 15 minutes. Get medical aid. If skin is exposed to liquid chlorine, it will most likely cause burns. The skin should be washed with flowing water for 30 minutes. If the skin is burned, get medical attention. Chlorine gas can become trapped in the clothing and react with body moisture to form

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[3] *Liquid chlorine becomes a solid around −103 to −105°C. The liquid can plug a chlorine gas line which operators refer to as a "frozen" line.*

SCOTT PRESUR-PAK IIa

SPECIFICATIONS	BACK-PAK STYLE
AIR SUPPLY	
Rated Duration at moderate exertion (MESA/NIOSH test procedure)*	30 min.
Cylinder Capacity at 2216 psi	45 cu. ft.
USE FACTORS	
Weight, as worn, fully charged (approx.)	32 lbs.
Donning Speed (trained personnel)	under 30 secs.
Facepiece (Scottoramic w/nose cup)	Wide vision, anti-fogging
Cylinder and Valve connection	Straight thread, gasket seal
Cylinder Change	Hand disconnect, no tools req'd
Harness Webbing (replaceable without tools or rivets)	Polypropylene
Transport and Storage	Custom Molded High Density Polyethylene Case
SHIPPING WEIGHT	48 lbs.

NOTES: POSITIVE PRESSURE

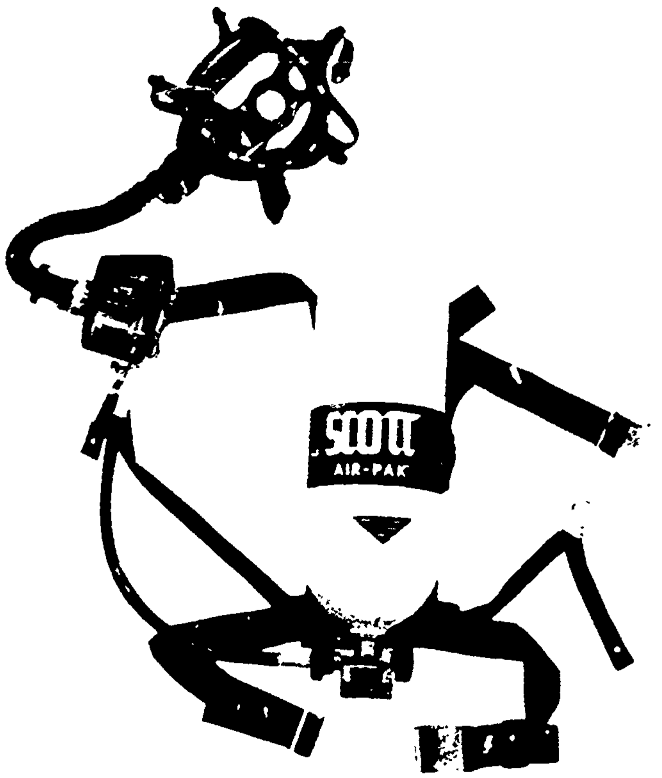


Fig. 20.4 Chlorine gas mask
(Permission of Nevada Safety & Supply)

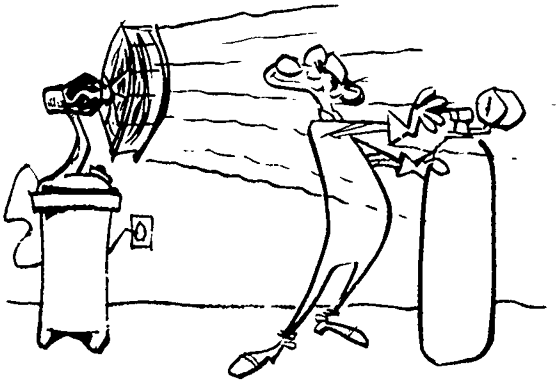
hydrochloric acid which could burn the skin. Remove the clothing of the victim and wash the body down with water. In case of inhalation, remove the victim to fresh air, administer oxygen if available, call a physician or transport the injured person to a medical facility. Ingestion is not a problem because chlorine is a gas at room temperature.

Each operator should have a copy of the Chlorine Institute's *CHLORINE MANUAL*.[4] You should read this manual and review it at least once every year. The manual gives data concerning chlorine as an element and gives you suggestions for safely handling this hazardous liquid or gas.

20.131 Carbon Dioxide (CO_2)

Water plant operators are not often exposed to carbon dioxide because of its limited use, but it is hazardous and can cause suffocation due to the lack of oxygen. Therefore, when using CO_2 keep in mind the carbon dioxide safety considerations. The problem with carbon dioxide is that it is odorless, colorless, and will accumulate at the lowest possible level because it is heavier than air.

Carbon dioxide is obtained in bulk lots, as a liquid under pressure. This gas must be vaporized before using. CO_2 is also prepared by generation on site. In either case, good ventilation will reduce the hazards of using CO_2. This will control the accumulating effects of the gas. If you must go into a CO_2-filled room, use a self-contained breathing apparatus, not a canister gas mask. Carbon dioxide displaces oxygen and you may suffocate with the canister type of mask. Exposure to carbon dioxide does not require any protection of the eyes, skin or other parts of the body, but take precautions when entering rooms, low spots, or manholes that may be filled with carbon dioxide.



First aid involves moving the victim to fresh air, giving resuscitation if the victim has stopped breathing, and getting medical attention.

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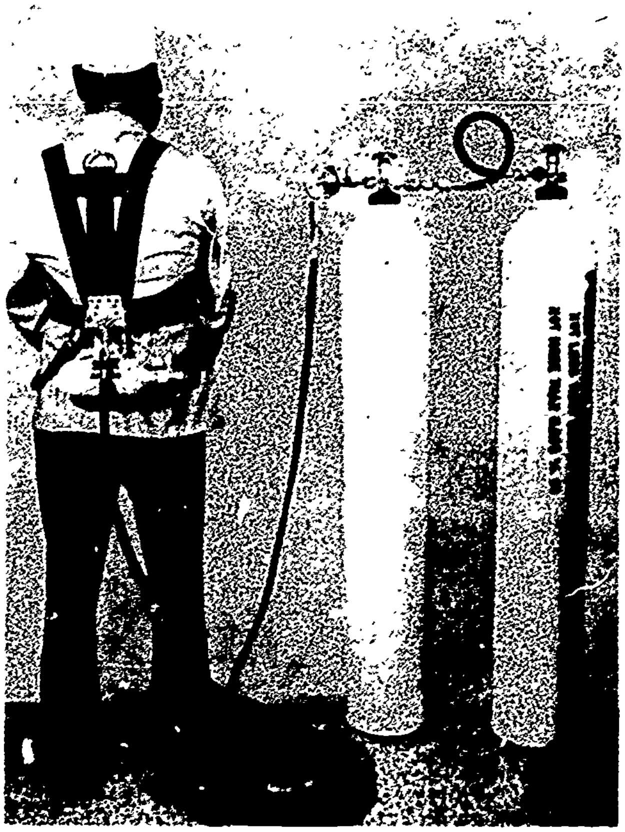
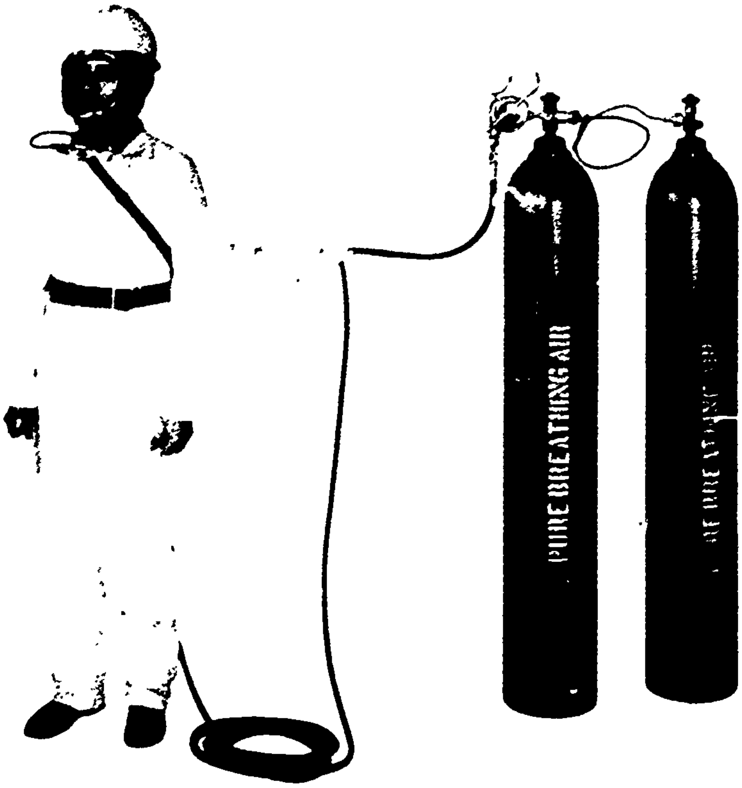
[4] *CHLORINE MANUAL (4th Edition), The Chlorine Institute, Inc., 2001 L Street, SW, Washington, DC 20036. Price, $10.00*



Dual air supply cylinder being used with 900007 series hoseline Air-Pak with Egress.



Typical fixed air supply installation using high pressure air cylinders.

Fig. 20.5 Hose-type mask supplied with air

(Permission of Nevada Safety & Supply)

20.132 Sulfur Dioxide (SO_2)

This gas is about 2.3 times as heavy as air and therefore will accumulate in low areas. Sulfur dioxide is colorless in the gaseous form. As a liquid it is also colorless and, when unconfined, will vaporize rapidly into a gas. The gas is extremely irritating and, like chlorine, will react readily with the respiratory system if inhaled. Sulfur dioxide causes varying degrees of irritation to the mucous membranes — eyes, nose, throat and lungs. The damage is caused by the formation of sulfurous acid in reaction with moisture in these locations. Sulfur dioxide can be readily detected in concentrations of 3 to 5 ppm. In higher concentrations, it is unlikely that you will remain in the area unless you are unconscious or trapped. If the liquid comes into contact with the skin, it may cause local freezing as the liquid evaporates.

Always use self-contained breathing apparatus around sulfur dioxide and never use the canister type. As with other gases, good ventilation is essential in a room where sulfur dioxide is being used. The fans should be used to dissipate any gas vapors that may occur. There should always be an eye wash fountain close to the work area where sulfur dioxide is used.

First aid for eyes exposed to or splashed with sulfur dioxide is washing immediately with water for at least 15 minutes, then getting medical attention. In case of inhalation, remove victim to fresh air, give resuscitation if needed, consult a physician or transport the injured person to a medical facility. Sulfur dioxide leaks and injuries should be treated similar to chlorine problems.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439.

20.13A Where are chlorine leaks most often found?

20.13B What is the purpose of the fusible metal plugs on chlorine cylinders?

20.13C How can chlorine leaks be detected?

20.13D What safety considerations must be observed when using carbon dioxide?

20.14 Salts

There are many salts (chemicals) used in water treatment. Table 20.6 lists the salts that will be discussed in this section. If you would like additional information about compounds not listed, request a data sheet about specific compounds from the suppliers of the chemicals. Review the chemistry of the compounds in Table 20.6 and become familiar with each chemical's characteristics. You should become well trained in how to handle each chemical and know and observe the appropriate safety precautions. For most of these salts, ventilation, respiratory protection and eye protection will prove adequate. Other problems may involved chemical solutions and dust. The solution may attack skin and clothing. The dust may attack the respiratory system or cause an explosion. Even though these chemicals do not normally react violently, use the following procedures when handling such salts to reduce the hazards and to provide a safe working location.

TABLE 20.6 SALTS USED IN WATER TREATMENT

Name, Formula	Common Name	Available Forms	Density, Lbs/Cu Ft	Flammability	Color	Odor	Containers
Aluminum Sulfate, $Al_2(SO_4)_3 \cdot 14H_2O$	Alum, Filter Alum	Liquids, Powder, Lump	1.69 (S.G.) 38-67	None	Ivory	N/A	Bags, Tank Truck, Bulk
Ferric Chloride, $FeCl_3$	Ferrichlor, Chloride of Iron	Syrup, Liquid, Lump	60-90	None	Dark Brown, Yellow-Brown	N/A	Carboys, Tank Cars
Ferric Sulfate, $Fe_2(SO_4)_3$	Ferrifloc, Ferrisul	Powder, Granule	70-72	None	Red-Brown	N/A	Bags, Drums
Ferrous Sulfate, $FeSO_4 \cdot 7H_2O$	Coppras, Green Vitriol	Crystal, Granule, Lump	63-66	None	Green	N/A	Bags, Drums, Bulk
Sodium Aluminate, $Na_2O \cdot Al_2O_3$	Soda Alum	Dry Crystal, Liquid	(27° Bé)	None	White, Green-Yellow	N/A	Bags, Bulk
Fluoride Compounds, NaF H_3SiF_6,		Liquid and Powder	50-75	None	Blue, White	Dust	Bags, Carboys, Tank Trucks
Sodium Hexametaphosphate, $(NaPO_3)_6$	Calgon, Glassy Phosphate	Crystal, Flake	47	None	White	N/A	Bags, Drums
Copper Sulfate, $CuSO_4$	Blue Vitriol, Blue Stone	Crystal, Lump, Powder	60-90	None	Blue	None	Bags, Drums
Sodium Chlorite, NaOCl	Technical Sodium Chlorite	Powder, Flake, Liquid	70 dry	Oxidizer	Light Orange	None	Tank Truck, 100 lb. Drums
Potassium Permanganate, $KMnO_4$	Permanganate	Crystal	90-100	Oxidizer	Purple	None	Drums, Bulk

When handling, storing or preparing solutions of chemicals, treat them all as being hazardous. All chemicals require careful consideration. They may be sources of an explosion, violent reaction, loss of eyesight, burns and illness.

Do not store acid or basic compounds with salts. Keep these chemicals in a clean, dry area. When handling dry bulk materials, store in a fire-safe area. Keep all lids on containers and follow the instructions on the container. Make sure that the operator who is mixing or dispensing these chemicals is well trained and wears proper clothing to meet all safety requirements, such as chemical goggles, face shield, rubber gloves, rubber boots, rubber apron and chemical respirator. When working with chemical salts, be aware that fumes, gases, vapors, dusts or mists may be given off and this represents a hazard to the safety of the operator. *PROTECT YOURSELF!*

20.140 Aluminum Sulfate (alum)

There are two forms of alum; dry and liquid. Both have to be handled with care. Dry alum is available in the lump, ground or powdered form and should be stored in a dry location because moisture can cause caking. Liquid alum is acidic and very corrosive. Store liquid alum in corrosion resistant storage tanks such as:

1. Steel, wood (Douglas Fir), or concrete-lined, all lined with 8-lb lead,
2. Steel, lined with 3/16 inch (5 mm) soft rubber,
3. Stainless steel,
4. Steel, lined with plastic if temperature remains below 150°F (65°C), and
5. Glass reinforced epoxy or polyester plastic.

When working with dry alum, use respiratory protection and ensure adequate ventilation of the work area. There should be a good mechanical dust-collection system to minimize any dust collection.

Never use the same conveyor for quicklime and alum. This mixture may explode under proper conditions.

Exposure to alum dust greater than 15 milligrams per cubic meter of air for more than an 8-hour period is dangerous. Avoid skin exposure to this chemical by using long-sleeved, loose fitting, dust-proof clothing.

Liquid alum is an acidic solution and should be handled as you would handle a weak acid. Reduce exposures to the skin and eyes. Avoid ingestion. Although the chemical will not cause any lasting internal damage, it will be uncomfortable. Use good ventilation for removing any mists. Rubber gloves and protective clothing is recommended.

As a general precaution, avoid prolonged exposure to dry or liquid forms of alum. If used dry, a dust mask and goggles are desirable for the comfort of the operator. Alum dust can be extremely irritating to the eyes. When handling the liquid, normal precautions should be used to prevent splashing of the compound onto the operator, particularly if the liquid is hot. Wear a face shield to protect your eyes and a rubber apron to protect clothing.

First aid for liquid or dry alum is immediate flushing of the eyes for 15 minutes with large amounts of water. Alum should also be washed off the skin with water because prolonged contact will cause irritation.

20.141 Ferric Chloride

This is a very corrosive compound and should be treated as you would treat any acid. The salt is highly soluble in water, but in the presence of moist air or light, it decomposes to give off hydrochloric acid, which may cause other problems regarding safety. Avoid prolonged exposure to this liquid (there is a dry form but it is not often used). When handling liquid ferric chloride, normal precautions should be taken to prevent splashing, particularly if the liquid is hot. Use a face shield to protect your eyes and rubber aprons to protect clothing. This compound will not only attack the clothing, but also stain it. First aid for eyes exposed to the liquid is that the eyes must be flushed out immediately for 15 minutes with large amounts of water. Ferric chloride should also be washed off the skin with water as prolonged contact will cause irritation and staining of the skin.

20.142 Ferric Sulfate

This compound produces an acidic solution when mixed with water. Because of its acidic nature, operators using this compound should be provided with protection suitable for dry or liquid alum. The hazards associated with the use of dry ferric sulfate are those usually connected with an acid. Use protective clothing, neck cloths, gloves, goggles or face shield, and a respirator. Avoid prolonged exposure to the dry form because of its acidic reaction with moisture on the skin, eyes and throat. The normal precautions should be used including a dust mask and protective clothing. First aid for exposure to the eyes requires the eyes to be flushed immediately with lots of water. The skin should also be flushed with large amounts of water. Prolonged contact may cause irritation.

20.143 Ferrous Sulfate

This chemical may be obtained in liquid or dry form. The safety hazards are some of those for dry or liquid forms of alum. The operator should be provided with adequate ventilation and respiratory protection. The material should be stored in a clean, dry location. Mechanical dust collecting equipment must be used to minimize the dust. Wear chemical goggles or a face shield, loose fitting, long-sleeved clothing, and make an effort to minimize all skin exposure.

First aid for ferrous sulfate in the eyes is to flush out immediately with large amounts of water for 15 minutes. The chemical should be washed off the skin to reduce irritations.

20.144 Sodium Aluminate

Sodium aluminate dissolved in water produces a non-corrosive solution. In the dry form, its powder consistency raises the usual dust problems. There are few hazards with this compound, but as with other chemicals, you should use precautions when handling it. Use respiratory protection when handling the dry compound to prevent the inhalation of dust. First aid for eyes that are exposed is to flush with water; keep the skin clean with water.

20.145 Fluoride Compounds

All fluoride compounds should be treated with care when you are handling them because of their long term accumulative effects. Provide good ventilation; always wear respiratory protection; and be careful not to expose any open cuts, lesions (wounds), or sores to fluoride compounds Clean up any spills promptly and wash immediately after handling such compounds.

When handling acid compounds of fluoride, always wear a face shield and/or chemical goggles, rubber gloves, rubber apron and rubber boots. Your wearing apparel should always be washed after working around fluoride, and the respirator should be kept clean and sanitary Keep the acid feeder for fluoride in good repair. Use plastic guards to prevent acid spray from glands or other parts of the chemical feeder This prevents attack upon the equipment and protects operators All fluoride compounds must be regarded as hazardous chemicals that are toxic to operators. Every means possible must be taken to prevent exposure to these compounds by use of respirator and protective clothing.

First aid for fluoride compounds is limited, but the following precautions should be used. For the eyes, flush immediately with warm water and consult a physician. For external injuries, wash with large amounts of warm water. For poisoning, the victim should drink a glass of lime water, or a one percent solution of calcium chloride, or a large amount of milk. See a doctor.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439.

20 14A What kind of protection does an operator need when handling salts?

20.14B What is the recommended first aid when either liquid or dry alum comes in contact with your skin or your eyes?

20 14C What happens when ferric chloride is exposed to moist air or light?

20.15 Powders

20.150 Potassium Permanganate ($KMnO_4$)

Under normal conditions in a water treatment plant, potassium permanganate is considered to be a safe chemical. However, potassium permanganate is a strong oxidizing agent and will react with certain easily oxidizable substances. Keep potassium permanganate away from the possibility of reacting with sulfuric acid, hydrogen peroxide, metallic powders, elemental sulfur, phosphorus, carbon, hydrochloric acid, hydrazine, hydroxylamine, and metal hydrides. When in contact with potassium permanganate, the following compounds may ignite: ethylene glycol (antifreeze), glycerine, sawdust compounds, propylene glycol, and sulfuric oxide.

Potassium permanganate is available either as pellets or as a powder. This chemical can be kept indefinitely if stored in a cool, dry area in closed containers. The drums should be protected from damage that could cause leakage or spillage Potassium permanganate should be stored in fire-resistant buildings, having concrete floors instead of wooden floors. The chemical must not be exposed to intense heat, or stored next to heated pipes. Organic solvents, such as greases and oils, should be kept away from stored potassium permanganate.

Potassium permanganate spills should be swept up and removed immediately. Flushing with water is an effective way to eliminate spillage on floors. Potassium permanganate fires should be extinguished with water.

To avoid inhalation of potassium permanganate dust, use an approved mask which is an air-purifying half-mask respirator with an outblower Safety glasses or a full face shield should be worn to protect your eyes. Protective clothing that should be worn includes rubber or plastic gloves and apron, and a long-sleeved shirt for handling both dry and dissolved potassium permanganate.

Mild exposure will cause sneezing and mild irritation of the mucous membranes Prolonged inhalation of potassium permanganate should be avoided. If potassium permanganate gets on your skin, flood the contacted skin with water If it gets in your eyes, flush with plenty of water and call a physician immediately.

20.151 Powdered Activated Carbon

Powdered activated carbon is the most dangerous powder that you will be exposed to as a treatment plant operator. If you understand how to handle activated carbon properly, other dust problems or powdered chemicals will not be very difficult for you to handle.

There are two problems when handling activated carbon. One is dust and the second is fire. The two may or may not be related. The dust causes uncomfortable working conditions; fire causes damage to equipment and a hazard to personnel. If the two problems are treated together, it will reduce the hazards to operators. Left unattended they may cause loss of life and property. If you will use the following safety precautions, you can minimize the hazards of handling activated carbon and aid the other operators in handling other powders.

Store activated carbon in a clean, dry, fireproof location. Keep free of dust, protect from flammable materials, and do not permit smoking in the area at any time when handling or unloading activated carbon. Install carbon dioxide fire extinguishers. Store bagged carbon in single rows. Keep access aisles free to prevent damage to the bags and thus reduce the dust and fire potential.

Electrical equipment in and around activated carbon storage should be explosion proof and protected from the carbon dust. Keep the equipment clean and dry. Wet or damp carbon is a good conductor of electrical current and can cause short-circuit fires Heat can also build up from the motors if covered with carbon dust, causing fires. The key to controlling fires with activated carbon is keeping the storage area clean and dust free.

Next to electrical fires, activated carbon gives the operator the most difficult fire to control. The carbon gives off an intense heat; it burns without smoke or visible flame. The fires are difficult to locate and are very hard to control. They cannot readily be detected in a large storage bin or in large stacks of bags.

Bags of activated carbon should be stored in single rows.

You will detect the indications of the fire before seeing any evidence of flames, such as the smell of charred paper, burned paint or other odor.

Do not douse a carbon fire with a stream of water. The water may cause burning carbon particles to fly, resulting in a greater fire problem. The carbon fire should be controlled with carbon dioxide (CO_2) extinguishers or hoses equipped with fog nozzles. However, when using CO_2, be aware that there is a potential of carbon monoxide formation and take the precaution of using a self-contained breathing apparatus

Activated carbon supports fire without atmospheric oxygen because it may have absorbed sufficient oxygen for combustion. The best means of controlling a carbon fire is to reduce its temperature below the ignition point. This can be done by applying cold water with fog or spray nozzles and soaking the burning carbon, but do not hit the carbon with a stream of water. If the fire is small, just a few bags, they should be removed to a safe location and dealt with by CO_2 or spray nozzles Blocks of dry ice can be used to control fires in storage bins or other confined areas, but do not expect this method to be very effective.

A final word about fire and explosions involving activated carbon. Tests performed by carbon manufacturers have not shown that dust mixtures of carbon have explosive tendencies. Activated carbon is a charcoal and performs in a like manner, the carbon burns without smoke or visible flame, burns very hot, and will spread if doused with a large stream of water

There are no specific first aid methods for carbon exposure because the carbon will not attack the human body. Carbon does sometimes cause problems with the nasal passages, however, and may be difficult to wash off your hands and body. Therefore, methods here are those of prevention Provide good dust collection at the point where carbon is being unloaded, in storage bins for liquid preparation, and in dry storage bins. Wear an approved dust mask, loose fitting and dust-proof clothing. If there is an excess of dust, you should use chemical goggles, close your shirt collar and tape your trousers to cover your ankles. You will need adequate shower facilities and should use mild liquid soap. Most, if not all, hard soap bars are ineffective in removing activated carbon dust from pores of the human body.

20.152 Other Powders

You may come in contact with other powdered compounds in the water treatment plant, but they do not present the problem in handling that activated carbon does. Bentonite creates no significant hazard other than dust, and this can be controlled by using dust collection systems.

Similarly, calcium carbonate presents a slight dust hazard that can be controlled by a dust collection system. Also, when handling calcium carbonate in bags, use the same methods of control that you would use with bags of carbon

Of the many organic coagulant aids used in water treatment, only a few are applied in powder form Most of these compounds are used in the liquid form which reduces the danger in their use to operators. The dry compounds present a slight hazard in dust irritation to the nasal passages, this can be prevented by use of approved dust masks. The liquid compounds can and will attack the skin, but can be treated by washing with ample amounts of water and/or soap and water Organic coagulant aids (polymers) are extremely slippery when wet. Floors and walkways should be clean and dry to prevent slips and falls.

As new compounds are introduced to the waterworks field, ask for training in their use Such a training program should provide information about detailed safety precautions, the toxicity of the compound, and the appropriate first aid methods Supervisors have the responsibility to provide this type of training, either in conjunction with the supplier or sponsored entirely by the utility The training must be reinforced periodically for those compounds that are not often used by the operator A review and updating of information will go a long way in preventing accidents

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439

20 15A How can potassium permanganate spills be cleaned up?

20 15B What is the most dangerous powder the water treatment plant operator will be exposed to?

20 15C How should activated carbon be stored?

20 15D How can fires caused by activated carbon be prevented?

20 15E How should an activated carbon fire be extinguished?

20.16 Chemical Storage Drains

Safety regulations prohibit the use of a common drain and sump for acid and alkali chemicals, oxidizing chemicals and organic chemicals because of the possibility of the release of toxic gases, explosions and fires If both an acid and an alkali chemical come in contact, an explosion could occur. If an organic chemical such as a polymer solution comes in contact with an oxidizing chemical such as potassium permanganate, a fire could develop Be sure that if a leak develops from any chemical container or storage facility, the chemical will not be able to reach, mix or react with another chemical

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439.

20 16A Why should drains from chemical storage areas not use common drains and sumps?

20.16B What could happen if a leak from a polymer storage container comes in contact with potassium permanganate?

End of Lesson 2 of 4 Lessons
on
SAFETY

DISCUSSION AND REVIEW QUESTIONS

Chapter 20. SAFETY

(Lesson 2 of 4 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1

9 What does an operator need to know about chemicals used in a water treatment plant?

10. How can hydrochloric acid be handled safely?

11 How should hydrochloric acid be stored?

12. How can ammonia leaks be detected?

13. What is the first aid treatment for lime burns?

14. What special precautions should be taken when handling and storing caustic soda?

15. How should hypochlorite be handled and stored?

16 What first aid is required for a person overcome by carbon dioxide?

17 What safety hazards may be caused by salt dust?

18 What types of safety hazards might an operator encounter when handling alum?

19 What are the two major problems encountered when handling activated carbon?

20 How can an operator detect an activated carbon fire?

CHAPTER 20. SAFETY

(Lesson 3 of 4 Lessons)

20.2 FIRE PROTECTION

20.20 Fire Prevention

Fire prevention is the best fire protection the plant operator can afford. Fire protection is just good housekeeping. The word "housekeeping" best describes the action any water plant operator can take to protect from or prevent fires. This means a well-kept, neat and orderly plant represents a good fire safety policy. Fire hazards can be easily removed. The prompt disposal of cartons, crates and other packing materials, a system of waste paper collection, and the removal of other debris can greatly reduce fire hazards. Provide suitable containers for used wiping cloths and have fire extinguishers conspicuously located in hallways, near work areas and near potential fire problem areas. All of these housekeeping activities are low-cost measures that also improve the appearance of the plant and create a better work environment.

You can call upon the service of the local fire department for advice on fire prevention in and around the treatment plant. You may also ask the utility insurance underwriter for cooperation in your fire prevention program. All operators should be trained in the proper use and maintenance of fire control equipment. These simple steps can reduce fire losses to a minimum and prevent most fires from happening at very low cost to the utility.

You should make a fire analysis of your plant once a year to determine what new measures should be taken to prevent fires. As activity changes occur, there may be a need to change the location of hoses and extinguishers or it may be necessary to add fire control equipment. Fire and police departments' telephone numbers must be posted in a conspicuous location along with escape routes. Post emergency numbers near all telephones throughout the plant. In hazardous locations the means of exit should be lighted and all doors equipped with "panic bars." As indicated above, your best fire protection or prevention is good housekeeping.

20.21 Classification

Fire classifications are important for determining the type of fire extinguisher needed to control the fire. Classifications also aid in recordkeeping and for comparison with other agencies. Fires are classified as "A" — Ordinary combustibles, "B" — Flammable liquids, "C" — Electrical equipment, and "D" — Combustible metals.

A Class A fires involve miscellaneous combustible materials These include fabrics, paper, wood, dried grass, hay and stubble.

B. Class B fires involve flammable liquids and vapors. This may include oils, lacquers, fats, waxes, paints, petroleum products and gas This class is subdivided into two subclasses:

   B-2 - are those fires in which the source of flammable vapors is substantially in a single place such as tanks, vats, spills and trenches.

   B-3 - are those fires that are complicated by a falling stream. LPG and other vapor fires are in this class.

C The Class C fire involves electrical equipment such as starters, breakers and motors. The circuits should always be killed before extinguishing this type of fire.

D. Class D fires involve metals such as sodium, zinc, magnesium and other similar metals. Operators rarely encounter this type of fire.

20.22 Extinguishers

There are many types of hand-held fire extinguishers. All are classified for class of fires. There is no one extinguisher that is effective for all fires, so it is important that you understand the class of fire you are trying to control. You must be trained in the use of the different types of extinguishers, and the proper types should be located near the area where that class of fire may occur.

A. There are four types of water extinguishers: stored pressure, cartridge operated, water pump tank, and soda-acid. All of these perform well in Class A fires, but they do require maintenance. A preventive maintenance schedule on all water extinguishers should include a monthly check by the operator responsible for the maintenance and completion of appropriate maintenance records. Some agencies make the safety officer responsible for ensuring that an operator checks the fire extinguishers.

   1. The method of operation for a stored pressure extinguisher is simply to squeeze the handle or turn a valve. The maintenance is also simple: check air pressure, record and recharge the extinguisher as needed.

   2. For the cartridge type, the maintenance consists of weighing the gas cartridge and adding water as required. To operate, turn upside down and bump.

   3 To use the water pump tank type of extinguisher, simply operate the pump handle. For maintenance, one has only to discharge the contents and refill with water annually or as needed.

   4. The soda-acid type must be turned upside down to operate; it also requires annual recharging.

B. The foam type of extinguishers will control Class A and Class B fires well. They, like soda-acid, operate by turning upside down and require annual recharging.

The foam and water type extinguishers should not be used for fires involving electrical equipment. However, they can be used in controlling flammable liquids such as gasoline, oil, paints, grease and other Class B fires.

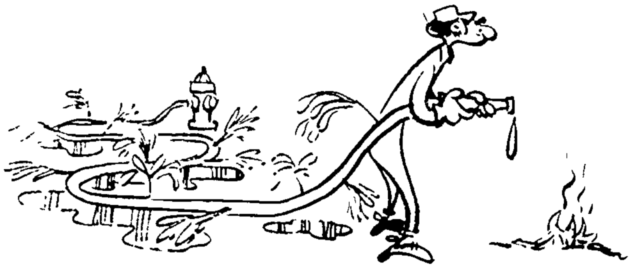
C The carbon dioxide (CO_2) extinguishers are common (Figures 20.6 and 20.7). They are easy to operate, just pull the pin and squeeze the lever For maintenance, they must be weighed at least semi-annually. Many of these extinguishers will discharge with age. They can be used on a Class C (electrical) fire. All electrical circuits should be killed, if possible, before trying to control this type of fire. A carbon dioxide extinguisher is also satisfactory for Class B fires, such as gasoline, oil and paint, and may be used on surface fires of the Class A type.

D. There are two types of dry chemical extinguishers. These extinguishers are either (1) cartridge operated or (2) stored pressure. These are recommended for Class B and C fires and may work on small surface Class A fires

1. The cartridge-operated extinguishers only require you to rupture the cartridge, usually by squeezing the lever The maintenance is a bit more difficult, requiring weighing of the gas cartridge and checking the condition of the dry chemical.
2. For the stored-pressure extinguishers, the operation is the same as the CO_2 extinguisher. Just pull the pin and squeeze the lever. The maintenance requires a check of the pressure gages and condition of the dry chemical

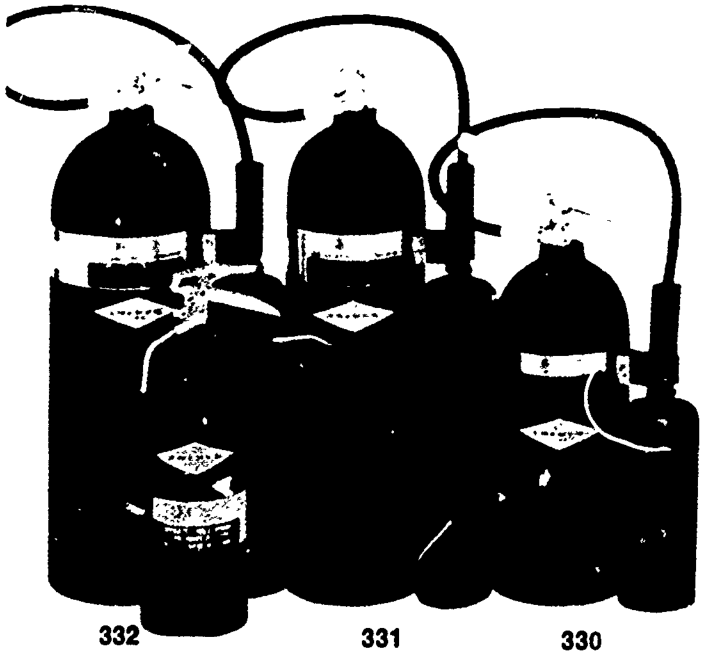
As suggested above. a preventive maintenance program for fire extinguishers requires a considerable amount of time from the operator and requires a system of recordkeeping

You might consider hiring a local fire prevention agency to perform this part of your maintenance program. These service agencies will check and maintain the plant's fire fighting equipment on a regular basis. This does not relieve the operator of ultimate responsibility for the equipment, but assures that the equipment is in proper working order when needed



20.23 Fire Hoses

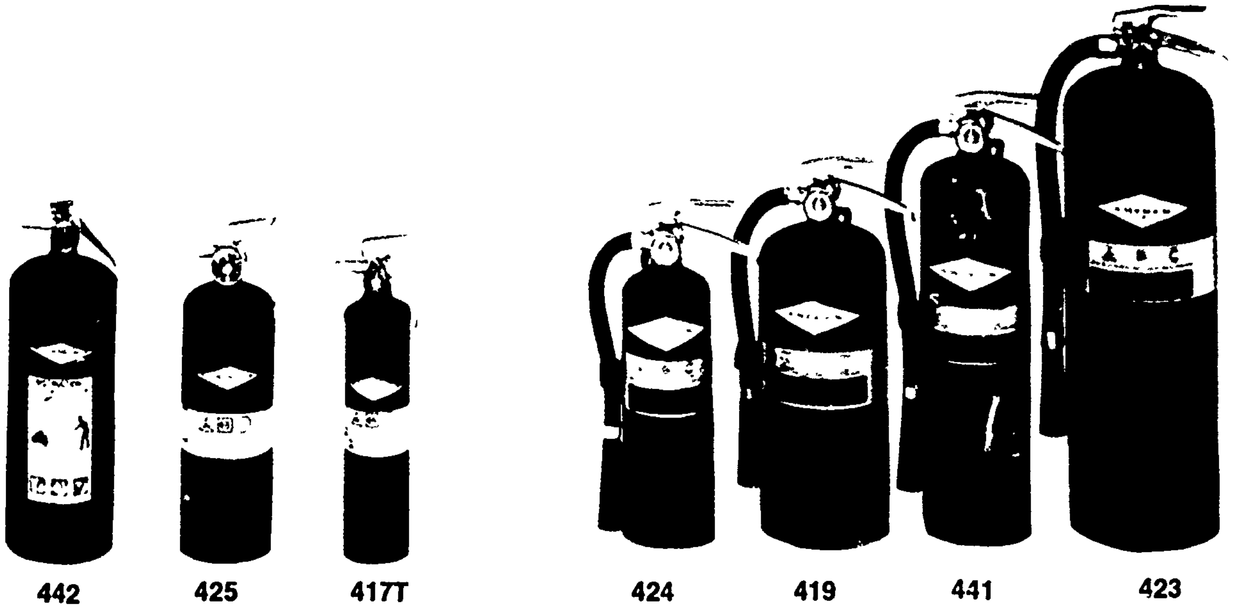
Fire hoses are usually stationed throughout the treatment and pumping plants. These are the type of fire fighting equipment that an operator may see every day, but never give due consideration to their maintenance. Without proper maintenance, the hoses may develop dry rot and be untrustworthy at the time they are needed. Under some conditions, you may be tempted to use these hoses for cleaning settling basins or filters. The fire hoses should only be used for fighting fires, and after their use, they must be cleaned and stored properly The hose should be tested periodically and replaced as required, or at regular time intervals. Check with the local fire department for recommendations.



SPECIFICATIONS	CARBON DIOXIDE			
Size/Type	5 Horn	10 Hose	15 Hose	20 Hose
Model Number	322	330	331	332
U/L Rating	5B C	10B C	10B C	10B C
Capacity (lbs)	5	10	15	20
Shipping Wt (lbs)	15	29½	39½	51½
Height	17¾"	24"	30"	30"
Width	8¼"	12"	12'	13"
Depth (Diam)	5¼"	7"	7"	8"
Range (Ft)	3-8	3-8	3-8	3-8
Discharge Time—Seconds	10	10	12 5	19
Coast Guard App	Yes	Yes	Yes	Yes
FM Approved	Yes	Yes	Yes	Yes
Bracket	Wall	Wall	Wall	Wall

ig. 20.6 Carbon dioxide extinguishers

(Permission of Nevada Safety & Supply)



SPECIFICATIONS	ABC						
Size/Type	2½ Nozzle	5 Nozzle	6 Nozzle	5 Hose	10 Short Hose	10 Tall Hose	20 Hose
Model Number	417T	425	442	424	419	441	423
U/L Rating	1A:10 B:C	2A:10 B.C	3A.40 B.C	2A:10 B:C	4A.60 B:C	4A:60 B:C	20A.120 B.C
Capacity (lbs.)	2½	5	6	5	10	10	20
Ship. Wt. (lbs.)	5½	8½	11	10½	19½	18	40
Height	14⅛"	14⅝"	15½"	14⅝"	17"	20½"	24"
Width	3⅞"	5"	5"	8"	9½"	9"	10"
Depth (Diam.)	3"	4¼"	5"	4¼"	6"	5"	7"
Range (Ft.)	9-15	12-18	12-18	12-18	15-21	15-21	15-21
Discharge Time-Seconds	10	10	14	10	17	17	30
Coast Guard Ap.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FM Approved	Yes	Yes	Pending	Yes	Yes	Yes	Yes
Bracket	Veh/Mar	Wall	Wall	Wall	Wall	Wall	Wall

A TRASH•WOOD•PAPER B LIQUIDS•GREASE ● ELECTRICAL EQUIP

Fig. 20.7 Typical carbon dioxide extinguishers
(Permission of Nevada Safety & Supply)

20.24 Flammable Storage

The storage of flammable material should be isolated, if possible, from other plant structures. Ideally, these storage areas should have explosion-proof lighting. The floor should be grounded and the operator should only use sparkproof tools when working near or handling flammable materials. The room should have an alarm system, be equipped with automatic extinguishers and have supplementary equipment located outside of the room. In and around the storage area, smoking or welding must be prohibited. The flammable storage areas must be clearly marked with distinctive signs and all entrances should be lighted.

More often than not, however, you will be compelled to use rooms within the plant for storage of flammable material. Here you must make the room fireproof, equip the room with a fire door, automatic extinguishers and alarms. Keep passageways free from obstructions. Station fire-fighting equipment at a suitable location, readily accessible and with plainly labeled operating instructions. The room must be equipped with explosion-proof lights, grounded floor, no smoking permitted, and distinctive signs indicating that this room is a flammable storage area.

20.25 Exits

Access and exit are very important in plant safety. Therefore, all exit [illegible]ns should be distinctly marked and well lighted. All doors should open outward and, in hazardous areas, there should be "panic bars" on the doors. To provide positive protection around the filter and sedimentation basins, install hand rails or other enclosures for the protection of operating personnel as well as visitors.

In high-fire-hazard occupied areas, there should be at least two means of emergency exit located, if possible, at opposite ends of the room or building. These would include areas containing woodworking and paint spraying residues that burn rapidly or give off poisonous fumes.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439.

20.2A Class A fires involve what types of materials?

20.2B What kinds of fires can be controlled by a foam type of extinguisher?

20.2C How can an electrical fire be extinguished?

20.3 PLANT MAINTENANCE

20.30 Maintenance Hazards

Plant maintenance, housekeeping, cleaning up, or whatever you wish to call it, is a very important function of the treatment plant and essential for plant equipment. This function requires the use of cleaning materials and hand tools Maintenance may require you to go into a manhole, repair electrical motors, lift boxes and use power tools. All of these functions may in some way be hazardous, and if not given proper consideration, may cause injury, fire, disease or even death.

20.31 Cleaning

Any effort spent keeping the entire plant clean and sanitary will provide a much nicer place for you to work and will also make visitors feel as if the water being produced is safe. Even if you can just keep all working areas free of tripping hazards, this will add greatly to the safety in the plant

Cleaning duties should be performed at such times of day or night as to cause a minimum of exposure to other operators. For example, floors become slippery when wet so give some consideration to the time of day and the type of wax to be used. When cleaning floors, there are problems of exposure to others of cleaning equipment, mops, mop and broom handles, other tools, cleaning compounds, and most of all, wet floors. When cleaning, try to keep others out of the area Warn others about newly waxed floors. Use wax compounds containing nonslip ingredients. Try to do such cleaning and waxing during off-duty hours, weekends or at night.

As part of your maintenance program, provide trash containers for collecting waste paper and for separating used, oily rags. Dispose of garbage and flammable refuse on a routine, frequent basis. Hazardous waste, acids and caustics should be cleaned up immediately. These steps will add to the safety in the plant and to the safety of operators in the plant.

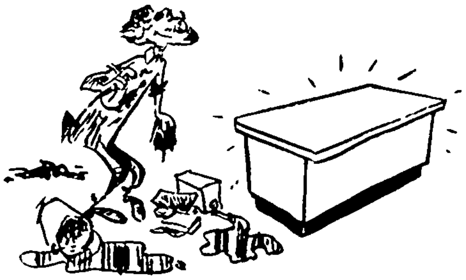
Keeping aisles, doorways, stairs and work areas free of refuse reduces hazards of tripping and other injuries, as well as reducing the possibility of fires.

Cleaning windows is a hazardous occupation, but the operator who gives due consideration to the task can perform it safely. If windows are high, time of day is important. Cleaning tools may be dropped and fall on pedestrians or vehicles. There may be a need for safety harnesses; check the harness each time it is used. Make sure all parts of the harness are in good working condition. Cleaning compounds that are acid or alkaline may attack the harness or the safety rope. Also, such compounds may attack human skin; therefore, use rubber gloves when appropriate.

20.32 Painting

There are a number of considerations when painting in a treatment plant. First, is the paint exposed to the drinking water being treated and are there toxic compounds in the paint? Next, is the paint being applied by brush or spray? In either case, is there sufficient ventilation if the operator is painting indoors or in a closed area?

When working with toxic paints, for example, those containing lead, zinc, or organics, be sure to clean your hands before eating or handling food. Also, avoid exposing your skin to solvents and thinners and try not to use compounds such as carbon tetrachloride. When spray painting, always use a respirator to avoid inhaling fumes. Do not allow smoking or open flames of any kind around areas being painted. Also, when painting or cleaning the spraying equipment, avoid closed containers where heat is involved. At a certain temperature called the flash point, spray or vapors could ignite and burn the operator or start fires. Always clean the spray equipment in an area having sufficient ventilation If the painting operation is taking place in a paint booth, use only explosion-proof lighting and permit no open flame and no electric switch that may cause a spark.



Some of the other hazards when painting include scaffolding, rags and threats to your personal health. Be very careful when using scaffolding and ladders. The scaffolding must be in good repair and conform to current safety regulations. Ladders must also be in good repair. If they are broken or badly worn, they should be replaced with new ones.

Rags are always a problem if they contain oils, paint or other cleaning compounds; there is always the possibility of fire. The rags should be placed into a closed metal container to reduce the fire hazard.

As to personal protection, consider using creams to help reduce skin exposure to paint and solvents. Always use an approved respirator to reduce inhalation of fumes and paint mists. As a final note, avoid any unnecessary exposure to paint or solvents to the skin.

20.33 Cranes

Overhead traveling cranes require safety considerations. First, only authorized personnel should be allowed to operate them. Inspections should be made to check out the circuit breaker, limit switches, the condition of the hook, the wire rope and other safety devices. The load limits should be posted on the crane and you should never overload the unit. Always check out each lift for proper balance. Use only a standard set of hand signals, and make sure that each operator involved with the crane knows all of the signals. Personnel in and around an overhead crane should be required to wear hard hats. When making repairs to the crane lock out the main power switch and allow only authorized personnel to make repairs.

Never move loads over areas where operators or other people are working. Do not let the load remain over the heads of operators or other workers or allow them to work under loaded cranes. If loads must be moved over populated areas, give a warning signal and make sure everyone is in a safe location. Set up monthly safety inspection forms to be filled out and placed into the maintenance file. The plant supervisor should review the forms and authorize any maintenance necessary on the crane in addition to following a good preventive maintenance program.

20.34 Manholes

There are many hazards involved with manholes and all of them can cause injury to the operator. Just removing the manhole cover can cause the loss of hands or fingers. You should never remove the manhole cover with your hands. Use a manhole hook or special tool such as a pick with a bent point to remove the lid. Be very careful when lifting the lid. Use your legs, not your back for lifting. This will help prevent back strains. Locate the cov tside the working area to provide adequate working area und the manhole opening.

Next is the problem of traffic around an open manhole. The public, other operators and vehicles must be protected. Therefore, barricades, warning devices and lights must conform to local and state regulations. There also should be a barricade around the manhole to protect the operators. All personnel around manholes should wear hard hats for their safety.

Always inspect the ladder rungs in the manhole before using them. They may become loose or corroded and therefore should be tested, using your own weight. One should never enter a manhole alone; there should be at least one other person standing by at the top and at least one or more people within hearing distance in case of injury.

Perhaps the greatest threats to operators working in manholes are air contamination or depletion of oxygen. Many operators have lost their lives because of leaking gas mains, decaying vegetation or other gases. Never enter a manhole without checking the atmosphere for (1) sufficient oxygen, (2) presence of toxic gases (hydrogen sulfide), or (3) explosive conditions (methane or natural gas). In any event, always provide adequate ventilation. This will remove any hazardous gases. To check the safety of the atmosphere in a manhole, use a gas-detection instrument (Figure 20.8). These devices can detect explosive gases, oxygen deficiency, and/or toxic conditions. Remember, just because there are no toxic or explosive gases present does not mean that you may not lose your life because of a deficiency of oxygen. Normal air contains about 21 percent oxygen. The first effects of insufficient oxygen occur when the oxygen content drops to about 15 percent. Operators who work around manholes should be trained in applying artificial respiration (C.P.R).

Smoking should nc be permitted in or around manholes. Always use a mechanical lifting aid (rope and bucket) for raising or lowering tools and equipment in and out of a manhole The use of a bucket or basket will keep your hands free when climbing down into or out of the manhole

To review the hazards of underground structures, remember to give consideration to proper tools for opening and closing the manhole. Keep in mind the need for barricades and lights to warn traffic and to prevent endangering other operators. Be sure that operators are trained in artificial respiration methods and in the way to test the manhole for oxygen, explosive and toxic gases.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 439.

20.3A What safety precautions should be taken when waxing floors?

20.3B How should rags containing oils, paint or other cleaning compounds be stored?

20.3C What safety precautions should be exercised when operating an overhead crane?

20 3D How can traffic be warned that operators are working in a manhole?

20.3E How should tools and equipment be lowered into and removed from manholes?

20.35 Power Tools

The two general classes of portable power tools are (1) pneumatic and (2) electrical. Safety precautions for handling these types of tools are much the same for both types. Wear eye and ear protection when operating grinding, chipping, buffing, or pavement breaking equipment. Sometimes when using grinding or buffing tools you will encounter toxic materials and, therefore, will need respiratory protection. At

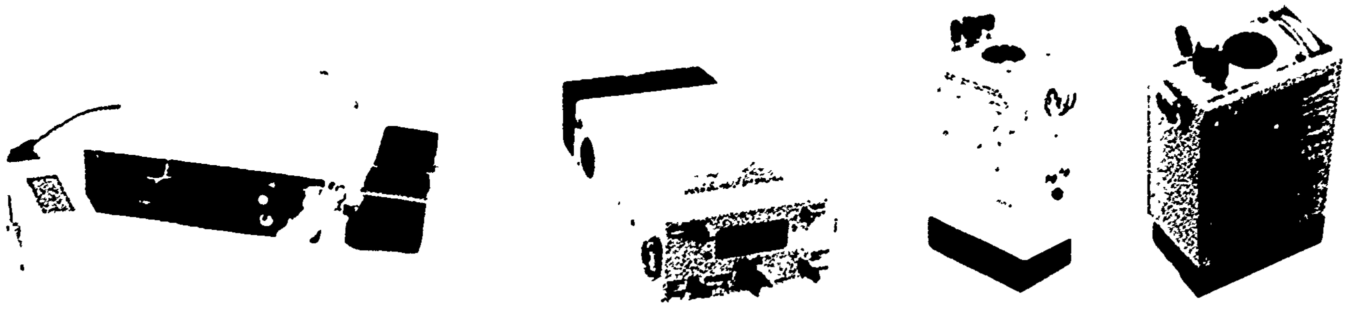


Fig. 20.8 Gas-detection instruments (toxic gas, combustible gas and oxygen deficiency)

(Permission of ENMET Corporation)

other times there is a need for full face protection because of flying particles; you should use a face shield or at least goggles In the use of electrical tools. always replace worn out extension cords and never expose cords to oils or chemicals Extension cords also present a tripping hazard if left in the way Avoid leaving extension cords in aisles or in work areas Do not hang extension cords over sharp edges which could cut the cord and always store the cords in a clean, dry location When working in a wet or damp location, some consideration should be given to the use of rubber mats or insulated platforms. As indicated above, use only grounded tools. When using pneumatic tools, never use the compressed air to clean off your clothing or parts of your body Air can enter your tissues or other openings and cause problems Always check hose clamps. If they are loose or worn, tighten or replace as needed. Air hoses, like extension cords, are a tripping hazard. Therefore, consider their location when working with pneumatic tools For the large (3/4 inch or 18 mm) hoses, always use an approved safety-type hose connection with a short safety chain or other safety device attached. Air hoses that come apart can cause injuries as they are whipping about. Like electrical cords, keep air hoses away from oils, chemicals or sharp objects.

Sandblasting. using a pneumatic tool, requires some special consideration. The operator should protect all skin surfaces with protective clothing, wear eye and face protection. use a respirator, and be very careful of toxic fumes which are discharged from a blasting operation

The grinding wheel, pneumatic or electric, requires the same safety considerations. Eye and face protection is required. Do not use this tool without safety guards Be careful of gloves being caught on the grinding wheel. Never operate a wheel with loose nuts on its spindle. When the grinding wheel is badly worn, replace it and use the proper wheel and speed of rotation.

All persons using power tools must be trained in their use and maintenance. Use the manufacturer's operations and maintenance guide for details of proper training. Most injuries by power tools are caused by incorrect setup and operation due to poor training.

Finally, a high level of noise is frequently encountered when operating power tools. For example, air drills produce 95 dB[5] and circular saws 105 dB. Ear protection must be provided when exposed to long periods of high levels of noise. In areas of noise exposure, all operators should be provided with approved ear protective devices.

20.36 Welding

The first safety rule in operation of gas or electric welding equipment is that the operator be thoroughly trained in the correct operating procedures. The second rule concerns fire protection. The third rule is personnel protection. None of these rules is first or last — they should *ALL* be followed.

If you are not thoroughly trained in the use of the welding equipment, do not use it. If you absolutely must use the equipment, do so only under the supervision of a trained welder. Whenever such work must be performed in or around a water treatment plant, take time to consider the fire problem. For example, welding can be very dangerous in an oxidizing chemical location, near powdered activated carbon storage, and in storage areas for other bagged chemicals. Avoid welding around oil and grease when possible, and when that's not possible, at least provide for ventilation of fumes. When welding or cutting is done in the vicinity of any combustible material, you must take special precautions to prevent sparks or slag from reaching the combustible material and causing a fire

Regarding the safety of other personnel in the welding area. eye protection comes first The person using the welding equipment must wear protective clothing, gloves, helmets and goggles Others in and around the welding operation should be kept at a safe distance. Always be careful of overhead welding because of falling sparks and slag If other operators are (or must be) working in the vicinity of the welding operation, they too must be protected from the rays of arc welding, never look at the welding operation without eye protection.

The storage of welding gas cylinders should be given the same consideration as those of other gases in water treatment. They are stored upright, kept out of radiation of heat and sunlight and stored with protective covers in place when not in use. Store cylinders away from elevators and stairs, and secure them with a chain or other suitable device.

20.37 Safety Valves

There are quite a number of safety valves in a water treatment plant, operators are not always aware of their locations or functions For example, most operators know of the safety plugs on chlorine cylinders, but there are also large safety valves in any plant that stores large amounts of chlorine on site. These containers take on truck load lots of 17 tons (15,540 kilograms). The safety valves on such containers should be certified at least every two years or as often as the state requires. Such relief valves must be maintained on a regular basis. Inspect the inside of these tanks at regular time intervals and keep a record of the findings, for example, evidence of deposits and corrosion.

Water heater safety valves should be checked on an annual basis and maintained or replaced as needed. If the plant has a boiler room, the steam safety valve should be maintained and checked for proper operating pressures. These valves should not discharge in such a manner as to be a hazard to operating personnel.

There also may be surge relief valves on discharge piping (high lift) of the treatment plant. These valves also act as a safety valve to the pumping equipment and must be maintained on some regular time interval. They should be checked for proper pressure setting, with all pilot valves being reconditioned or replaced as needed.

There may be other safety valves located in the pumping plant's hydraulic system for opening and closing discharge valves that require maintenance. In the maintenance of water treatment plants, you or your supervisor must set up a maintenance system for all equipment. Hand tools, power tools and other maintenance equipment must also be kept in safe working condition. Operators must be furnished protection for the eyes, the ears, the hands, the head, feet and at other times, the body. Work areas should be well ventilated and noise should be reduced whenever possible. Each operator should always be on the lookout for additional ways of making the treatment plant a safer place to work.

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[5] *Decibel (dB) (DES-uh-bull) A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average level at which sound causes pain to humans.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 440

20.3F What type of protection do operators need when operating portable power tools?

20.3G How can operators be protected from high noise levels when operating air drills and circular saws?

20.3H What personal protection should be used when operating welding equipment?

20.4 VEHICLE MAINTENANCE AND OPERATION

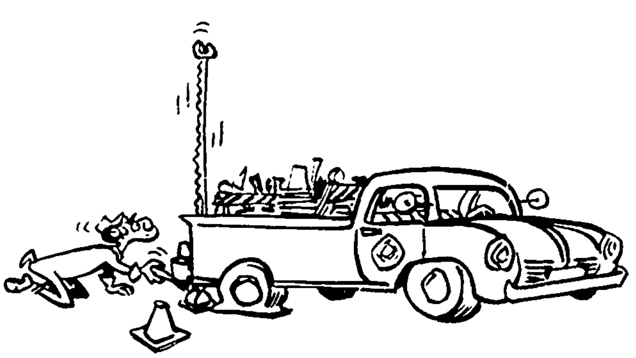
20.40 Types of Vehicles

Many types of vehicles are used in the waterworks industry. However, the plant operator may only come into contact with a few. Cars, pickup trucks, forklifts, dump trucks and some electrically driven cars are the types of vehicles the operator is most likely to be involved with and need to maintain. In addition to motor vehicle safety, this section will also consider the storage of fuel for these and other engines in the plant.

20.41 Maintenance

To have a safe motor vehicle, there must be a preventive maintenance program. Figure 20.9 gives a checklist for finding potential safety problems and a means of recording the preventive maintenance.

Tire inflation is a good example of proper safety checks Not only is it unsafe to operate on under inflated tires, but it also causes undue wear on the tire. Therefore, tires should be checked regularly for wear, which may be caused by misalignment or low inflation. If tires are badly worn, they should be replaced. Always maintain the recommended pressure in the tires. when checking, set the hand brake and turn off the motor.



Next, when changing tires, be sure the jack you are using has sure footing Position the jack at right angles to the direction of the lift Jacks are a problem in general, and you should make sure that proper jacks are in each vehicle. In other words, select the proper jack for each job and choose only one that is safe and strong enough. If blocking is required, only use safe supports, avoid leaning the jack and protect hands Always stay a safe distance from the jack handle as many injuries are caused by flying jack handles. Also, injuries are caused by overloading jacks. In addition, where needed, use braces or other supports to prevent tipping the vehicle over, another cause of serious injuries.

Fueling motor vehicles also involves some hazards. Always stop the vehicle's engine. Remember to remove the fuel hose immediately after using it. You could start a fire if you carelessly drive off with the hose still attached. Also, make sure the cap is replaced tightly on the tank. Do not permit smoking in the vicinity of gas delivery pumps at anytime. Avoid any sparks, and skin contact. Use only high-flash point solvent for cleaning up any gasoline. Some other safety tips when refueling are: do not let the tank overflow, always set the brake, hang nozzle up properly onto the pump and eliminate any leaks on the hose connections.

Most small water treatment plants do not have hoists or pits for vehicle lubrication. However, most of the following suggestions are applicable. First, keep all walkways, steps, tools and containers free from grease, oil and other dirt. This will reduce the possibility of accidents caused by these items. As when maintaining any equipment, use the right tools, keep shoes free of all oil or grease and use only non-slip soles on the shoes.

If the plant is equipped with a hoist, do not permit anyone to remain inside the vehicle when it is on the hoist. When lifting the vehicle, do not permit tools on the hoist or vehicle that may fall onto you or other personnel in the work area. Keep the driveway free of hoses, tools, and cars and always keep you hand on the operating level when raising or lowering the vehicle.

Most water treatment plants have assigned specific areas for washing or steam cleaning vehicles. If your plant does not have such an area, you should have one assigned. This area does not have to be elaborate, but should have water hoses and steam cleaning equipment and be adequately drained. The same safety rules apply to makeshift installations as apply to completely equipped cleaning areas. The most important consideration is the steam cleaner. Keep the nozzle clean, check water level on coils before turning on the flame, and always wear protection for your eyes and face Make sure that the cleaner is adequately ground and be careful of cleaning compounds (see Caustic Section for burns). Maintain steam hoses, check connections and never permit horseplay with steam cleaning equipment. As in other work areas, keep the wash rack free from grease and oil and oily rags. Hoses should be stored on the rack when not in use. Always use scaffolding or platforms when cleaning the tops of vehicles.

20.42 Seat Belts

Many water treatment plant operators have some reason for not wearing seat belts. The reasons may sound good, but they won't protect you in the event of an accident. Many lives would have been saved if seat belts were used. The water utility should equip all vehicles with seat belts and require every operator to use them.

Month ____________ Vehicle Number ____________ Assignment ____________

CHECK		WEEKS				
		1st	2nd	3rd	4th	5th
1	Oil					
2	Water					
3	Tires					
4	Horn					
5	Headlights, High - Low					
6	Tail Lights					
7	Turn Signals					
8	Stop Lights					
9	Battery Water					
10	Fire Extinguisher					
11	First Aid Kits					
12	Windshield Wipers					
13	Visual Inspection - Wire Rope					
14	" " - Hook					
15	" " - Sheaves					
16	" " - Boom					
17	" " - Hydraulic Level					
18	Operational Test Controls					

SERVICE MILEAGE READINGS				FUEL CONSUMPTION	
Week	Present	Last Service	Difference	Start Mileage	
1st				End Mileage	
2nd				Total Miles	
3rd				Fuel Used	
4th				MPG Average	
5th					

Fig. 20.9 Mobile Equipment Check List

20.43 Accident Prevention

The best overall means of preventing vehicle accidents is defensive driving. This method requires training and a certain mental outlook on the part of the vehicle operator. Most, if not all, drivers think they are good at what they do and this may be true to some extent. However, if each driver would operate all vehicles as if all other drivers were the world's worst drivers, accidents would be greatly reduced

Good drivers check out their vehicles each time they use them and have any maintenance performed when needed. They use proper signals for directional change, always observe traffic regulations and show courtesy to others. Remember that drivers in an agency vehicle represent the agency. Therefore, good driving skills are good for public relations.

Another way to avoid accidents is,

"Do Not Tailgate"

This is a very unwise practice which is dangerous to the vehicle and hazardous to its operator. A good rule to use when following another vehicle is the old one-car-length for every 10 MPH, and if there is limited visibility, increase that distance. Another rule is the "Three Second Rule" which says you must be at least three seconds behind the car in front of you. Take precautions when backing up. Always set the brake and/or shift to "Park" when parking the vehicle. Be cautious at intersections. As a defensive driver, always be ready to give the right of way. No right of way is worth injuring oneself.

In some cases, even the most defensive and careful driver has an accident. Because of this, each vehicle should carry flashlights, flares, flags and a fire extinguisher, along with a first aid kit. In the event, of an accident, the driver should know how to fill out all the forms, a supply of which should be provided in the vehicle.

Remember, when operating a vehicle, an accident can be prevented by defensive driving. The plant operator should have each member of the staff take a defensive driver training course. Each driver should develop a defensive driver frame of mind. Developing a good attitude and driving skills are the key to accident prevention when operating a vehicle. In any event, new employees should be given road tests in operating the types of vehicles they will be using.

Here are a few reminders when operating a vehicle. During a storm, roadways or pavement are likely to be slippery. Slow down, pump the brakes when stopping and remember the minimum distance rules. No driver should be required to operate an unsafe vehicle. Keep copies of a suitable form for reporting mechanical problems in each vehicle and encourage operators to use them.

20.44 Forklifts

Most water treatment plants and pumping stations have a forklift. Most, if not all, plant operators use this vehicle to move chemicals, repair parts, and even use it when making repairs to lift heavy objects. Therefore, every plant operator should be trained in the use of the forklift.

Following are a few points regarding safe operation of the forklift with suggestions for operator safety as well as protection of others who may be in the operating area of the forklift. Keep all aisles free of boxes and other debris. Do not permit anyone to ride on the forklift except the operator. Never overload the forklift. Always be sure the warning signals are operational and never leave the power on when leaving the forklift. Like other vehicles, check out the brakes before operating. Be careful at intersections of aisles and always face the direction of travel. If a loaded forklift is to be placed on an elevator, be sure that the load on the forklift and the weight of the vehicle do not exceed the lifting weight of the elevator. Also, make sure the forklift load is stacked properly before lifting or moving. When handling drums, special lifting and retaining devices are needed.

Figure 20.10 is a typical forklift inspection form.

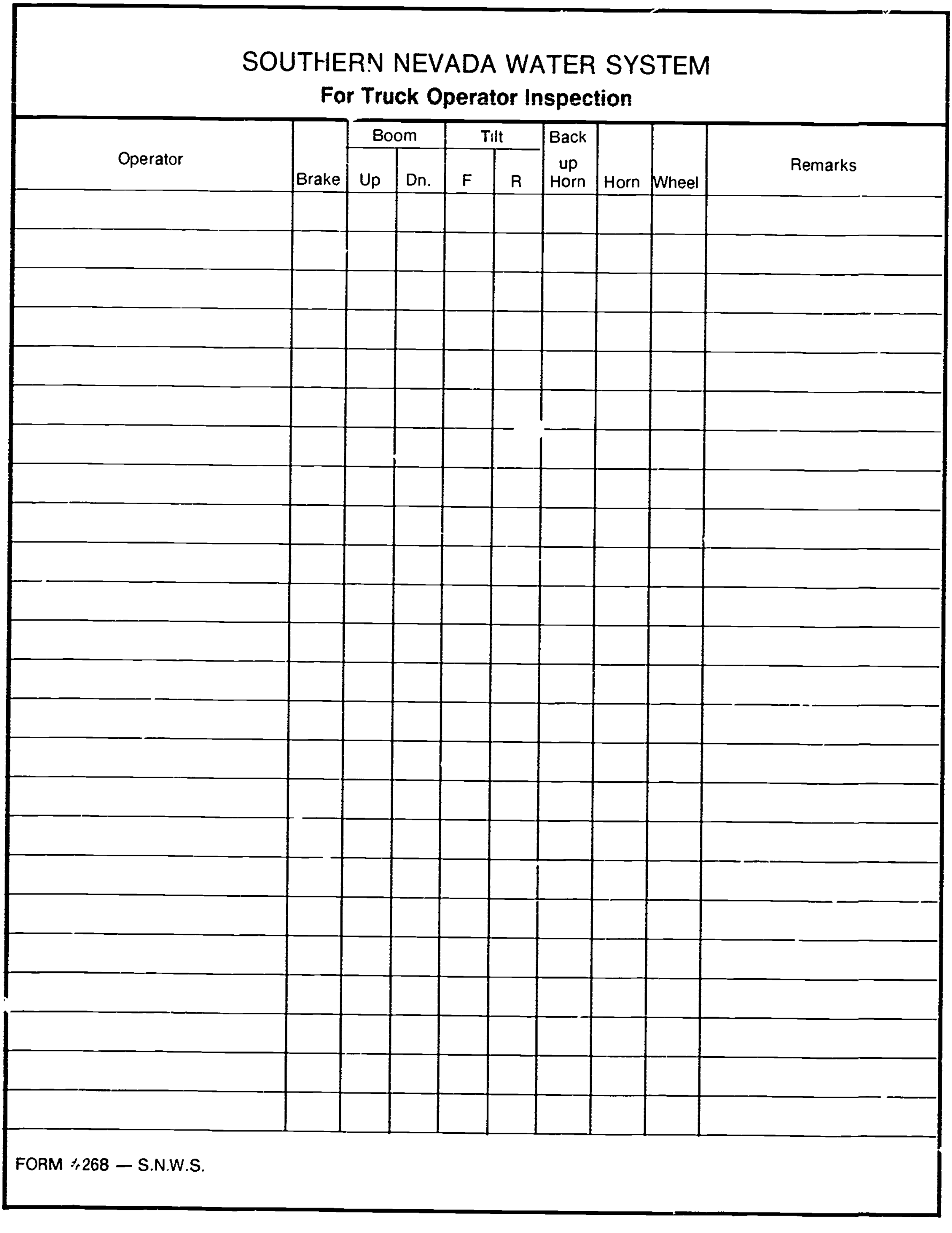
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 440.

20.4A What causes tire wear on motor vehicles?

20.4B Motor vehicles should contain what safety devices?

End of Lesson 3 of 4 Lessons
on
SAFETY



SOUTHERN NEVADA WATER SYSTEM

For Truck Operator Inspection

Operator	Brake	Boom		Tilt		Back up Horn	Horn	Wheel	Remarks
		Up	Dn.	F	R				

FORM #268 — S.N.W.S.

Fig. 20.10 Forklift inspection form

DISCUSSION AND REVIEW QUESTIONS

Chapter 20. SAFETY

Lesson 3 of 4 Lessons)

Write the answers to these questions in your notebook before continuing The problem numbering continues from Lesson 2.

21 How can an operator prevent fires in a water treatment plant?

22. How would you maintain water-type fire extinguishers?

23. How would you maintain fire hoses in your water treatment plant?

24 What precautions should be taken in areas where flammable material is stored?

25 How can an operator make visitors feel as if the water being produced is safe to drink?

26 How would you remove a manhole cover?

27. What precautions should be taken when operating power tools in a wet or damp location?

28. What fire hazards should be considered before doing any welding?

29. How would you safely refuel a motor vehicle?

30 What safety precautions should be taken when driving during a storm?

CHAPTER 20. SAFETY

(Lesson 4 of 4 Lessons)

20.5 ELECTRICAL EQUIPMENT

20.50 Electrical Safety

As a water plant operator, you are not expected to be an expert in electrical equipment, but you must have a working understanding of electricity. This includes an understanding of the safety precautions needed to operate the electrical equipment. After all, electrical energy is required to power most of the treatment plant operations. The objective of this section is to show you how to operate safely and to become involved to a limited degree in the maintenance of electrical equipment. Electricity is unforgiving to the careless treatment plant operator.

20.51 Current — Voltage

Many types of electrical current are used in water treatment plants and the associated pumping plant. Each day the plant operator is exposed to this equipment, giving little thought to the potential hazards of the equipment. Current may come into the plant at a high voltage, for example, 69 KVA, reduced to 4160 volts or 2300 volts. This current may power pump motors, blowers and other equipment at lower voltages of 440, 220, or 120 volts and within starters may be reduced to 24 or 12 volts or changed over into DC voltages. Given all of these various voltages, the operator must be careful not to become careless working with equipment. Therefore, become familiar with the types of current and voltage in the plant. By knowing this, you will avoid the mistake of becoming involved with unsafe electrical currents or practices for which you are not trained. This will also enable you to know when to ask for a qualified person to perform any necessary repairs.

20.52 Transformers

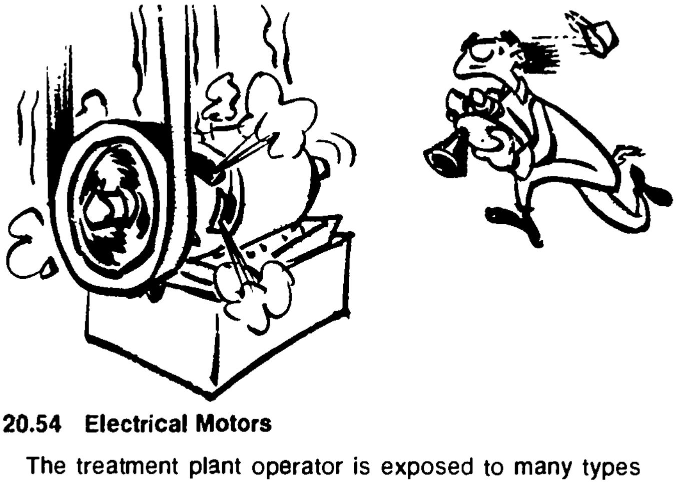
Electrical power entering a plant is routed through transformers to reduce the voltage in most cases. There are many types of transformers although the operator may only think of the larger ones that bring the power into the plant. Sometimes these are owned by the waterworks and therefore the maintenance is the responsibility of the operator. There are few, if any, plant operators who are qualified to perform such maintenance. Never attempt to work on a high voltage transformer without the assistance of qualified personnel. Such personnel can be located at the power company or contact an electrical contractor who specializes in the repair and maintenance of electrical transformers. You will, however need to keep records of the transformer's operation. This information is helpful to repair personnel and is useful to operators who need to know the status of the transformer.

There are many small transformers within the plant's operating gear and it is these you may have to maintain. Most often these low-voltage transformers become overworked; they overheat and burn out. Any fire in the electrical gear can be hazardous. Be very careful when opening a starter, breaker box or indicating instrumentation if a fire or overheated transformer is suspected. Operators have been badly burned by not thinking before opening such devices when they smell smoke in pumping stations or treatment plants. When solving problems with hot, overheated, or burning transformers, remember what you learned in Section 20.2 about electrical fires. For the safety of operating personnel and the safety of the plant, regularly inspect or have someone inspect both large and small transformers. If you detect any overheating, have a qualified electrician inspect and replace any transformer that is not functioning properly.

There should be a fence around the transformer station, with a locked gate and only a limited number of keys issued to plant personnel. The operator may perform routine preventive maintenance such as removing weeds, brush and general cleanup. Replacing fuses and major maintenance or repairs should be made by the power company or qualified electricians. Maintenance must be performed by qualified and well trained personnel.

20.53 Electrical Starters

As a treatment plant operator, your most frequent contact with electrical power will probably be with electrical starters on the motor control panels. These devices are used throughout the plant and provide an interface between the operator and the flow of energy. The starter may be located on a switch panel or there may be a switch that is remotely located from the starter. One of the first safety procedures you should take is to use a special insulated mat on the floor at all switchboards. The starter should be provided with adequate lighting and clearly marked Start-Stop buttons. Replace indicating lights as needed without delay. There should always be clear and adequate working space around the starter or switch panels. To reduce the hazards of fire in electrical starters, they should be cleaned and maintained on a regular basis. Such maintenance must be performed by trained, qualified personnel. In electrical starting equipment, fires can easily occur because of accumulation of dust and dirt on the contactors, or when they become so badly burned that they do not make proper contact; thus, they become overheated and start fires. The key to preventing fires in starting equipment is a good preventive maintenance program.



20.54 Electrical Motors

The treatment plant operator is exposed to many types and sizes of electrical motors. In some plants, the motors are old and require more attention because of exposed parts. The newer electrical motors are enclosed and have all parts protected. For the old motors, you should install guards or guard rails to prevent accidental contact with live parts of the motors.

Some of the electric motors may have exposed couplings, pulleys, gears or sprockets that also require consideration For these and other moving devices, a wire cloth gear guard may be installed The gear guard can also be made of sheet metal However, no matter which type of guard is used, it must be securely fastened onto the floor or some other solid support The safeguards must be constructed and fitted to prevent material being handled by operators from coming into contact with the moving parts driven by the motors.

Another consideration is projections on couplings, pulley shafts and other revolving parts on the motor or on the device being driven These projections can be bolts, keys, set screws or other projections The projections should be removed, reduced or protected by one of the above guards.

Check grounding on all electrical motors as part of a routine maintenance program. The motor frames themselves must be grounded if the wires to the motor are not enclosed in an armored conduit or other metallic raceway. Check that all joints are mechanically secure to assure good grounding. In the case of portable electric motors, the simplest way of grounding is an extra conductor in the cord serving the motor. The best way is to install a ground fault interrupter (G F.I.) receptacle. This device will automatically disconnect the tool from the power supply if the ground is not connected and will supply the greatest protection to the operator and to the equipment.

When using portable electrical motors always check the service cord. If the cord or receptacles are in poor condition or showing signs of wear, they should be replaced. A badly worn cord must never be used in a wet location.

20.55 Instrumentation

In this area of water treatment the operator is not exposed to a great deal of hazard, but must give some consideration to these devices since they are operated by electrical current. This is also true of all other automatic equipment. Although most instruments protect the operator, there is still a degree of hazard when changing charts, calibrating or performing other maintenance. First, when calibrating an instrument, you are exposed to at least 12 Volts DC to 120 Volts AC If you become grounded with the 120 Volts AC, you may be killed or severely injured. Also, when maintaining automatic control equipment, adjustment of one instrument may start another device, exposing another operator to a hazard because of an unexpected start. As mentioned above, electronic devices operate on low current, but don't forget that there is still high voltage located somewhere in the instrument.

20.56 Control Panels

Control panels and switchboards should only be accessible to qualified personnel. The plant operator should have a standard operating procedure (SOP) for lockout of all electrical equipment (Figure 20.11). Two hazards due to the lack of a good lockout procedure are (1) accidentally starting a piece of equipment exposing a fellow operator to a hazard, and (2) turning electrical power on when someone is still working on the equipment, exposing that person to danger.

Always provide adequate working space in and around control panels. As with electrical motors, the panels must be well grounded. At some locations there may be a need for special insulating mats, such as in wet locations. Adequate lighting must be available inside the control panel as well as outside for those who do the maintenance Moisture or corrosive gases must be kept away from the control panels. To reduce fire hazard, never store any hazardous material next to switchboards or control panels. Panels carrying greater than 600 volts must be permanently marked warning of the hazards Areas of high voltage should be screened off and locked with a limited number of keys given to authorized personnel only

In a safe lockout procedure, the switches are locked open and are properly tagged, only the operator who is doing the maintenance should have a key. In fact, all people who perform electrical maintenance should have their own individual lock and key so as to maintain control over the equipment being worked on by each individual

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 440.

20 5A Why should each plant operator become familiar with the type of current and voltage in the water treatment plant?

20 5B List the moving parts on electrical motors that require safety guards

20 5C What are two hazards created by the lack of a good lockout procedure for control panels and switchboards?

20.6 LABORATORY SAFETY[6]

20.60 Laboratory Hazards

In general, water plant operators do not experience a great deal of exposure to hazardous laboratory conditions. However, you will be in contact with glassware, toxic chemicals, flammable chemicals, corrosive acids and alkalies. There may be times when you will be exposed to hazardous bacteriological agents. The seriousness of the hazards depends mainly upon the size of the plant and the operating procedures in the treatment plant. For your own safety, learn the proper procedures for handling laboratory equipment and chemicals.

20.61 Glassware

An important item in laboratory safety is handling of glassware Almost all tests performed by an operator will require the use of some glassware. The operator's hands, of course, are exposed to the greatest hazard. To reduce accidents when handling glassware, never used chipped, cracked or broken glassware in any testing procedures. All such glassware should be disposed of in a container marked "For Broken Glass Only" Never put broken glass in wastebaskets Although it may not be a hazard to the operator, it is a danger to those who clean out the wastebaskets. Clean up any broken glass and/or spilled chemicals to reduce hazards to others. Never let broken pieces of glass remain in the sink or in sink drains. This may cause cuts to others who unknowingly try to clean the sink.

Washing glassware is always potentially hazardous. The glassware can be broken while being washed, causing cuts, or cuts can be caused by chipped or cracked glassware. Also, the cleaning compounds themselves can be a problem. Sometimes strong acid cleaners are used to remove stains

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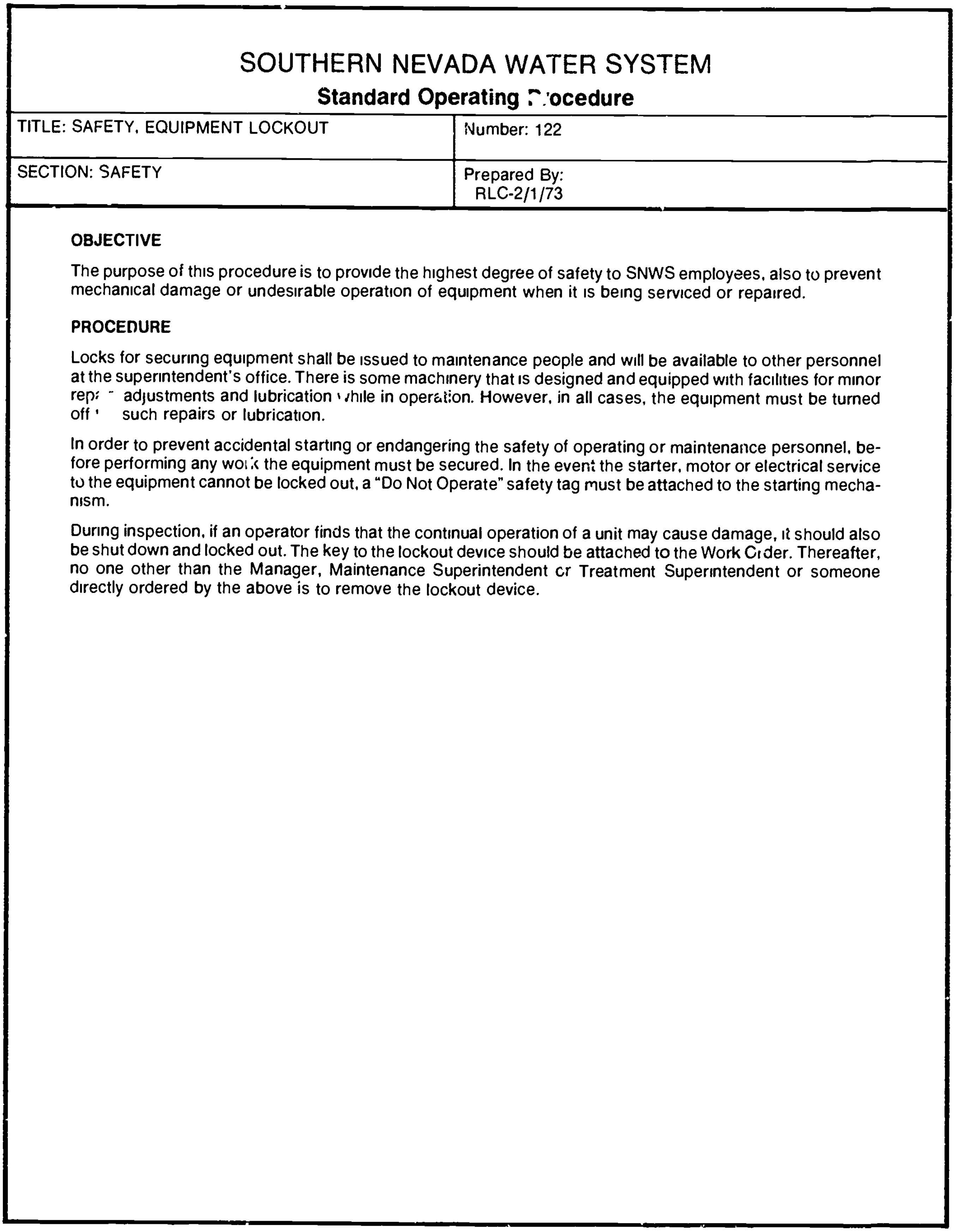
[6] *See FISHER SAFETY MANUAL. Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, PA 15210.*



SOUTHERN NEVADA WATER SYSTEM

Standard Operating Procedure

TITLE: SAFETY, EQUIPMENT LOCKOUT	Number: 122
SECTION: SAFETY	Prepared By: RLC-2/1/73

OBJECTIVE

The purpose of this procedure is to provide the highest degree of safety to SNWS employees, also to prevent mechanical damage or undesirable operation of equipment when it is being serviced or repaired.

PROCEDURE

Locks for securing equipment shall be issued to maintenance people and will be available to other personnel at the superintendent's office. There is some machinery that is designed and equipped with facilities for minor repairs, adjustments and lubrication while in operation. However, in all cases, the equipment must be turned off [illegible] such repairs or lubrication.

In order to prevent accidental starting or endangering the safety of operating or maintenance personnel, before performing any work the equipment must be secured. In the event the starter, motor or electrical service to the equipment cannot be locked out, a "Do Not Operate" safety tag must be attached to the starting mechanism.

During inspection, if an operator finds that the continual operation of a unit may cause damage, it should also be shut down and locked out. The key to the lockout device should be attached to the Work Order. Thereafter, no one other than the Manager, Maintenance Superintendent or Treatment Superintendent or someone directly ordered by the above is to remove the lockout device.

Fig. 20.11 Standard operating procedure for locking out of electrical equipment

from the glassware. Without protective gloves, you hands could be seriously burned by these acids.

20.62 Chemicals

When handling liquid chemicals such as acids and bases, always use safety glasses or face shields. If working with ether or chloroform, avoid inhalation of fumes and always do this type of work under the ventilation hood. Be sure to turn the ventilation fan on. Of course, be careful of open flames when using flammables such as ether. As a general rule, do not permit smoking in the laboratory. All chemicals should be stored in proper locations; do not set chemicals on the laboratory benches where they may cause an accident if spilled or if the container is broken.

When handling laboratory gases, give consideration to their location and potential accident hazards. Gas cylinders must be prevented from falling by using safety retaining devices such as chains. The valve and cylinder regulator should be protected from being struck by stools, ladders and other objects.

When mixing acid with water, always pour the acid into the water while stirring.

Never add water to acid because the water may remain on top of the acid, thus causing splattering and excess heat generation.

Always use safety goggles, gloves and protective garments. When cleaning up acid or alkali spills, dilute with lots of water even if you flush them down the sink drain. Baking soda can be used to neutralize acids, and vinegar is used to neutralize bases. Never allow mercury, gasoline, oil or organic compounds into the laboratory drains. Use only a toxic waste disposal drain system for these items. Pouring such compounds down sink drains can cause an explosion, allow toxic gases and vapors to enter the lab, or destroy the piping.

You must never use your mouth with the pipet for transferring toxic chemicals, acids or alkalis. Use a suction bulb, aspirator, pump or vacuum line. If you use your mouth, there is always the danger of getting the toxic solutions into your mouth.

20.63 Biological Considerations

Do not take chances with bacteria. A good policy is to have each operator immunized with anti-typhoid vaccine and to keep their booster shots current. Always use good sanitary practices, particularly when working with unknown bacteria or known pathogens. Never pipet bacteriological samples by mouth. *ALWAYS USE A PIPET BULB.*

When exposed to any bacteria, you should make it a habit to always wash your hands before eating or smoking. If you have any cuts or broken skin areas, these wounds should not come in contact with bacterial agents. You should wear protective gloves or cover the wound with a bandage when working with any kind of bacteria.

All work areas should be swabbed down with a good bacteriological disinfectant before and after preparing samples. As a general policy, the preparation or serving of food should never be permitted in the laboratory. Also, give some consideration to proper ventilation, because some bacteria may be transmitted via the air system.

20.64 Radioactivity

There are many laboratory and treatment plant instruments that use radioactive isotopes in laboratory tests and research. A plant operator may be exposed to radioactive compounds when calibrating sludge density meters or using research isotopes. From a safety standpoint, only qualified personnel should be involved in the use of radioactive compounds. If radioactive compounds are present in the laboratory, warning signs should be posted. The disposal of all radioactive compounds must be performed strictly by qualified laboratory personnel in accordance with government regulations.

20.65 Laboratory Equipment

20.650 Hot Plates

You will probably use a hot plate in your threshold odor number (TON) tests. You should turn the hot plate off when not in use, never place bare hands on the hot plate to check if it is hot. When using the hot plate to remove gas or fumes, always use the hood and turn on the hood ventilation fan. Never place glassware onto a hot plate if the outside of the glassware has water or moisture on the surface between the glass and the hot plate. Steam will form at this interface and cause the glass to break. When taking hot glassware off the hot plate, always use asbestos gloves.

20.651 Water Stills

Most water stills in the laboratory today are the electrical type. To observe good safety practices, check the items described in the electrical safety section of this chapter, such as good grounding. Set up a SOP (Standard Operating Procedure) for proper operation of the still and follow the manufacturer's instructions for proper starting and stopping. The still will require cleaning from time to time. Be very careful when disassembling the still. Parts may be frozen together because of hardness in the water and may require an acid wash to separate. Be sure that the boiler unit is full of water before turning the still on. Never allow cold water into a hot boiler unit because it may cause the unit to break.

20.652 Sterilizers

There are two types of sterilizers: (1) dry electrical sterilizers and (2) wet sterilizers (autoclaves). In the dry electrical sterilizers, check the cords frequently because the high heat may damage the wiring. Always let the unit cool off before removing its contents. Wet sterilizers (autoclaves) are under pressure by steam and should be opened very slowly. Use asbestos gloves and protective clothing when unloading the autoclave. Cover the steam exhaust with asbestos covering to prevent burns. Any leakage around the door should be repaired by replacing door gaskets, or even the door if it is worn or bent Always load the autoclave in accordance with the manufacturer's recommendations. Never allow an operator to work with this equipment without proper instruction in its operation.

20.653 Pipet Washers

Cleaning pipets can be hazardous. Many laboratories have a pipet cleaner which contains an acid compound or other cleaning agents. Always use protective clothing and a face shield when working with the washer unit. Try to avoid dripping or spilling the cleaning compound when transferring the pipets. If the acid comes into contact with your skin, use the remedies recommended in Section 20.11, "Acids."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 440.

20.6A Why is washing glassware always a potential hazard?

20.6B What precautions should be taken when handling liquid chemicals such as acids and bases?

20.6C Why should mercury, gasoline, oil or organic compounds never be allowed into laboratory drains?

20.6D How can an operator be exposed to radioactive compounds?

20.6E Why should cold water never be allowed into the hot boiler unit of a water still?

20.7 OPERATOR PROTECTION

20.70 Operator Safety

So far in this chapter we have discussed many means by which you can protect yourself and your equipment. In this section we wish to discuss your own personal protection. Take a look at the means of protecting the eye, the foot, the head and most of all — look at water safety. After all, a plant operator is always in contact with water. The water may be found in raw water reservoirs, settling basins, clear wells or filters. Operators have lost their lives by falling into the backwash gullet. Operators have lost their lives in the finished water reservoirs. As unlikely as it seems, fatal accidents have happened in the past and will happen again in the future. Therefore, it is the responsibility of each operator to watch for any safety problems in the plant's reservoirs, pumping stations, or filters You, the operator, are responsible for yourself. You should never expose yourself to unsafe conditions.

A major problem confronting many operators is where an how can reliable safety vendors and equipment be locate State, regional and national professional meetings, such as those sponsored by the American Water Works Association, often have displays or exhibits featuring manufacturers of safety equipment. This is an excellent opportunity to meet the representative of these companies and discuss with them what equipment they would recommend for your situation. Also other operators who have had experience with safety equipment of interest to you often attend these meetings and are anxious to share their experiences with you.

If you are unable to attend these meetings, the program announcements will often have a short description of the types of safety equipment that will be featured by each vendor exhibiting at the conference You can obtain the vendor's address by looking in professional journals, buyers' guides or by writing to the sponsor of the conference.

20.71 Respiratory Protection

There are many respiratory hazards in and around the treatment plant that an operator is exposed to daily including chemical dusts, chemical fumes, and chemical gases such as chlorine, ammonia, sulfur dioxide, and acid fumes, to name only a few. Whenever working around or handling these and other compounds, you must take adequate precautions.

Two types of conditions for which you should be prepared are: (1) oxygen deficient atmosphere, and (2) sufficient oxygen, but a contaminated atmosphere containing toxic gases or explosive conditions. In either circumstance you will need an independent oxygen supply. However, an independent oxygen supply will not protect you from an explosion.

Never enter a confined space with an explosive atmosphere.

Call your local gas company and ask their experts to enter the explosive area, if entry is essential. Your independent oxygen supply should be of the positive-pressure type to protect you if there are any leaks. Good ventilation can reduce explosive conditions.

20.72 Safety Equipment

All waterworks safety equipment such as life lines, life buoys, fire extinguishers, fencing, guards, and respiratory apparatus must be kept in good repair. This and other safety equipment is necessary to protect operators or visitors from injury or death. Safety equipment may fall into disrepair because it is only used occasionally and may deteriorate due to heat, time and other environmental factors. First aid equipment should also be provided and kept resupplied as it is used. The operating staff should be given regular instructions in the use and maintenance of the safety equipment.

Provide protective clothing for all operators handling chemicals or dangerous materials. Keep the clothing clean and store it in a protective environment when not in use.

The water utility is responsible for providing outward opening doors, remote-controlled ventilation, inspection windows and similar safety devices where appropriate. This equipment should be exercised, kept clean and well maintained so that it will operate when needed.

Respiratory (self-contained breathing) apparatus must be stored in unlocked cabinets outside of chlorination, sulfur dioxide, carbon dioxide, ozone and ammonia rooms. The storage cabinets must have a controlled environment to prevent deterioration of the equipment.

The operator has the responsibility to inspect each apparatus for deterioration and need for repair. Safety equipment is of no use to the operator if it fails when put to use, and may cost you your life if it is in poor condition. Some self-contained breathing apparatus (air packs) depend on compressed air to supply the oxygen. Under conditions of deficient oxygen supply, the canister type of respirator is useless. You could lose your life by entering a room containing chlorine gas (which is heavier than air) while depending on a poorly maintained respirator. Although you might have protection from the chlorine, you would not have adequate oxygen. Never take a chance with a toxic gas. In water treatment plants, use only the positive-pressure type of self-breathing apparatus.

Many newer plants are being constructed with independent air supplies consisting of a helmet, hose and compressed air. The helmet is connected by a hose to an uncontaminated air source. The key word here is "uncontaminated." Not only should the operator follow a maintenance program for the hose and mouth pieces of the apparatus, but the operator must maintain the air supply. The air is supplied by mechanical equipment which requires maintenance. The air pressure is controlled by a reducer or regulator which must be kept clean and maintained to be available when needed. Set up a preventive maintenance program for this equipment. It should be checked out on a weekly basis, and records should be kept of each inspection. The record should show conditions of the hoses, regulators, air filters, compressors, helmet and any other apparatus furnished with the system.

The old standby, of course, has been the air packs or self-breathing apparatus. These units are carried by the user, giving the operator an independent source of air (oxygen). The unit can be used in any concentration of contamination of gases, dust or anywhere the atmosphere is oxygen deficient. There are two types of units. One type of unit depends on compressed air or oxygen, and the second system generates oxygen by use of chemicals in a canister. The oxygen is generated by the moisture exhaled by the user. Because this equipment is not used daily in the water treatment plant, there must be a preventive maintenance program, with records, inspection and operator check out. As with any system, self-breathing equipment requires maintenance. This is vital because the operator's life will depend on how well this apparatus performs.

Training is another important consideration. Even though you may have used the breathing apparatus many times in the past, you should be checked out each month on the equipment. There should be a maximum allowable time for putting on the apparatus. The apparatus should be checked out under field conditions, such as using ammonia or some other non-toxic gas. Remember, it is too late to learn how fast an operator can put on a self-breathing apparatus when a room is filled with chlorine.

Be aware that there have been cases where operators have been saved because they knew how to use the breathing apparatus properly. Only repeated practice will enable you to master this survival skill.

20.73 Eye Protection

The water treatment plant operator has only two eyes. You may think that everyone is aware of this fact. However, some operators behave as though they have many eyes and are very careless about protecting them from hazards.

Because some operators fail to see the value of eye protection, it will take a maximum effort on behalf of the supervisory staff to enforce an adequate eye protection program. There must be an intense program of education, persuasion, and appeal to guarantee compliance with an eye protection program.

Most conditions in which a plant operator needs eye protection are not too difficult to understand. Eye protection is needed when handling many of the liquid chemicals, acids and caustics. Some of the tests performed in the laboratory require eye protection. Only a few moments are required to put on a face shield or safety glasses, and remember — the loss of an eye will last a lifetime.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 440.

20.7A When entering an oxygen-deficient atmosphere, what type of oxygen supply is recommended?

20.7B Where should respiratory apparatus be stored?

20.7C How frequently should independent air supply equipment be checked out and what should be inspected?

20 7D How can compliance with an eye protection program be encouraged?

20.7E Under what conditions does an operator need eye protection?

20.74 Foot Protection

There are few situations under which a water treatment plant operator needs foot protection. In the normal routine of daily operation of the plant, there are not many hazards to the operator's feet. But in some plants the operator also performs plant maintenance. Here the steel toed safety shoes are useful. The shoe should be able to resist at least a 300-pound (136 kg) impact. An important consideration in any plant under operating conditions is the use of rubber boots. The rubber boots are needed when handling acid or caustic, or when the operator is working in wet conditions such as reservoirs, filters or chemical tanks. Under these circumstances, the agency should have an adequate supply of boots in various sizes. If these conditions are something that the operator is exposed to daily or weekly, the agency should give the operator a pair of boots for personal use.

20.75 Hand Protection

The treatment plant operator's hands are always exposed to hazards. These include not only minor scratches or cuts, but also exposure to chemicals that may not attack immediately. Some compounds, such as alum, attack the skin slowly. Because there is no immediate pain, you may think there is no damage. This is not true; the attack on the skin is slow and may cause an infection at a later date. Therefore, when handling chemicals, always use rubber gloves. As part of a safety package, each operator should be issued a pair of rubber gloves and also a pair of leather gloves. These gloves should be replaced when they no longer provide the necessary protection.

There are other compounds such as solvents that will absorb through the skin and can cause long-term effects. For such special problems, there is a need for neoprene gloves. Another problem is that of handling hot materials, such as laboratory flasks and beakers. Here you may need asbestos fabric gloves. When working around machinery that is revolving, wearing gloves or other hand protection can be dangerous. If a glove gets caught in the machinery, you could become injured. Don't let your protective equipment itself become a hazard.

Be sure that the gloves you are wearing are the right type for the job you are doing. The gloves should allow for quick removal and be in good condition. Always check for cracks and holes, flexibility and grip. Keep them clean and in good condition. There are many types of gloves and the proper type should be worn for each job.

1. *CLOTH GLOVES* protect from general wear, dirt, chafing, abrasions, wood slivers and low heat.
2. *LEATHER GLOVES* protect from sparks, chips, rough material and moderate heat.
3. *RUBBER GLOVES* protect against acids and some chemical burns.
4. *NEOPRENE AND CORK-DIPPED GLOVES* give better grip on slippery or oily jobs.
5. *ASBESTOS OR ALUMINIZED GLOVES* are heat-resistant to protect against sparks, flames and heat.
6. *METAL MESH GLOVES* protect from cuts, rough materials and blows from edge tools.
7. *PLASTIC GLOVES* protect from chemicals and corrosive substances.
8. *INVISIBLE GLOVES* (barrier creme) protect from excessive water contact and from substances which dissolve in skin oil.

20.76 Head Protection

In most areas of a water treatment plant, there is really no need for a hard hat. However, there are certain hazardous conditions under which the operators should be required to wear a metal, plastic-impregnated fabric, or fiberglass hat. The hard hat should have a suspended crown with an adjustable head band; provide good ventilation; and be water resistant. Operators should be required to wear the hard hats when work is being performed overhead, or in any location where there is danger of tools or other materials falling, for example, working in filters, settling basins or trenches. There has been a long history showing the value of hard hats in reducing injuries and death.

20.77 Water Safety

Every operator in a treatment plant is exposed to situations in which the operator's life can be lost due, either directly or indirectly, to water. Although during your daily activity you may never think in terms of drowning, this hazard is always present in the treatment plant. If you are working at a reservoir or a lake in a boat, you may think of water safety, but still never pay real attention to the danger.

Starting at the treatment plant, you can take simple measures that will reduce hazards. To reduce the hazard of slipping when working around clarifiers or settling basins, use non-skid surfaces on ladders and walkways going into and out of clarifiers or sedimentation basins. Be very cautious during cold or wet weather. Water freezes into ice which is slippery.

Keep all handrails or other guards in good repair; replace any that become unsafe. Many older plants do not have protective handrails; install rails or chain off the unsafe area to all employees and mark off with warning signs. The unsafe areas can be guarded with ⅜-inch (9 mm) manila rope, chains or cables that you may have around the plant.

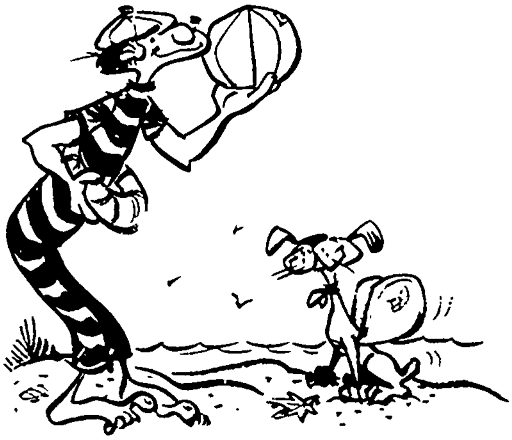
Filters are an important area of safety consideration because there is always activity in or around each filter, such as washing or maintenance. Here you should make repairs to handrails immediately when needed. Station emergency gear around the filter areas; equipment such as life jackets are good, but buoys, ⅜-inch (9 mm) manila line or a long wooden pole are much more useful. These types of devices can be used to rescue someone who has fallen into the filter. An operator should never work in the filter when it is being backwashed. There is always the danger of falling into the washwater gullet and being unable to get out before drowning.

Sedimentation basins, flocculation basins or clarifiers present many of the same problems as filters. Maintain handrails, place warning signs or put up guard ropes or chains. Also keep life rings and manila or nylon lines in good repair. A lift ring, life pole and lines should be stationed at each basin. A good idea is to shelter the safety gear from the weather, but do not cause the gear to become inaccessible.

In reservoir operation and maintenance you will encounter two types of water: (1) raw water and (2) treated water. In a raw water reservoir or lake, you have to worry only about personnel safety. In a treated water reservoir, you must also be concerned about the safety of the water going to the customer. If you are working out of a boat, make sure that everyone in the boat is wearing a life jacket. Also take on board both a safety line and buoys. Cold weather conditions are an added problem. Even though you may be a good or excellent swimmer, the thermal shock of cold water may quickly paralyze you, making you unable to save yourself. Under such conditions, if a second operator goes into the water to save you, there may be two lives lost.

Of course, when taking a boat out on the water it should first be checked out for safety. Check the bilge pump, ventilation in the compartments, the safety cushions, fire extinguishers, battery and the engine. Also check for safety equipment, life jackets, lights, mooring lines and fuel. If you are applying copper sulfate powder or solution, other safety equipment will be needed, such as respiratory and eye protection equipment. Prepare a detailed equipment checklist to use each time the boat goes out onto the lake or reservoir. The boat should never be taken out on choppy waters or when the wind is high.

On some occasions, there is a need for underwater examination of valves, intake or other underwater equipment or apparatus. Such work should only be performed by employees who are trained in underwater diving. If there are no qualified divers on your staff, you should hire such personnel to do the diving and underwater inspections. There are organizations with people who do this type of work and they are well qualified in underwater examinations. If an operator on staff is to do the diving, the operator should be certified by a local diving school or other certifying agency. The operator's certificate should always be kept current and the operator should be required to perform the number of dives necessary to keep this certification current.



In closing, all plant operators should know how to swim. If they do not, they should take a Red Cross class and learn the minimum fundamentals to save their own lives. Any operator working over open water should be required to wear a buoyant vest. All basins should have approved safety vests, buoys and life lines stationed at outside edges.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 440.

20.7F Under what operating conditions should an operator wear rubber boots?

20.7G Under what specific conditions should an operator be very careful wearing gloves?

20.7H Why should operators never work in a filter when it is being backwashed?

20.7I What items should be checked before an operator takes a boat out in the water?

20.8 PREPARATION FOR EMERGENCIES[7]

Emergencies are very difficult to plan and prepare for because you never know what will happen and when it will occur. Catastrophic events could include floods, tornados, hurricanes, fires and earthquakes. Serious injuries to anyone on the plant grounds is an emergency.

Conduct periodic tours of your facilities with the local fire, police and emergency response organizations to familiarize them with the site, potentially hazardous locations, and location of fire hydrants will be very helpful if an emergency ever occurs. Emphasize to these people that if a disaster occurs, how important it is for your plant to be a top priority for assistance because the entire community relies on you for its drinking water.

You should know the names and phone numbers of your local and state civil preparedness coordinators.

If a chemical emergency occurs such as a chemical spill, leak, fire, exposure, or accident, phone *CHEMTREC*, 800-424-9300. *CHEMTREC*, (Chemical Transportation Emergency Center) provides immediate advice for those at the scene of a chemical emergency, and then quickly and promptly alerts experts from the manufacturers whose products are involved for more detailed assistance and appropriate follow up

Prepare a procedure for quick and efficient handling of all accidents or injuries occurring in your treatment facilities and your outside crews. All personnel must be familiar with these procedures and must be prepared to carry them out with a minimum amount of delay or confusion.

A copy of these procedures must be posted in all working areas accessible to a phone and in all vehicles containing work crews. Names, addresses and phone numbers of operators in each working area should be listed in that area and also those immediately available (day or night) by telephone.

Everyone must study these procedures carefully and be able to respond properly and quickly. Your health and life may depend on these procedures.

Table 20.7 is an example of a typical safety procedure and Table 20.8 is a checklist of what must be done if someone is seriously injured.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 441.

20.8A What types of emergencies should operators be prepared to handle?

20.8B Who should be contacted if a serious chemical emergency occurs such as a chemical spill, leak, fire, exposure or accident?

20.9 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.36, "Safety." Work the example problems on your electronic pocket calculator. You should be able to get the same answers.

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[7] *Some of the information in this section was provided by M Richard R. Metcalf, Training Officer, County of Onondaga, New York*

TABLE 20.7 EMERGENCY SAFETY PROCEDURE

1. *DO NOT MOVE THE INJURED PERSON* except when conditions would cause additional injury, such as a gas leak or a fire.
2. *ADMINISTER ONLY SUCH AID AS NECESSARY TO PRESERVE LIFE — TREAT FOR SHOCK*
   (a) clear throat and restore breathing
   (b) stop bleeding
   (c) closed heart massage
3. *DO NOT ATTEMPT MEDICAL TREATMENT* such as
   (a) do not apply splints or attempt to set broken bones
   (b) do not remove foreign objects from the body
   (c) do not administer liquids or oxygen
4. *NOTIFY YOUR SUPERVISOR*

IF AN AMBULANCE IS REQUIRED:

1. CALL AMBULANCE — phone ____________________
2. Give this information carefully and accurately:
   - (a) Location of the injured -- be specific.
     1. Street location and number, Town or City **Remember some streets have north or south or east or west designation — use the full street name. Also, many streets in different towns have the same name — specify the Town.
     2. Location within the Plant area
   - (b) Phone number from which you are calling
   - (c) Number of persons injured and nature of the injury
   - (d) Post an operator to direct the ambulance to the victim
3. Upon arrival of the ambulance:
   - (a) give name, address and phone number of the injured person to the ambulance crew
   - (b) notify relatives of injury and hospital to which person is being taken (Medical treatment cannot be given without the permission of the injured or a relative, if a minor)
4. Call your supervisor

IF AN AMBULANCE IS NOT REQUIRED:

1. Take injured: (see map) (Phone ____________________, ask for Emergency Room)
   Emergency Room
   St. Joseph's Hospital
   301 Prospect Avenue
2. If possible, call ahead. Give the names of injured and nature of injury.
3. Notify relatives of injury and address of hospital
4. Call your supervisor

TABLE 20.8 INJURED PERSON CHECKLIST

1. *CALL AMBULANCE SERVICE,* Phone ______________

LOCATION OF INJURED ____________ ______________
STREET

____
TOWN

____
BUILDING LOCATION

____
PHONE NUMBER

NUMBER OF PERSONS INJURED ______________

NATURE OF INJURY ______________________

2. *POST OPERATOR TO DIRECT THE AMBULANCE*
NAME, ADDRESS, PHONE OF INJURED PERSON

NAME ______________________________

ADDRESS ______________________________

____

______________________________ ____

PHONE ______________________________ __

3. *GIVE ABOVE INFORMATION TO AMBULANCE CREW*
NAME AND LOCATION OF HOSPITAL

HOSPITAL NAME ____ ______________________

ADDRESS ______________________________

____

______________________________ ____

PHONE ______________________________

4. *NOTIFY RELATIVES*
5. *NOTIFY SUPERVISORS*
6. *MAKE OUT ACCIDENT REPORT AS SOON AS POSSIBLE*

SUGGESTED ANSWERS

Chapter 20. SAFETY

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 394.

20.0A A safety officer should evaluate every accident, offer recommendations, and keep and apply statistics

20.0B The supervisors should be responsible for the implementation of a safety program.

20.0C Both state and federal regulatory agencies enforce the OSHA requirements.

20.0D Each utility should develop a policy statement on safety, giving its objective concerning the operator's welfare. The statement should be brief, but give the utility's recognition of the need for safety to stimulate efficiency, improve service, improve morale and to maintain good public relations. The policy should recognize the human factor (the unsafe act), and emphasize the operator's responsibility. The operators should be provided with proper equipment and safe working conditions. Finally, the policy must reinforce the supervisory responsibility to maintain safe work practices.

Answers to questions on page 395.

20.0E A supervisor may be responsible, in part or completely, for an accident by causing unsafe acts to take place, by requiring that work be performed in haste, by disregarding an unsafe environment of the work place, or by failing to consider any number of safety hazards.

20.0F Each operator must accept, at least in part, responsibility for fellow operators, for the utility's equipment, for the operator's own welfare, and even for seeing that the supervisor complies with established safety regulations.

20.0G First aid means emergency treatment for injury or sudden illness, before regular medical treatment is available.

20.0H First aid training is most important for operators who regularly work with electrical equipment and those who must handle chlorine.

Answers to questions on page 399.

20.0I The mainstay of a safety program is the method of reporting and keeping statistics.

20.0J Even a minor injury should be reported because it may be difficult at a later date to prove the accident occurred on the job in order to have the utility accept the responsibility for costs.

20.0K A safety officer should review an accident report form to (1) determine corrective actions and (2) make recommendations.

20.0L A new inexperienced operator must receive instruction on all aspects of plant safety. This training includes instruction in the handling of chemicals, the dangers of electrical apparatus, fire hazards, and proper maintenance of equipment to prevent accidents. Special instructions are required for specific work environments such as manholes, gases (chlorine and hydrogen sulfide (H_2S)), water safety, and any specific hazards that are unique to your facility. All new operators should be subjected to a safety orientation program during the first few days of employment, and an overall training program in the first few months.

20.0M If an operator is unsure of how to perform a job, then it is the operator's responsibility to ask for the training needed.

Answers to questions on page 401.

20.0N Statistical accident reports should contain accident statistics showing lost time, costs, type of injuries and other data, based on some time interval.

20.0O Injuries can be classified as fractures, burns, bites, eye injuries, cuts and bruises.

20.0P Causes of injuries can be classified as heat, machinery, falling, handling chemicals, unsafe acts and miscellaneous.

20.0Q Costs of accidents can be classified as lost time lost dollars, lost production, contaminated water or any other means of showing the effects of the accidents

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 405.

20.10A An operator needs to know how to handle the problems associated with the chemicals used in a water treatment plant. The operator needs to know how to store chemicals, the fire problem, the tendency to "arch" in a storage bin, how to feed dry, how to feed liquid, and how to make up solutions. Overheating gas containers, dust problems with powdered carbon, burns caused by acid, reactivity of each chemical under a variety of conditions that may cause fire and explosions are other safety hazards that an operator needs to know about and know how to control. Also, the operator needs to know the usable limits because of toxicity, the protective equipment required for each chemical, each chemical's antidote, and how to control fires caused by each chemical.

20.11A To give first aid when acid vapors are inhaled, remove the victim to fresh air, restore breathing, or give oxygen when necessary.

20.11B Acetic acid will react violently with ammonium nitrate, potassium hydroxide and other alkaline material.

20.11C Acetic acid can be handled safely if the operator uses adequate ventilation and prevents skin and eye contact.

20.11D When handling hydrofluosilicic acid, always use complete protective equipment including rubber gloves, goggles or face shield, rubber apron, rubber boots and have lime slurry barrels, epsom salt solution and safety showers available. Always provide adequate ventilation.

20.11E Inhalation of hydrochloric (HCl) vapors or mists can cause damage to teeth and irritation to the nasal

SUGGESTED ANSWERS

Chapter 20. SAFETY

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20 11B Acetic acid will react violently with ammonium nitrate, potassium hydroxide and other alkaline material.

20 11C Acetic acid can be handled safely if the operator uses adequate ventilation and prevents skin and eye contact.

20.11D When handling hydrofluosilicic acid, always use complete protective equipment including rubber gloves, goggles or face shield, rubber apron, rubber boots and have lime slurry barrels, epsom salt solution and safety showers available. Always provide adequate ventilation.

20 11E Inhalation of hydrochloric (HCl) vapors or mists can cause damage to teeth and irritation to the nasal

passages. Concentrations of 750 ppm or more will cause coughing, choking and produce severe damage to the mucous membranes of the respiratory tract. In concentrations of 1300 ppm, HCl is dangerous to life.

20.11F Nitric acid should be stored in clean, cool, well-ventilated areas. The area should have an acid-resistant floor and adequate drainage. Keep away from oxidizing agents and alkaline materials. Protect containers from damage or breakage. Avoid contact with skin and provide emergency neutralization materials and safety equipment in use areas.

Answers to questions on page 408.

20.12A Operators use two forms of ammonia. The gaseous form (anhydrous) and the liquid form (hydroxide) are used by operators.

20.12B Care must be used when storing or transporting ammonia containers. Always keep cylinders with caps in place when not in use. Store cylinders in a cool, dry location away from heat and protect from direct sunlight. Do not store in the same room with chlorine.

20.12C The two forms of lime used in water treatment plants are (1) hydrated lime (calcium hydroxide) and (2) quicklime (calcium oxide).

20.12D If someone swallowed sodium hydroxide, give large amounts of water or milk and immediately transport to a medical facility; do not induce vomiting.

20.12E If sodium silicate comes in contact with your skin, wash thoroughly with water, followed by washing with a 10 percent solution of ammonium chloride or 10 percent acetic acid.

Answers to questions on page 412.

20.13A Chlorine leaks are most often found in the control valve.

20.13B The purpose of the fusible metal plugs is to melt at 158 to 168°F. If a cylinder becomes overheated, the plugs will melt and let the gas escape rather than the cylinder bursting.

20.13C Chlorine leaks can be detected by the odor, by the use of ammonia water on a small cloth or swab on a stick, or by the use of an aspirator containing ammonia water. (Remember not to spray ammonia into a room full of chlorine because a white cloud will form and you won't be able to see anything.) Also, a chlorine gas detector may be used.

20.13D Carbon dioxide is a safety hazard because it is odorless, colorless, and will accumulate at the lowest possible level. Carbon dioxide will displace oxygen so you must use a self-contained breathing apparatus.

Answers to questions on page 414.

20.14A For handling most salts, ventilation, respiratory protection and eye protection will prove adequate.

20.14B First aid when liquid or dry alum gets into the eyes consists of flushing them immediately for 15 minutes with large amounts of water. Alum should be washed off the skin with water because prolonged contact will cause skin irritation.

20.14C When exposed to moist air or light, ferric chloride decomposes and gives off hydrochloric acid.

Answers to questions on page 415.

20.15A Potassium permanganate spills can be swept up. Flushing with water is an effective way to eliminate spillage on floors.

20.15B Powdered activated carbon is the most dangerous powder the water treatment plant operator will be exposed to.

20.15C Activated carbon should be stored in a clean, dry, fire-proof location. Keep free of dust, protect from flammable materials, and do not permit smoking in the area at any time when handling or unloading activated carbon.

20.15D The key to preventing activated carbon fires is keeping the storage area clean and free of dust.

20.15E Carbon fires should be controlled by carbon dioxide (CO_2) extinguishers or hoses equipped with fog nozzles. An activated carbon fire should not be doused with a stream of water. The water may cause burning carbon particles to fly, resulting in a greater fire problem.

Answers to questions on page 415.

20.16A Safety regulations prohibit the use of common drains and sumps from chemical storage areas to avoid the possibility of chemicals reacting and producing toxic gases, explosions and fires.

20.16B If a polymer solution comes in contact with potassium permanganate, a fire could develop.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 420.

20.2A Class A fires involve miscellaneous combustible materials. These include fabrics, paper, weed, dried grass, hay and stubble.

20.2B Foam extinguishers can control Class A and Class B fires. They can control ordinary combustibles ("A") such as fabrics, paper, wood and grass, as well as flammable liquids and vapors ("B") such as oils, lacquers, fats, waxes, paints, petroleum products and gas.

20.2C An electrical fire can be extinguished by the use of carbon dioxide (CO_2) extinguishers or with a dry chemical extinguisher.

Answers to questions on page 421.

20.3A When waxing floors use compounds containing nonslip ingredients. Warn others about newly waxed floors. Try to do cleaning and waxing during off-duty hours, weekends or at night.

20.3B Rags are always a problem and if they contain oils, paint or other cleaning compounds there is always the possibility of fire. The rags should be placed into a closed metal container to reduce the fire hazard.

20.3C When operating an overhead crane, the following safety precautions must be exercised:

1. Allow only trained and authorized personnel to operate the overhead crane,
2. Inspect the circuit breaker, limit switches, condition of hook, wire rope and other safety devices,

3. Post load limit on crane and never overload crane,
4. Check each lift for proper balance,
5. Use a standard set of hand signals,
6. Be sure everyone in vicinity wears a hard hat,
7. Allow only authorized personnel to make repairs,
8. Lock out the main power switch before repairs begin,
9. Try to avoid moving loads over populated areas, and
10. Set up monthly safety inspection forms to be filled out and placed into the maintenance file.

20 3D Traffic can be warned that operators are working in a manhole by the use of barricades, signs, flags, lights and other warning devices. Warning devices and procedures must conform to local and state regulations.

20.3E Operators should always use a mechanical lifting aid (rope and bucket) for raising or lowering tools and equipment into and out of a manhole. The use of a bucket or basket will keep your hands free when climbing down into or out of a manhole.

Answers to questions on page 423.

20.3F Operators should wear eye and ear protection when operating grinding, chipping, buffing, or pavement-breaking equipment. Sometimes when using grinding or buffing tools, operators encounter toxic dusts or fumes and therefore need respiratory protection. At other times there is a need for full face protection because of flying particles.

20.3G Operators can be protected from high noise levels by wearing approved ear protection devices.

20.3H When operating welding equipment, the operator should wear protective clothing, gloves, helmets and goggles.

Answers to questions on page 425.

20.4A Tire wear is caused by misalignment and low inflation

20.4B Motor vehicles should have flashlights, flares, flags and a first aid kit.

ANSWERS TO QUESTIONS IN LESSON 4

Answers to questions on page 429.

20.5A Each operator should become familiar with the type of current and voltage in the plant in order to avoid any mistake of becoming involved with unsafe electrical circuits or practices for which they are not trained. This will also permit operators to ask for a qualified person to perform any necessary repairs.

20 5B Moving parts on electrical motors that require safety guards include exposed couplings, pulleys, gears and sprockets, as well as projections such as bolts, keys, or set screws.

20.5C Two hazards due to the lack of a good lockout procedure for control panels and switchboards are (1) accidentally starting a piece of equipment exposing a fellow operator to a hazard, and (2) turning electrical power on when someone is still working on the equipment, exposing that person to danger.

Answers to questions on page 432.

20 6A Washing glassware is always a potential hazard because the glassware can be broken while being washed, causing cuts, or cuts can be caused by chipped or cracked glassware. If your hands come in contact with strong acid cleaners, the acids may cause serious burns.

20 6B When handling liquid chemicals such as acids and bases, always use safety glasses or face shields.

20 6C Never allow mercury, gasoline, oil or organic compounds into the laboratory drains. Use only a toxic waste disposal drain system for these items. Letting such compounds down sink drains can cause an explosion, allow toxic gases and vapors to enter the lab or destroy the piping.

20.6D The plant operator may be exposed to radioactive compounds when calibrating sludge density meters or using research isotopes.

20 6E Never allow cold water into the hot boiler unit of a water still because it may cause the unit to break.

Answers to questions on page 433.

20.7A When entering an oxygen-deficient atmosphere, you should have an independent oxygen supply of the positive-pressure type to protect you if there are any leaks in your mask.

20.7B Respiratory apparatus must be stored outside of chlorinating, sulfur dioxide, carbon dioxide, ozone and ammonia rooms in an unlocked cabinet. The storage cabinets must have a controlled environment to prevent deterioration of the equipment.

20 7C Independent air supply equipment should be checked out on a weekly basis, and records kept of each inspection. The record should show conditions of the hoses, regulators, air filters, compressors, helmet and any other apparatus furnished with the system.

20.7D To obtain compliance with an eye protection program, supervisors should undertake an intense program of education, persuasion, and appeal.

20 7E An operator needs eye protection when handling many of the liquid chemicals, acids and caustics. Many of the tests performed in the laboratory also require eye protection.

Answers to questions on page 435.

20 7F Rubber boots are needed when handling acid or caustic, or when the operator is working in wet conditions such as reservoirs, filters or chemical tanks.

20.7G An operator should be very careful wearing gloves when working around machinery that is revolving.

20.7H Operators should never work in a filter when it is being backwashed because there is always the danger of falling into the washwater gullet and being unable to get out before drowning.

20 7I Before taking a boat out on the water, it should be checked out for safety. The operator should check the bilge pump, ventilation in the compartments, the safety cushions, fire extinguishers, battery and the engine. For safety equipment, check oars, life jackets, lights, mooring lines and fuel.

Answers to questions on page 435.

20.8A Operators should be prepared for catastrophic events such as floods, tornados, hurricanes, fires and earthquakes. Serious injuries to anyone on the plant grounds is an emergency.

20.8B If a serious chemical emergency occurs such as a chemical spill, leak, fire, exposure, or accident, phone CHEMTREC, 800-424-9300

OBJECTIVE TEST

Chapter 20. SAFETY

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. The OSHA Law provides for civil penalties only.
   1. True
   2. False
2. Supervisors can prevent most accidents.
   1. True
   2. False
3. First aid training will prevent accidents.
   1. True
   2. False
4. On-the-job training is a good way of preventing accidents for an inexperienced operator.
   1. True
   2. False
5. Acetic acid exposure must be treated immediately to prevent damage.
   1. True
   2. False
6. Potassium permanganate fires should be extinguished with water.
   1. True
   2. False
7. Some weak bases will attack human tissue very rapidly and cause burns.
   1. True
   2. False
8. Bases must be neutralized with dilute acids.
   1. True
   2. False
9. Ammonia gas is capable of forming explosive mixtures with air.
   1. True
   2. False
10. Never neutralize ammonia with an acid.
    1. True
    2. False
11. Quicklime is less caustic than hydrated lime.
    1. True
    2. False
12. When quicklime is mixed with water, a great deal of heat is generated and explosions can occur.
    1. True
    2. False
13. The loss of water supply to a lime slaker can create explosive temperatures.
    1. True
    2. False
14. The storage area for chlorine cylinders must have force-exhaust ventilation.
    1. True
    2. False
15. Never use an open flame on cylinders or pipes carrying chlorine.
    1. True
    2. False
16. All safety equipment should be located inside the chlorination room.
    1. True
    2. False
17. First aid for a sulfur dioxide victim is similar for the victim of any acid injury.
    1. True
    2. False
18. Never use the same conveyor for quicklime and alum.
    1. True
    2. False
19. Ferric chloride is an acid.
    1. True
    2. False

20 Ferric chloride should be treated as you would treat any acid.

1. True
2. False

21. Activated carbon burns without smoke or visible flame

1. True
2. False

22. Explosion-proof lighting must be used in paint booths.

1. True
2. False

23. Never use compressed air to clean off your clothing or parts of your body.

1. True
2. False

24. Never look at a welding operation without eye protection.

1. True
2. False

25. Chlorine may be the only chemical used in a simple well system.

1. True
2. False

26. A special insulated mat should be used on the floor at all switch boards.

1. True
2. False

27. Badly worn electrical cords should be used only in wet locations.

1. True
2. False

28. In the laboratory, broken glass should be disposed of in wastebaskets.

1. True
2. False

29. Always pour acid into water, never the reverse.

1. True
2. False

30. Never enter a confined space with an explosive atmosphere.

1. True
2. False

MULTIPLE CHOICE

31. A safety officer should be responsible for

1. Applying accident statistics.
2. Evaluating every accident.
3. Implementing safety program.
4. Keeping accident statistics.
5. Offering recommendations.

32. A routine OSHA violation could cost an employer up to ___ for each violation.

1. $1000
2. $2500
3. $5000
4. $7500
5. $10,000

33. A supervisor could be responsible for an accident, in part or complete, by

1. Causing unsafe acts to take place.
2. Disregarding an unsafe work environment.
3. Overlooking a potential hazard.
4. Requiring operators to attend safety meetings.
5. Requiring work to be performed in haste.

34. A review of accident causes shows that the accident victim often has not

1. Accepted any responsibility for the safety program.
2. Acted responsibly.
3. Been concerned about fellow operators.
4. Been fully aware of the working conditions.
5. Complied with the safety regulations.

35. Tailgate safety meetings should be

1. Held where distractions can be avoided.
2. Held where everyone can hear.
3. Held in an auditorium.
4. Kept short.
5. Scheduled in a suitable location.

36. Hydrofluosilicic acid is

1. Corrosive.
2. Fuming.
3. Pungent.
4. Transparent.
5. Yellow.

37. Hydrochloric acid is highly reactive with

1. Amine.
2. Carbonate.
3. Glass.
4. Metals.
5. Porcelain.

38. Nitric acid

1. Attacks glass.
2. Attacks most metals.
3. Forms fumes in the presence of light.
4. Is a powerful reducing agent.
5. Is unstable even when properly handled.

39. Sulfuric acid may be contained in ______-lined containers.

1. Glass
2. Metal
3. Plastic
4. Rubber
5. Wooden

40. The most common strong bases are compounds of

1. Ammonia.
2. Calcium.
3. Carbonate.
4. Hypochlorite.
5. Sodium.

41. Sodium hydroxide

    1. Absorbs carbon dioxide from the air.
    2. Causes heat when mixed with water.
    3. Dissolves human skin.
    4. Is used to neutralize lime.
    5. Is very hazardous to the operator.

42. Dissolving sodium hydroxide in water

    1 Causes splintering.
    2. Develops sludges.
    3. Generates excessive heat.
    4. Lowers pH.
    5. Produces mists.

43. Types of hypochlorite compounds used in water treatment plants include

    1 Calcium.
    2. Iron.
    3. Lithium
    4. Magnesium.
    5. Sodium.

44. Chlorine cylinders may be lifted using

    1. Cables.
    2. Chains.
    3. Clamps.
    4. Cradles.
    5. Ropes.

45. Chlorine cylinders should be stored

    1. Below ground level.
    2 In a clean, dry location.
    3. On their sides.
    4 So they cannot fall.
    5. With the protective cap off.

46. Improper handling, storing or preparing solutions of chemicals can cause

    1. Burns.
    2. Cost savings.
    3. Explosions.
    4. Illness
    5. Loss of eyesight.

47. The most dangerous powder the water treatment plant operator could be exposed to is

    1. Alum.
    2. Calcium carbonate.
    3. Potassium permanganate.
    4. Powdered activated carbon.
    5 Quicklime.

48. The operator's *BEST* fire protection or prevention is

    1. Annually making a fire analysis of plant.
    2 Good housekeeping.
    3. Properly locating fire extinguishers
    4. Providing suitable containers for used wiping cloths
    5. Removal of fire hazards.

49. Class A fires involve

    1. Electrical equipment.
    2. Fabrics.
    3. Oils.
    4. Paints.
    5. Sodium.

50. Hazardous atmospheric conditions that may be encountered in manholes include

    1 Hydrogen sulfide.
    2. Insufficient oxygen.
    3 Methane.
    4. Natural gas
    5. Nitrogen.

51. Which of the following rules apply to the operation of gas or electric welding equipment?

    1. Adequate fire protection must be provided.
    2. Have a buddy observe your performance.
    3. Operators must be thoroughly trained.
    4. Protection of other personnel must be provided and used.
    5 Work during regular hours only.

52. Types of safety valves in a water treatment plant that should be inspected and maintained on a regular basis include:

    1 Butterfly valves.
    2. Chlorine relief valves
    3. Gate valves.
    4. Surge relief valves.
    5. Water heater valves.

53 What safety precautions must be exercised around vehicle wash and steam cleaning areas?

    1. Always use scaffolding or platforms when cleaning the tops of vehicles.
    2 Check level of water on coils before turning on steam.
    3. Eye and face protection is not necessary.
    4. Keep the steam nozzle clean.
    5. Keep the wash rack free from oil and grease.

54. Good drivers

    1. Always observe traffic regulations
    2 Check out their vehicles each time they use them.
    3 Drive defensively.
    4. Operate vehicles as if all other drivers are the world's worst drivers.
    5 Use proper signals for directional change.

55 When safely operating a forklift, be sure to

    1. Always face the direction of travel.
    2 Check warning lights for proper operation.
    3 Leave the power on when leaving the forklift to keep the battery charged.
    4. Never overload the forklift.
    5. Use special lifting and retaining devices when handling drums.

56. The purpose of most transformers where power enters a water treatment plant is to

    1. Decrease electrical resistance.
    2. Detect overheating.
    3. Increase the electrical voltage
    4. Reduce the electrical voltage.
    5. Transform low voltage to high voltage.

57. Hazardous conditions an operator may encounter in the laboratory include

    1. Alkalies.
    2. Distilled water
    3. Flammable chemicals.
    4. Glassware.
    5. Toxic chemicals.

58. Toxic chemicals, acids or alkalis can be transferred with a pipet by using
    1. Aspirators.
    2. Pumps.
    3. Suction bulbs.
    4. Vacuum lines.
    5. Your mouth.

59. Respiratory hazards in and around the treatment plant that operators are exposed to on a daily basis include
    1. Acids.
    2. Bases.
    3. Dusts.
    4. Fumes.
    5. Gases.

60. Types of gloves that an operator may need include
    1. Asbestos fabric.
    2. Cloth.
    3. Leather.
    4. Neoprene.
    5. Rubber.

End of Objective Test

CHAPTER 21

ADVANCED LABORATORY PROCEDURES

by

Jim Sequeira

TABLE OF CONTENTS

Chapter 21. Advanced Laboratory Procedures

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* *Test Procedures in Chapter 11 include alkalinity, chlorine residual, chlorine demand, coliform bacteria, hardness, jar test, pH, temperature and turbidity.*

OBJECTIVES

Chapter 21. ADVANCED LABORATORY PROCEDURES

Following completion of Chapter 21, you should be able to:

1. Explain how a spectrophotometer analyzes samples of water, and

2. Perform the following field or laboratory tests -- algae counts, calcium, chloride, color, dissolved oxygen, fluoride, iron, manganese, marble test, metals, nitrate. pH, specific conductance, sulfate, taste and odor, trihalomethanes and total dissolved solids.

CHAPTER 21. ADVANCED LABORATORY PROCEDURES

(Lesson 1 of 2 Lessons)

21.0 USE OF A SPECTROPHOTOMETER

In the field of water analysis, many determinations such as iron, manganese, and phosphorus are based on the color intensity formed when a specific color developing reagent is added to the sample being tested. Measuring the intensity of the color enables the concentration of the substance to be determined. The simplest means of accomplishing this is through either nessler tubes or a pocket comparator. The color developed in a sample is compared by the operator to a series of known standards, to each of which has been added the same color developing reagents. For the analysis of phosphorus present in a water sample, for example, ammonium molybdate reagent is added as the color developing reagent. If phosphorus is present, a blue color develops. The more phosphorus there is, the deeper and darker the blue color.

The human eye can detect some differences in color intensity; however, for very precise measurements an instrument called a spectrophotometer (SPEK-tro-fo-TOM-uh-ter) is used.

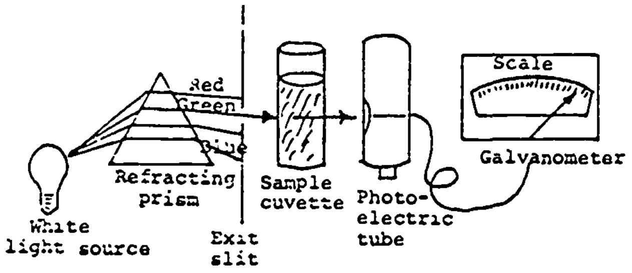
THE SPECTROPHOTOMETER. A spectrophotometer is an instrument generally used to measure the color intensity of a chemical solution. A spectrophotometer in its simplest form consists of a light source which is focused on a prism or other suitable light dispersion device to separate the light into its separate bands of energy. Each different wave length or color may be selectively focused through a narrow slit. This beam of light then passes through the sample to be measured. The sample is usually contained in a glass tube called a cuvette (QUE-vet). Most cuvettes are standardized to have a 1.0 cm light path length, however many other sizes are available.

After the selected beam of light has passed through the sample, it emerges and strikes a photoelectric cell. If the solution in the sample cell has absorbed any of the light, the total energy content will be reduced. If the solution in the sample cell does not absorb the light, then there will be no change in energy. When the transmitted light beam strikes the photoelectric tube, it generates an electric current that is proportional to the intensity of light energy striking it. By connecting the photoelectric tube to a galvanometer (a device for measuring electric current) with a graduated scale, a means of measuring the intensity of the transmitted beam is achieved.

The diagram at the top of the next column illustrates the working parts of a spectrophotometer.

The operator should always follow the working instructions provided with the instrument.

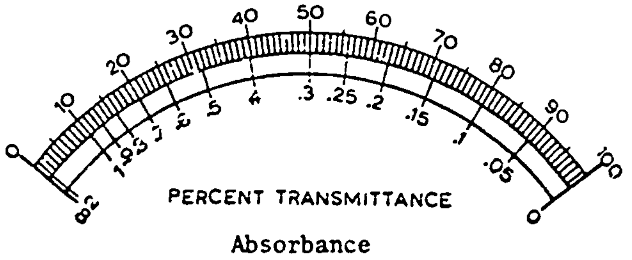
UNITS OF SPECTROSCOPIC MEASUREMENT. The scale on spectrophotometers is generally graduated in two ways:



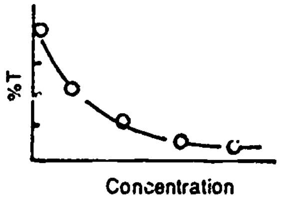
(1) in units of percent transmittance (%T), an arithmetic scale with units graded from 0 to 100%; and

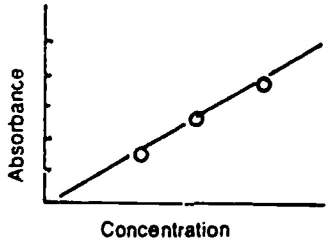
(2) in units of absorbance (A), a logarithmic scale of nonequal divisions graduated from 0.0 to 2.0.

Both the units percent transmittance and absorbance are associated with color intensity. That is, a sample which has a low color intensity will have a high percent transmittance but a low absorbance.



As illustrated above, the absorbance scale is ordinarily calibrated on the same scale as percent transmittance on spectrophotometers. The chief usefulness of absorbance lies in the fact that it is a logarithmic function rather than linear (arithmetic) and a law known as Beer's Law states that the concentration of a light-absorbing colored solution is directly proportional to absorbance over a given range of concentrations. If one were to plot a graph showing (%T) percent transmittance versus concentration on straight graph or line paper and another showing absorbance versus concentration on the same paper, the following curves (graphs) would result:





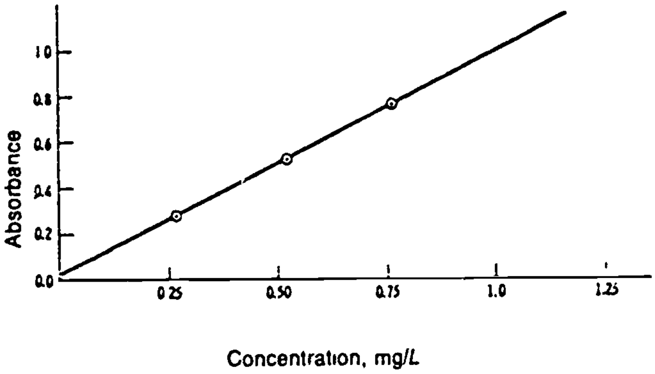
CALIBRATION CURVES: The calibration curve is used to determine the concentration of the water quality indicator (iron or manganese) contained in a sample. Three steps must be completed in order to prepare a calibration graph.

First, a series of standards must be prepared. A standard is a solution which contains a known amount of the same chemical constituent which is being determined in the sample.

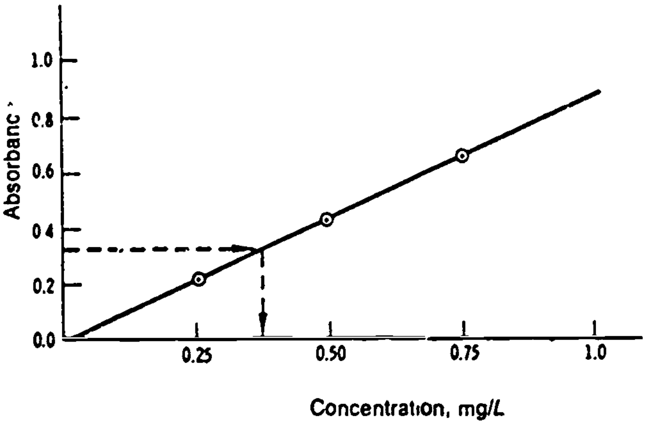
Secondly, these standard solutions and a sample containing none of the constituent being tested for (usually distilled water and generally referred to as a blank) must be treated with the developing reagent in the same manner as the sample would be treated.

Thirdly, using a spectrophotometer the absorbance or transmittance at the specified wave length of the standards and blank must be determined From the values obtained, a calibration curve of absorbance (or %T) versus concentration can be plotted. Once these several points have been plotted, you can then extend the plotted points by connecting the known points with a straight line. For example, with the data given below one could construct the following calibration curve.

Absorbance	Concentration, mg/*L*
0.0	0.0
0.30	0.25
0.55	0.50
0.80	0.75



Once you have established a calibration curve for the water quality indicator in question, you can easily determine the amount of that substance contained in a solution of unknown concentration. You merely take an absorbance reading on the color developed by the unknown and locate it on the vertical axis. Then a straight line is drawn to the right on the graph until it intersects with the experimental standard curve. A line is then dropped to the horizontal axis and this value identifies the concentration of your unknown water quality indicator.



In this example, an absorbance reading of 0.32 was read on the unknown solution or sample, which indicates a concentration of about 0.37 mg/*L*.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 482.

21.0A When measuring the color intensity of phosphorus, what color is measured?

21.0B What are the units of measurements for spectrophotometers?

21.0C Using the above absorbance vs. concentration calibration graph, if the absorbance reading of 0.60 was read on an unknown solution or sample, what was the concentration of the unknown?

21.1 TEST PROCEDURES

1. Algae Counts

A. Discussion

The quality of water in any lake, reservoir or stream has a very direct effect on the abundance and types of aquatic organisms found. By knowing the nature and numbers of these aquatic organisms one can obtain a good idea of the water quality. A biological method used for measuring water quality is the collection, counting, and identification of algae contained in a particular body of water. Information from algae counts can serve one or more of the following purposes:

1. Help explain the cause of color and turbidity and the presence of tastes and odors in the water,
2. Help explain the clogging of screens or filters, and
3. Help document variability in the water quality.

Algae counting and identification may be done very simply or it may be developed into a highly technical operation. The beginner should use great caution applying the results of algae identifications until considerable experience has been gained.

Some operators perform algae counts on both the raw water and treated water. Taking algae counts on treated water is a means of studying the effectiveness of coagulation and the performance of filters. If the filters are performing properly, there should not be any countable algae in the treated water.

(Calcium)

B. Materials and Procedures

See page 1043, *STANDARD METHODS*, 16th Edition.[1]

2. Calcium

A Discussion

In most natural waters, calcium is the principal cation. The element is widely distributed in the common minerals of rocks and of soil. Calcium in the form of lime or calcium hydroxide may be used to soften water or to control corrosion through pH adjustment.

B. What is Tested?

Sample	Common Range, mg/*L*
Raw and Treated Surface Water	5 to 50
Well Water	10 to 100

C. Apparatus Required

Buret, 25 m*L*
Buret support
Graduated cylinder, 100 m*L*
Beaker, 100 m*L*
Magnetic stirrer
Magnetic stir-bar

D. Reagents

(*NOTE:* Standardized solutions are commercially available for most reagents. Refer to *STANDARD METHODS* if you wish to prepare your own reagents.)[2]

1. Sodium hydroxide, NaOH, 1 *N*.
2. Eriochrome Blue Black R indicator.
3. Standard EDTA titrant, 0.01 *M*. Standardize against Standard Calcium Solution and store in plastic polyethylene bottle.
4. Standard Calcium Solution. Store in polyethylene plastic bottle. 1 m*L* of this solution = 1 mg calcium hardness as $CaCO_3$ or 400.8 micrograms (μg) Ca
5. 1 + 1 HCl. Carefully add 50 m*L* concentrated HCl to 50 m*L* distilled water.
6. Ammonium hydroxide, 3 *N*.
7. Methyl Orange indicator solution.

E. Procedure

1. Take a clean beaker and add 50 m*L* of sample.
2. Add 2.0 m*L* NaOH solution.
3. Add 0.1 to 0.2 g indicator mixture.
4. Titrate immediately with EDTA titrant until last reddish-purple tinge disappears. Mix with magnetic stirrer during titration.
5. Calculate calcium concentration

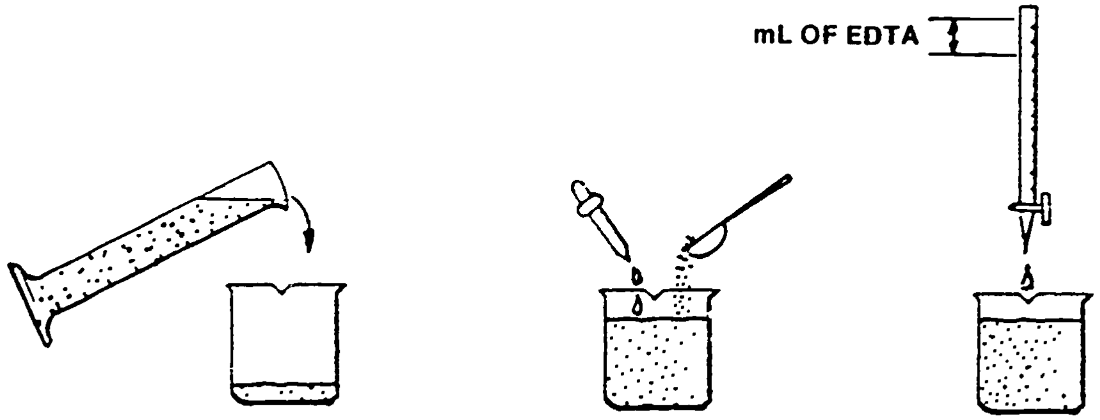
F. Example

Results from calcium testing of a treated water sample were as follows:

sample size = 50 m*L*

m*L* EDTA titrant used, A = 7.3 m*L*

OUTLINE OF PROCEDURE FOR CALCIUM



1. Add 50 m*L* to a clean beaker.

2. Add 2 m*L* NaOH and 0.2 g indicator mixture.

3. Titrate with EDTA. Mix with magnetic stirrer

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[1] *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 16th Edition, 1985, Order No. 10035. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver Colorado 80235. Price to members, $72.00; nonmembers, $90.00.*

[2] *See "Prepared vs. Do-It-Yourself Reagents," by Josephine W. Boyd, OPFLOW, Vol. 9. No. 10, October 1983.*

G. Calculation

$$\text{mg Ca}/L = \frac{A \times 400.8^{*}}{mL \text{ of sample}}$$

$$= \frac{(7.3\ mL) \times 400.8}{50\ mL}$$

$$= 58\ \text{mg}/L$$

---

* 400.8 is a constant for this calculation.

H. Precautions

1. Titrate immediately after adding NaOH solution.
2. Use 50 mL or a smaller portion of sample diluted to 50 mL with distilled water so that the calcium content is about 5 to 10 mg.
3. For hard waters with alkalinity greater than 300 mg $CaCO_3/L$, use a smaller portion or neutralize alkalinity with acid, boiling for one minute, and cooling before beginning the titration.

I. Reference

See page 199, *STANDARD METHODS*, 16th Edition.

3. Chloride

A. Discussion

Chloride occurs in all natural waters, usually as a metallic salt. In most cases, the chloride content increases as mineral content increases. Mountain water supplies usually are quite low in chloride while groundwaters and valley rivers often contain a considerable amount. The maximum allowable chloride concentration of 250 mg/L in drinking water has been established for reasons of taste rather than as a safeguard against a physical or a health hazard. At concentrations above 250 mg/L, chloride may give a salty taste to the water which is objectionable to many people.

B. What is Tested?

Sample	Common Range, mg/L
Surface or Groundwater	2 to 100

C. Apparatus Required

Graduated cylinder, 100 mL
Buret, 50 mL
Erlenmeyer flask, 250 mL
Pipet, 10 mL
Magnetic stirring apparatus

D. Reagents

(*NOTE:* Standard solutions may be purchased from chemical suppliers.)

1. Chloride-free water — distilled or deionized water.
2. Potassium chromate (K_2CrO_4) indicator solution.
3. Standard Silver Nitrate Titrant, 0.0141 *N*.
4. Standard Sodium Chloride, 0.0141 *N*.

E. Procedure

1. Place 100 mL or a suitable portion of sample diluted to 100 mL in a 250 mL Erlenmeyer flask.
2. Add 1.0 mL K_2CrO_4 indicator solution.
3. Titrate with standard silver nitrate to a pinkish yellow end point. Be consistent in end point recognition. Compare with known standards of various chloride concentrations.

F. Calculation

$$\text{Chloride (as Cl), mg}/L = \frac{(A-B) \times N \times 35{,}450}{mL \text{ of sample}}$$

A = mL $AgNO_3$ used for titration of sample

B = mL $AgNO_3$ used for blank

N = normality of $AgNO_3$

G. Example

Sample size = 100 mL

A = mL $AgNO_3$ used for sample = 10.0 mL

B = mL $AgNO_3$ used for blank = 0.4 mL

N = normality of $AgNO_3$ = 0.0141 *N*

$$\text{Chloride, mg}/L = \frac{(10.0 - 0.4) \times (0.0141) \times 35{,}450}{100}$$

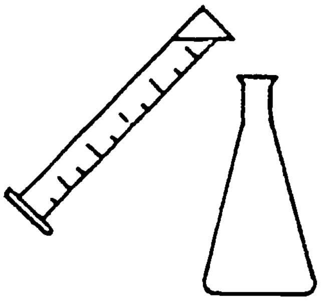
$$= 48\ \text{mg}/L$$

H. Special Notes

1. Sulfide, thiosulfate, and sulfite ions interfere, but can be removed by treatment with 1 mL of 30 percent hydrogen peroxide (H_2O_2).
2. Highly colored samples must be treated with an aluminum hydroxide suspension and then filtered.
3. Orthophosphate in excess of 25 mg/L and iron in excess of 10 mg/L also interfere.
4. If the pH of the sample is not between 7 to 10, adjust with 1 *N* sulfuric acid or 1 *N* sodium hydroxide.

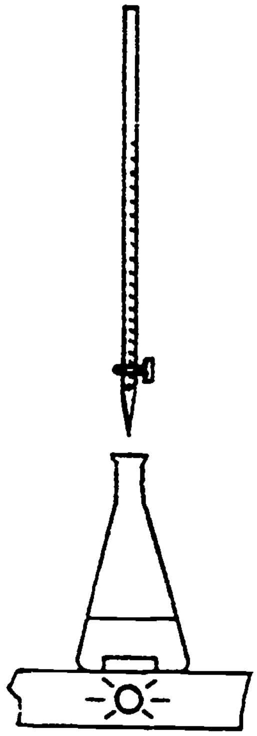
(Chloride)

OUTLINE OF PROCEDURE FOR CHLORIDE



1. Place 100 m*L* or other measured sample in flask.

2. Add 1 m*L* chromate indicator.



3. Place flask on magnetic stirrer and titrate with standard silver nitrate.

5. Procedure for standardization of $AgNO_3$:
   a. Add 10 m*L* (1 mg Cl) standard sodium chloride solution to a clean 250 m*L* Erlenmeyer flask.
   b. Add 90 m*L* distilled water.
   c. Titrate as in Section E above.

$$\text{Normality, } N, \text{ AgNO}_3 = \frac{\text{m}L \text{ CaCl standard} \times 0.0141}{\text{m}L \text{ AgNO}_3 \text{ used in titration}}$$

EXAMPLE

10.0 m*L* NaCl standard used
10.0 m*L* $AgNO_3$ used in titration
0.0141 *N* = normality of NaCl standard

$$\text{Normality, } N, \text{ AgNO}_3 = \frac{10.0 \text{ m}L \times 0.0141}{10 \text{ m}L}$$

$$= 0.0141$$

I. Reference

See page 286, *STANDARD METHODS*, 16th Edition

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 482.

21.1A Does the quality of water in any lake, reservoir or stream effect the abundance and types of aquatic organisms found in the water? Yes or No?

21.1B How are calcium compounds used to treat water?

21.1C How soon should a sample be titrated for calcium after the sodium hydroxide (NaOH) solution has been added?

21.1D Why are concentrations of chloride above 250 mg/*L* objectionable to many people?

4. Color

A. Discussion

Color in water supplies may result from the presence of metallic ions (iron, manganese, and copper), organic matter of vegetable or soil origin, and industrial wastes. The most common colors which occur in raw water are yellow and brown. There are two general types of color found in water. True color results from the presence of dissolved organic substances or from certain minerals such as copper sulfate dissolved in the water. Suspended materials (including colloidal substances) can add what is called apparent color. True color is normally removed or at least reduced by coagulation and chlorination or ozonation. The method given below is suitable only for the measurement of color in clear treated water supplies having a turbidity of less than one unit of turbidity. When greater amounts of turbidity are present in the sample, some form of pretreatment for turbidity removal must be used before measuring the color.

B. What is Tested?

Sample	Common Range, mg/*L*
Treated Surface Water	1 to 10
Groundwater	0 to 5

C. Apparatus Required

Nessler tubes, matched, 50 m*L* tall form
Pipet, 1.0 m*L*

D. Reagents

1 Color Standard. Use a stock standard with a color of 500 units.

2 Prepare color standards by adding the following increments of stock color standard to a nessler tube and diluting to 50 m*L*.

Color Unit Standard	m*L* of Stock Color Standard
1	0.1
2	0.2
3	0.3
4	0.4
5	0.5

Protect these standards against evaporation and contamination when not in use.

E. Procedure

1. Fill a clean matched nessler tube to the 50 m*L* mark with sample.
2. Compare the sample with the various color standards by looking downward vertically through the tubes toward a white surface.
3. Match as closely as possible sample color with a color standard.

F. Other Procedures

Color may also be measured by the use of

1. Color comparator kits, and
2. Spectrophotometers.

G. Notes

1. If the color exceeds 70 units, dilute sample with distilled water in known proportions until the color is within range of the standards. Calculate color units by the following equation:

$$\text{Color units} = \frac{A \times 50}{B}$$

where:

A = estimated color of diluted sample

B = m*L* of sample taken from dilution

2. If turbidity is greater than one unit, consult *STANDARD METHODS* for pretreatment for turbidity removal.

H. Reference

See page 67, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 482.

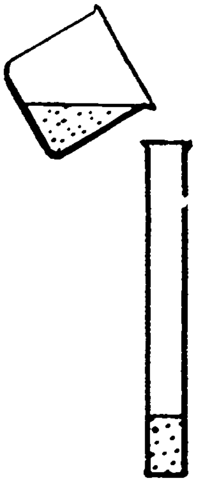
21.1E What are the most common colors which occur in raw water?

21.1F How can true color be removed from water?

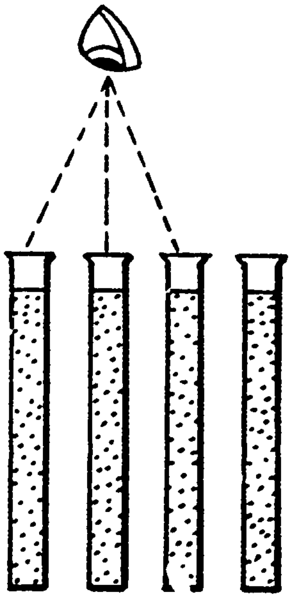
21.1G When not in use, stock color standards should be protected against what?

(Dissolved Oxygen)

OUTLINE OF PROCEDURE FOR COLOR



1. Fill nessler tube to 50 m*L*



2. Compare sample to color standards.

5. Dissolved Oxygen

A. Discussion

Dissolved oxygen (DO) is important to the water treatment plant operator for a number of reasons. In surface waters, dissolved oxygen must be present in order for fish and smaller aquatic organisms to survive. The taste of water is improved by dissolved oxygen. However, the presence of dissolved oxygen in water can contribute to corrosion of piping systems. Low or zero dissolved oxygen levels at the bottom of lakes or reservoirs often cause taste and odor problems in drinking water.

B. What is Tested?

Sample	Common Range, mg/*L*
Surface Water	5 to 11*
Groundwaters	0 to 2

* Some reservoirs and lakes may have zero DO near the bottom.

C. Apparatus Required

Method A (Sodium Azide Modification of Winkler Method)

Buret, graduated to 0.1 m*L*
Buret support
BOD bottle, 300 m*L*
Magnetic stirrer
Magnetic stir-bar
Pipets, 10 m*L*

Method B (Membrane Electrode Method)

Follow manufacturer's instructions. To be assured that the DO probe reading is accurate, the probe must be calibrated frequently. Take a sample that does not contain substances that interfere with either the probe reading or the Modified Winkler procedure. Split the sample. Measure the DO in one portion of the sample using the Modified Winkler procedure and compare this result with the DO probe reading on the other portion of the sample. Adjust the probe reading to agree with the results from the Modified Winkler procedure. To obtain good results when using a probe, you should be aware of the following *PRECAUTIONS:*

a. Periodically check the calibration of the probe,

b. Keep the membrane in the tip of the probe from drying out,

c. Dissolved inorganic salts, such as found in sea water, can influence the readings from a probe,

d. Reactive compounds, such as reactive gases and sulfur compounds, can interfere with the output of a probe, and

e. Don't place the probe directly over a diffuser because you want to measure the dissolved oxygen in the water being treated, not the oxygen in the air supply to the aerator.

D. Reagents

(Standardized solutions may be purchased from chemical suppliers.)

1. Manganous Sulfate Solution.
2. Alkaline Iodide-sodium Azide Solution.
3. Sulfuric Acid: Use concentrated reagent-grade acid (H_2SO_4). Handle carefully, since this material will burn hands and clothes. Rinse affected parts with tap water to prevent injury.

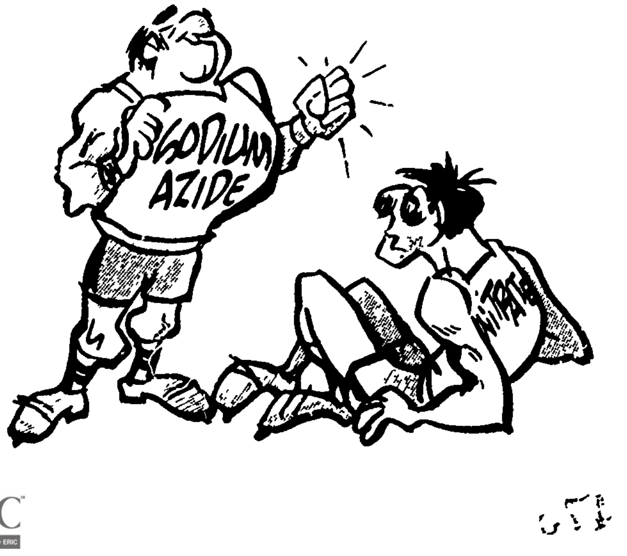
   CAUTION: When working with alkaline azide and sulfuric acid, keep a nearby water faucet running for frequent hand rinsing.
4. 0.025 *N* Phenylarsine Oxide (PAO) solution.
5. 0.025 *N* Sodium Thiosulfate solution.

   For preservation, add 0.4 g or 1 pellet of sodium hydroxide (NaOH). Solutions of "thio" should be used within two weeks to avoid loss of accuracy due to decomposition of solution.
6. Starch solution.

E. Procedure

SODIUM AZIDE MODIFICATION OF THE WINKLER METHOD

NOTE: The sodium azide destroys nitrate which would otherwise interfere with this test.



The reagents are to be added in the quantities, order, and methods as follows:

1 Collect a sample to be tested in 300 mL (BOD) bottle taking special care to avoid aeration of the liquid being collected. Fill bottle completely and add cap.

2. Remove cap and add 1 mL of manganous sulfate solution below surface of the liquid.

3. Add 1 mL of alkaline-iodide-sodium azide solution below the surface of the liquid.

4. Replace the stopper, avoid trapping air bubbles, and shake well by inverting the bottle several times. Repeat this shaking after the floc has settled halfway. Allow the floc to settle halfway a second time.

5. Acidify with 2 mL of concentrated sulfuric acid by allowing the acid to run down the neck of the bottle above the surface of the liquid.

6. Restopper and shake well until the precipitate has dissolved. The solution will then be ready to titrate. Handle the bottle carefully to avoid acid burns.

7. Pour 201 mL from bottle into an Erlenmeyer flask.

8. If the solution is brown in color, titrate with 0.025 *N* PAO until the solution is pale yellow color. Add a small quantity of starch indicator and proceed with Step 10. (Note: Either PAO or 0.025 *N* sodium thiosulfate can be used.)

9. If the solution has no brown color, or is only slightly colored, add a small quantity of starch indicator. If no blue color develops, there is zero Dissolved Oxygen. If a blue color does develop, proceed to Step 10.

10. Titrate to the first disappearance of the blue color. Record the number of mL of PAO used.

11. The amount of oxygen dissolved in the original solution will be equal to the number of mL of PAO used in the titration provided significant interfering substances are not present.

$$\underline{\text{mg DO}/L = \text{m}L\text{ PAO}}$$

F. Example

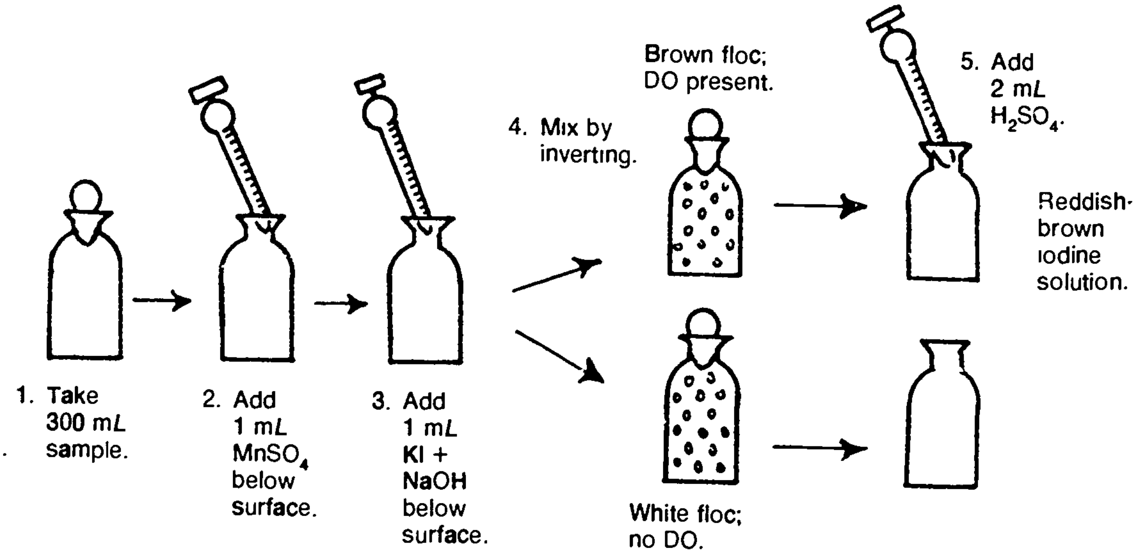
A sample is collected from just upstream of a river intake to a water treatment facility. The water temperature is 18°C. The sample is tested for DO and the operator uses 9.1 mL of 0.025 *N* PAO titrant.

G. Calculation

The DO titration of 201 mL sample required 9.1 mL of 0.025 *N* PAO. Therefore, the dissolved oxygen (DO) concentration in the sample is 9.1 mg/L.

The percent saturation of DO in the river can be calculated using the dissolved oxygen saturation values given in Table 21.1. Note that as the temperature of water increases, the DO saturation value (100% Saturation Column) decreases.

OUTLINE OF PROCEDURE FOR DO



Titration of Iodine Solution:

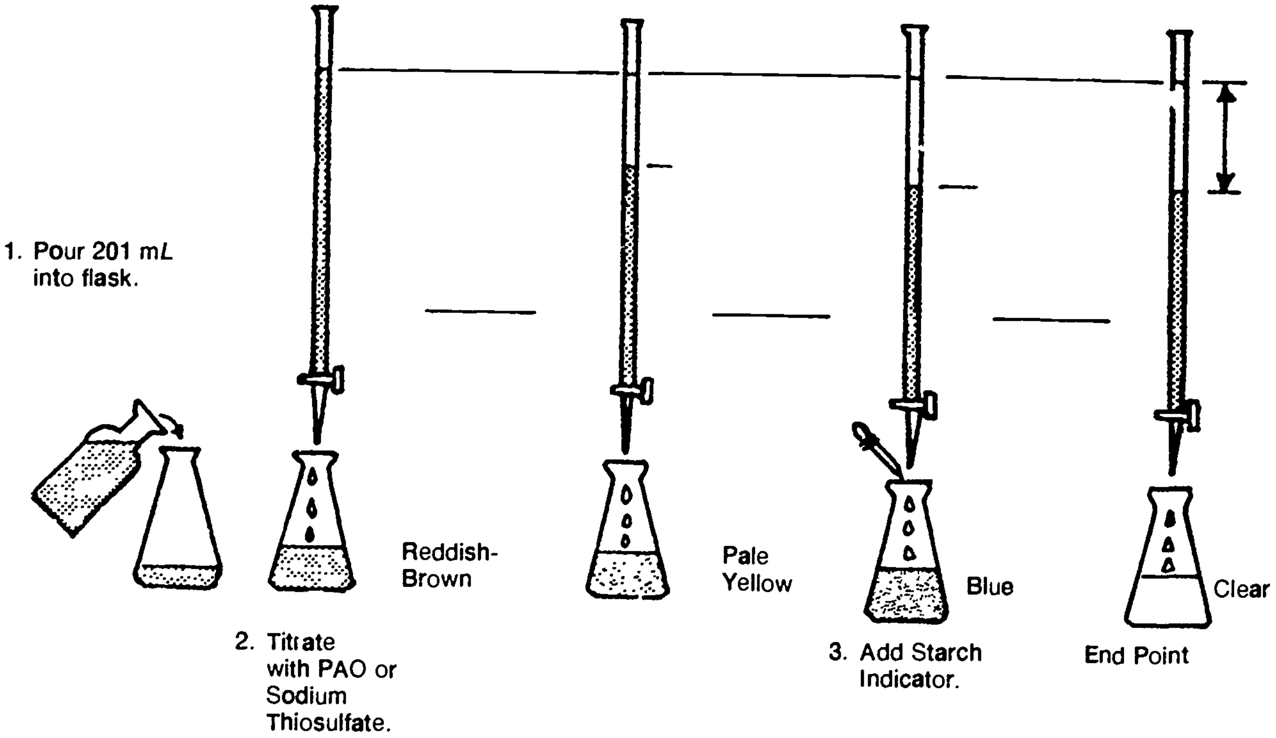


Table 21.1 gives 100 percent DO saturation values for temperatures in °C and °F.

$$\text{DO Saturation, \%} = \frac{\text{DO of sample, mg}/L \times 100\%}{\text{DO at 100\% Saturation, mg}/L}$$

For example, given

$$\text{DO Saturation, \%} = \frac{9.1 \text{ mg}/L}{9.5 \text{ mg}/L} \times 100\%$$

$$= 0.96 \times 100\%$$

$$= 96\%$$

where

9.1 mg/*L* = DO of sample

9.5 mg/*L* = DO at 100% Saturation at 18°C (river temperature)

TABLE 21.1

EFFECT OF TEMPERATURE ON OXYGEN SATURATION FOR A CHLORIDE CONCENTRATION OF ZERO mg/*L*

°C	°F	mg/*L* DO at Saturation
0	0	14.6
1	33.8	14.2
2	35.6	13.8
3	37.4	13.5
4	39.2	13.1
5	41.0	12.8
6	42.8	12.5
7	44.6	12.2
8	46.4	11.9
9	48.2	11.6
10	50.0	11.3
11	51.8	11.1
12	53.6	10.8
13	55.4	10.6
14	57.2	10.4
15	60.0	10.2
16	61.8	10.0
17	63.6	9.7
18	65.4	9.5
19	67.2	9.4
20	68.0	9.2
21	69.8	9.0
22	71.6	8.8
23	73.4	8.7
24	75.2	8.5
25	77.0	8.4

H. Precautions

1. Samples for dissolved oxygen measurements should be collected very carefully. Do not let sample remain in contact with air or be agitated. Collect samples in a 300 m*L* BOD bottle. Avoid entraining or dissolving atmospheric oxygen.
2. When sampling from a water line under pressure, attach a tube to the tap and extend tube to bottom of bottle. Let bottle overflow two or three times its volume and replace glass stopper so no air bubbles are entrapped.
3. Use suitable sampler for streams, reservoirs or tanks of moderate depth such as that shown in Figure 21.1. Use a Kemmerer-type sampler for samples collected from depths greater than 6½ feet (2 m).
4. Always record temperature of water at time of sampling.
5. Use the proper bottle with matched stopper.
6. When working with a lake or reservoir, examine the temperature and DO profile (measure temperature and DO at surface and at various depths all the way down to the bottom).
7. Measure the DO in the sample as soon as possible.

I. Reference

See page 418, *STANDARD METHODS,* 16th Edition.

6. Fluoride

A. Discussion

Fluoride may occur naturally or it may be added in controlled amounts. The concentration of fluoride in most natural waters is less than one mg/*L*. There are, however, several areas in the United States which have natural fluoride concentrations of as high as 30 mg/*L*. The importance of fluoride in forming human teeth and the role of fluoride intake from drinking water in controlling the characteristics of tooth structure has been realized only within the past 40 to 50 years. Studies have shown that a fluoride concentration of approximately 1.0 mg/*L* reduces dental caries of young people without harmful effects on health.

B. What is Tested?

Sample	Common Range, mg/*L*
Fluoridated Water	0.8 to 1.2

C. Apparatus Required

Spectrophotometer for use at 570 nanometers wavelength
Pipets, 5 m*L*
Flasks, Erlenmeyer, 125 m*L*

D. Reagents

1. Stock fluoride solution. 1.0 m*L* = 0.100 mg F.
2. Standard fluoride solution: Dilute 100 m*L* stock fluoride solution to 1000 m*L* with distilled water; 1.0 m*L* = 0.010 mg F.
3. SPADNS solution. This solution is stable indefinitely if protected from direct sunlight.
4. Zirconyl-acid reagent.

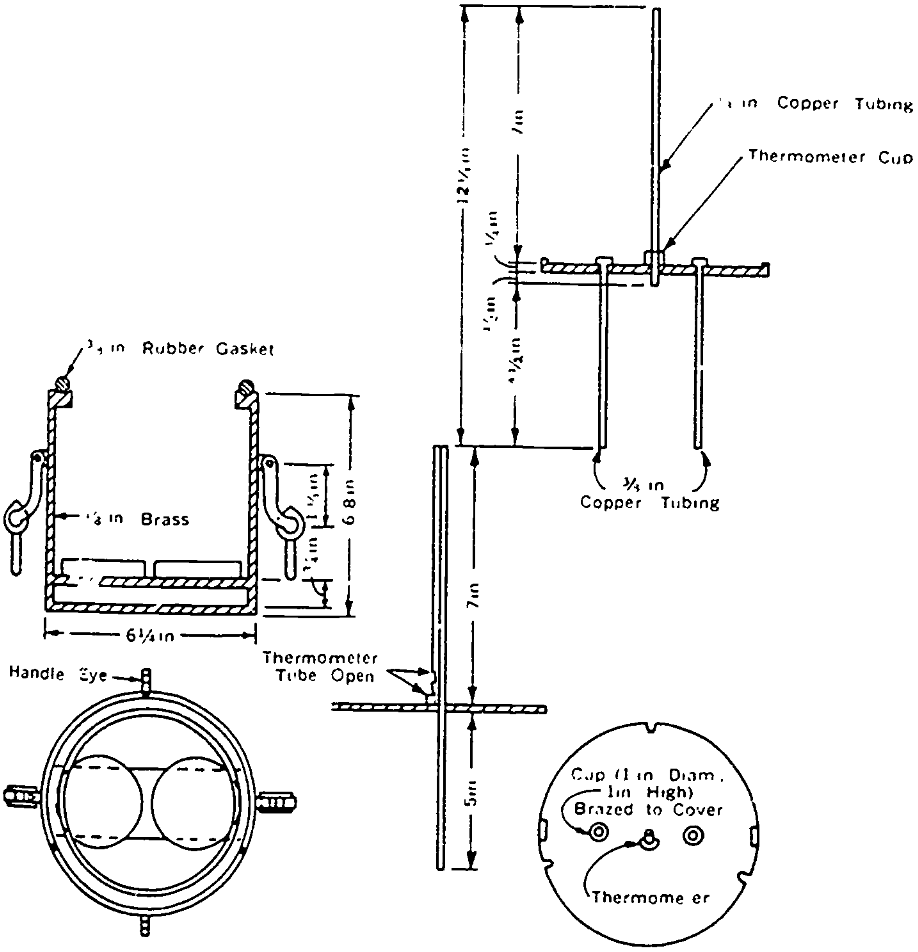


Fig. 21.1 DO sampler

(Reprinted from *STANDARD METHODS*, 15th Edition by permission Copyright 1980, the American Public Health Association)

5. Acid zirconyl-SPADNS reagent: Mix equal volumes of SPADNS solution and zirconyl-acid reagent. The combined reagent is stable for at least 2 years.
6. Reference solution: Add 10 m*L* SPADNS solution to 100 m*L* distilled water. Dilute 7 m*L* concentrated HCl to 10 m*L* and add to the diluted SPADNS solution. The resulting solution, used for setting the instrument reference point (zero), is stable and may be reused indefinitely. Alternatively, use a prepared standard as a reference.
7. Sodium arsenite solution. (*CAUTION.* Toxic — avoid ingestion).

E. Procedure

1. Measure 50 m*L* of sample and add to a clean 125 m*L* Erlenmeyer flask. (If sample contains residual chlorine, add one drop $NaAsO_2$ solution per 0.1 mg chlorine residual and mix.)
2. Add 5.0 m*L* each of SPADNS solution and zirconyl-acid reagent, or 10.0 m*L* acid zirconyl-SPADNS reagent. Mix.
3. Set spectrophotometer to 0.730 absorbance with reference solution containing zero mg/*L* of fluoride (see G. Example).
4. Read absorbance at 570 nm with spectrophotometer and determine the amount of fluoride from standard curve.

NOTE: A colorimeter may also be used to measure fluoride.

F. Construction of Standard Calibration Curve

1. Using the standard fluoride solution, prepare the following standards in 100 m*L* volumetric flasks.

m*L* of Standard Fluoride Solution Placed in 100 m*L* Volumetric Flask	Fluoride Concentration, mg/*L*
5.0	0.50
7.5	0.75
10.0	1.00
12.5	1.25

2. Dilute flasks to 100 m*L*.
3. Transfer 50 m*L* to 125 m*L* Erlenmeyer flask.
4. Determine amount of fluoride as outlined previously.
5. Prepare a standard curve by plotting the absorbance values of standards versus the corresponding fluoride concentrations.

G. Example

Results from a series of tests for fluoride were as follows:

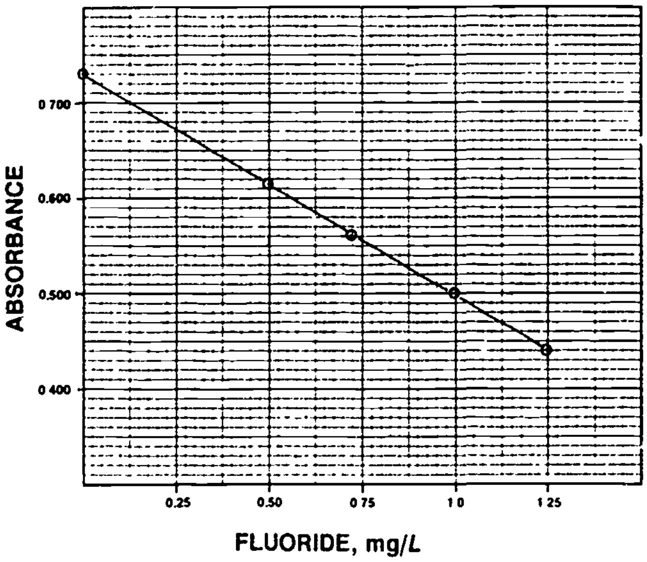
Flask No.	Sample	Volume, mg/*L*	Absorbance
1	Distilled Water	50	0.730
2	C Street Well	50	0.470
3	Plant Effluent	50	0.510
4	0.5 mg/*L* F	50	0.625
5	0.75 mg/*L* F	50	0.560
6	1.0 mg/*L* F	50	0.500
7	1.25 mg/*L* F	50	0.444

H. Calculation

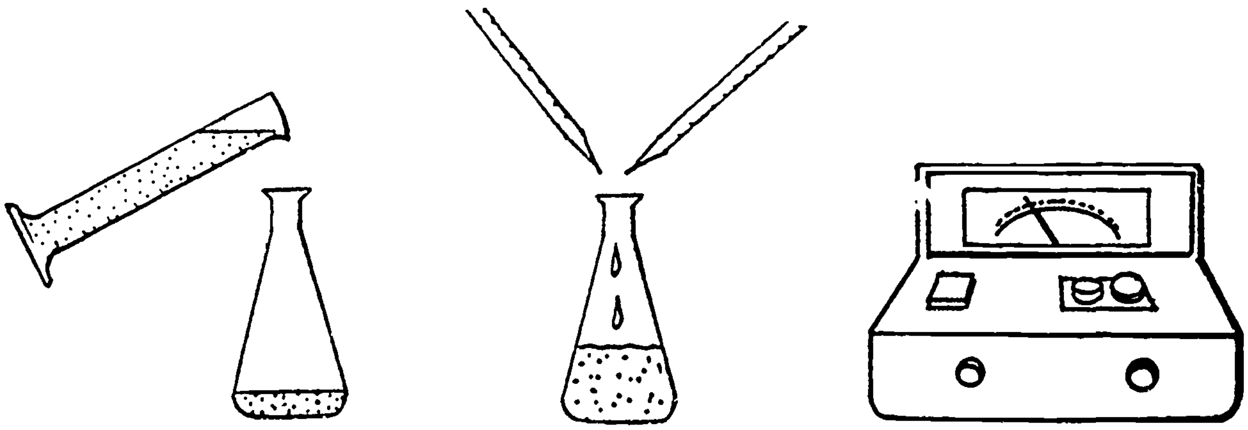
1. Prepare a standard curve by using data from prepared standards. From above example:

Fluoride Concentration, mg/*L*	Absorbance
0.0	0.730
0.5	0.625
0.75	0.560
1.0	0.500
1.25	0.444

The graph below is a result of plotting concentration of fluoride standards versus their corresponding absorbance.



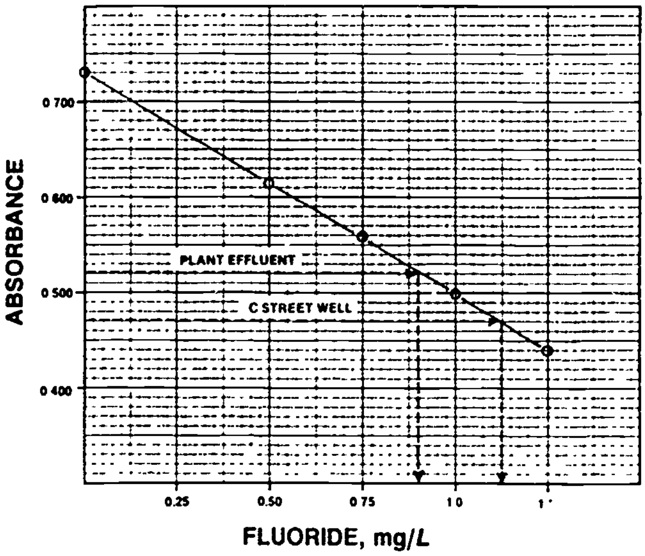
OUTLINE OF PROCEDURE FOR FLUORIDE



1. Measure 50 m*L* of sample into flask. Dechlorinate if necessary.
2. Add 5 m*L* each of SPADNS solution and zirconyl-acid reagent.
3. Measure absorbance at 570 nm with spectrophotometer.

(Fluoride)

2 Obtain concentration of unknown samples from curve.



PLANT EFFLUENT = 0.90 mg/L
C STREET WELL = 1.2 mg/L

I. Precautions

1. Whenever any of the following substances are present in the listed quantities, the sample must be distilled prior to analysis.

Substance	Concentration mg/L
Alkalinity	5,000
Aluminum	0.1
Chloride	7,000
Iron	10
Hexametaphosphate	1.0
Phosphate	16
Sulfate	200

2. Samples and standards should be at the same temperature throughout color development.

J. Reference

See page 359, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 482.

21.1H Why is the presence of dissolved oxygen (DO) in water in piping systems of concern to operators?

21.1I What is the common range of fluoride in fluoridated drinking water?

End of Lesson 1 of 2 Lessons
on
ADVANCED LABORATORY
PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 21. ADVANCED LABORATORY PROCEDURES

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. What is the purpose of spectrophotometer calibration curves?
2. How would you prepare a spectrophotometer calibration graph?
3. Why are algae counts in raw water important to operators?
4. The maximum allowable chloride concentration in drinking water has been established on what basis?
5. What are the two general types of color found in water and what is the cause of each type?
6. Why is dissolved oxygen (DO) in water important to the treatment plant operator?
7. What precautions would you take when collecting a lake sample for a dissolved oxygen measurement?
8. How does fluoride get into drinking waters?

Chapter 21. ADVANCED LABORATORY PROCEDURES

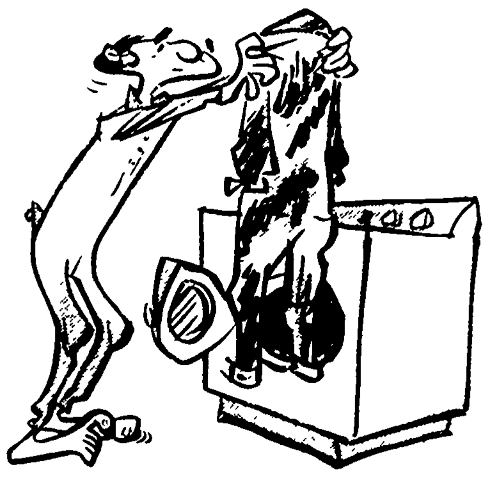
(Lesson 2 of 2 Lessons)

7. **Iron** (Total)

A. Discussion

Iron is an abundant and widespread constituent of rocks and soils. The most common form of iron in solution in groundwater and in water under anaerobic conditions (bottom of a lake or reservoir) is the ferrous ion, Fe^{+2}. Ferric iron can occur in soils, in aerated water, and in acid solutions as Fe^{3+}, ferric hydroxide and polymeric forms depending upon pH. Above pH of 4.8, however, the solubility of the ferric species is less than 0.1 mg/*L*. Colloidal ferric hydroxide is commonly present in surface water and small quantities may persist even in water that appears clear.

Iron in a domestic water supply can be the cause of staining laundry, concrete, and porcelain. A bitter astringent taste can be detected by some people at levels above 0.3 mg/*L*. When iron reacts with oxygen, a red precipitate (rust) is formed.



B. What is Tested?

Source	Common Range, mg/*L*
Untreated Surface Water	0.10 to 1.0
Treated Surface Water	<0.01 to 0.20
Groundwater	<0.01 to 10

C. Apparatus Required

Spectrophotometer for use at 510 nm
Acid-washed glassware. Wash all glassware with concentrated HCl and rinse with distilled water to remove deposits of iron oxide.
Flasks, Erlenmeyer, 125 m*L*
Pipets, 5 and 10 m*L*
Flasks, Volumetric, 100 m*L*
Hot plate

D. Reagents

Use reagents low in iron. Use iron-free distilled water. Store reagents in glass-stoppered bottles. The hydrochloric acid and ammonium acetate solutions are stable indefinitely if tightly stoppered. The hydroxylamine, phenanthroline, and stock iron solutions are stable for several months. The standard iron solutions are not stable; prepare daily as needed by diluting the stock solution. Visual standards in nessler tubes are stable for several months if sealed and protected from light.

1. Hydrochloric acid, HCl.
2. Hydroxylamine solution.
3. Ammonium acetate buffer solution. Because even a good grade of $NH_4C_2H_3O_2$ contains a significant amount of iron, prepare new reference standards with each buffer preparation.
4. Sodium acetate solution.
5. Phenanthroline solution. (NOTE: One milliliter of this reagent is sufficient for no more than 100 μg Fe.)
6. Stock iron solution. 1.00 m*L* = 0.200 mg Fe.
7. Standard iron solutions. Prepare daily for use. Pipet 50.00 m*L* stock solution into a one-liter volumetric flask and dilute to mark with iron-free distilled water; 1.00 m*L* = 0.010 mg Fe.

E Procedure

For Total Iron

1. Measure 50 m*L* of thoroughly mixed sample into a 125 m*L* Erlenmeyer flask.
2. Add 2 m*L* concentrated HCl and 1 m*L* hydroxylamine solution.
3. Heat to boiling. Boil sample until volume is reduced to 20 m*L*. Cool to room temperature.
4. Transfer to 100 m*L* volumetric flask.
5. Add 10 m*L* acetate buffer solution and 2 m*L* phenanthroline solution. Dilute to 100 m*L* mark with iron-free distilled water. Mix thoroughly.
6. After 15 minutes, measure the absorbance at 510 nm and determine the amount of iron from the standard curve.

F. Construction of Standard Calibration Curve

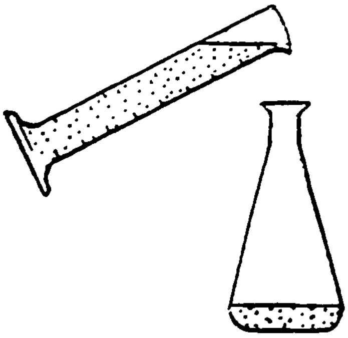
1. Using the standard solution, prepare the following standards in 100 m*L* volumetric flasks.

m*L* of Standard Iron Solution Placed in 100 m*L* Volumetric Flask	**Iron Concentration mg/*L***
0	0
1.0	0.10
2.5	0.25
5.0	0.50
7.5	0.75
10.0	1.00

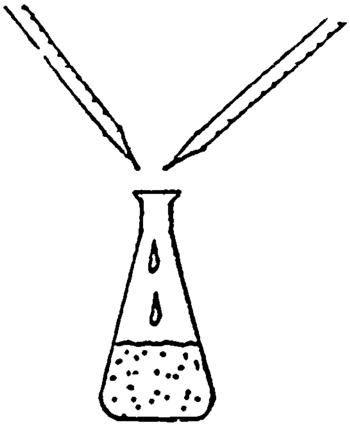
2. Dilute flasks to 100 m*L*.
3. Transfer 50 m*L* to 100 m*L* volumetric flask.
4. Add 1.0 m*L* hydroxylamine solution and 1 m*L* acetate solution to each flask.

(Iron)

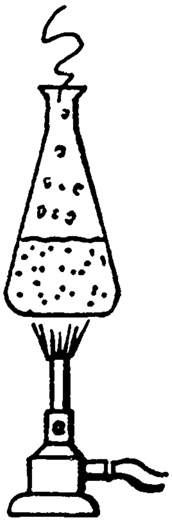
OUTLINE OF PROCEDURE FOR IRON



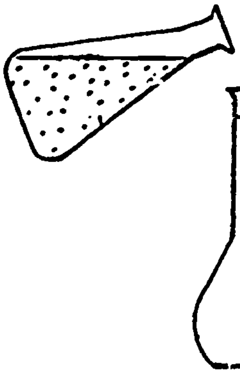
1. Measure 50 m*L* into flask.



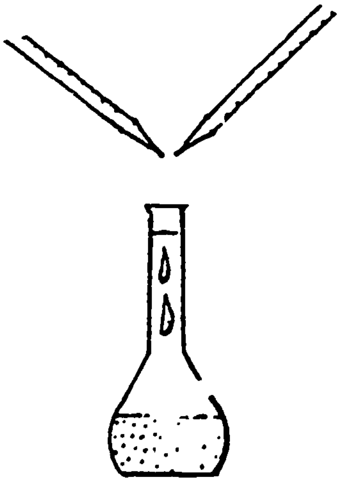
2. Add 2 m*L* conc. HCl and 1 m*L* hydroxylamine solution.



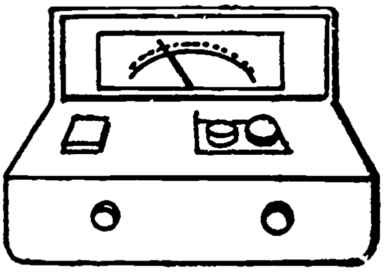
3. Heat to boiling. Reduce volume to 20 m*L*. Cool.



4. Transfer to 100 m*L* volumetric flask.



5. Add 10 m*L* acetate buffer and 2 m*L* phenanthroline solution. Dilute to 100 m*L*.



6. Measure absorbance at 510 nm with spectrophotometer.

5. Dilute to about 75 mL, add 10 mL phenanthroline solution, dilute to 100 mL mark. Mix thoroughly.
6. Measure absorbance at 510 nm against the reference blank.
7. Prepare a standard curve by plotting the absorbance values of standards versus the corresponding iron concentrations.

G. Example

Results from a series of tests for total iron were as follows:

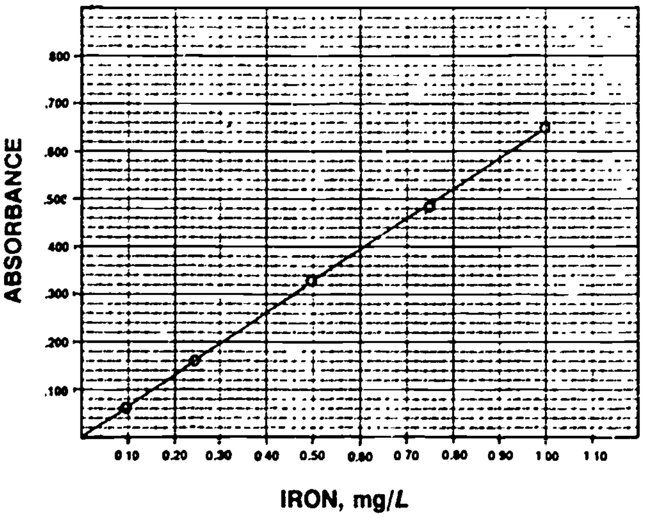
Flask #	Sample	Absorbance
1	Distilled Water	0.000
2	Plant Clear Well	0.100
3	River Sample	0.420
4	0.10 mg/L Fe Standard	0.066
5	0.25 mg/L Fe Standard	0.161
6	0.50 mg/L Fe Standard	0.328
7	0.75 mg/L Fe Standard	0.495
8	1.00 mg/L Fe Standard	0.658

H. Calculation

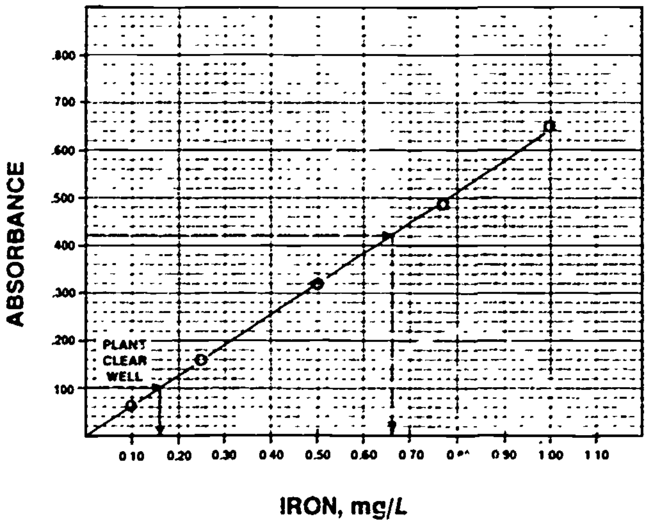
1. Prepare a standard curve by using data from prepared standards. From the above example:

Concentration Iron, mg/L	Absorbance
0.0	0.000
0.10	0.066
0.25	0.161
0.50	0.328
0.75	0.495
1.00	0.658

The graph below is a result of plotting concentration of standards versus their corresponding absorbance



2. Obtain concentration of unknown clear well and river samples from curve.



PLANT CLEAR WELL = 0.16 mg/L Fe
RIVER SAMPLE = 0.66 mg/L Fe

I. Notes

1. Iron in well water or tap samples may vary in concentration and form with duration and degree of flushing before and during sampling.
2. For precise determination of total iron, use a separate container for sample collection. Treat with acid at time of collection to place iron in solution and prevent deposition on walls of sample container.
3. Exercise caution when handling sulfuric acid.

J. Reference

See page 215, *STANDARD METHODS*, 16th Edition.

8. Manganese

A Discussion

Although manganese is much less abundant than iron in the earth's crust, it is one of the most common elements and widely distributed in rocks and soils. Some groundwaters

that contain objectionable amounts of iron also contain considerable amounts of manganese, but groundwaters that contain more manganese than iron are rather unusual. Manganese in surface waters occurs both in suspension and as a soluble complex. Although rarely present in excess of 1 mg/*L*, manganese imparts objectionable stains to laundry and plumbing fixtures. Manganese will also cause stains on the walls of tanks and driveways in treatment plants.

B. What is Tested?

Source	Common Range, mg/*L*
Treated and Untreated Surface Water	<0.01 to 0.10
Groundwater	<0.01 to 1.0

C. Apparatus Required

Spectrophotometer for use at 525 nm
Hot plate
Flask, Erlenmeyer, 250 m*L*
Pipets, 5 and 10 m*L*
Flask, Volumetric, 100 and 500 m*L*

D. Reagents

1. Special reagent.
2. Ammonium persulfate, $(NH_4)_2S_2O_8$, solid.
3. Standard manganese solution. 1 m*L* = 0.01 mg Mn. Prepare dilute solution daily.
4. 1% HCl: Add 10 m*L* concentrated HCl carefully to 990 m*L* distilled water.
5. Hydrogen peroxide, H_2O_2, 30 percent.

E. Procedure

1. Measure 100 m*L* of thoroughly mixed sample into a 250 m*L* Erlenmeyer flask which as been marked with a line at the 90 m*L* level.
2. Add 5 m*L* special reagent and 1 drop H_2O_2.
3. Concentrate to 90 m*L* by boiling. Add 1 gram ammonium persulfate. Cool immediately under water tap.
4. Dilute to 100 m*L*.
5. Measure the absorbance at 525 nm with a spectrophotometer and determine the amount of manganese from the standard curve.

F. Construction of Calibration Curve

1. Using the standard manganese solution, prepare the following standards in 100 m*L* volumetric flasks.

m*L* of Standard Manganese Solution Placed in 100 m*L* Volumetric Flask	**Manganese Concentration, mg/*L***
0	0
1.0	0.10
2.0	0.20
3.0	0.30
4.0	0.40

2. Dilute flasks to 100 m*L*.
3. Transfer to 250 m*L* Erlenmeyer flask.
4. Determine amount of manganese as outlined previously.
5. Prepare a standard curve by plotting the absorbance values of standards versus the corresponding manganese concentrations.

G. Example

Results from a series of tests for manganese were as follows:

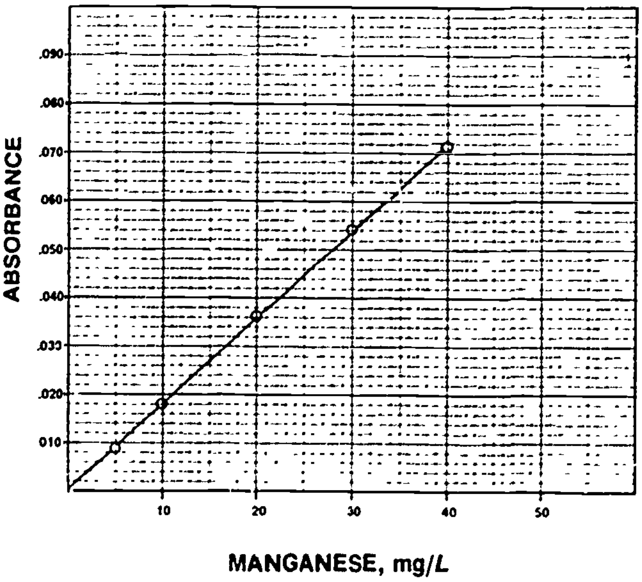
Flask	Sample	Absorbance
1	Distilled Water	0.000
2	Plant Effluent	0.000
3	Jones St. Well	0.030
4	0.05 mg/*L* Mn Standard	0.009
5	0.10 mg/*L* Mn Standard	0.018
6	0.20 mg/*L* Mn Standard	0.036
7	0.30 mg/*L* Mn Standard	0.053
8	0.40 mg/*L* Mn Standard	0.071

H. Calculation

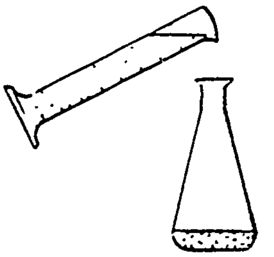
1 Prepare a standard curve by using data from prepared standards. From the above example:

Concentration Manganese, mg/*L*	**Absorbance**
0.0 (distilled water)	0.000
0.05	0.009
0.10	0.018
0.20	0.036
0.30	0.053
0.40	0.071

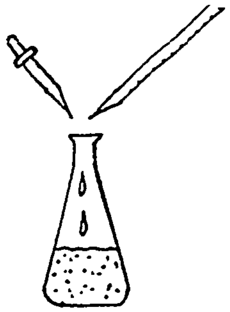
The graph below is the result of plotting concentration of standards versus their corresponding absorbance.



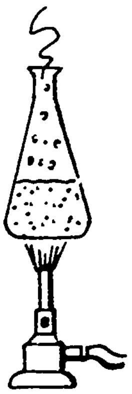
OUTLINE OF PROCEDURE FOR MANGANESE



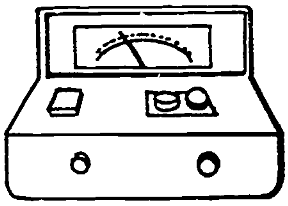
1. Measure 100 mL into flask.



2. Add 5 mL special reagent and 1 drop H_2O_2.

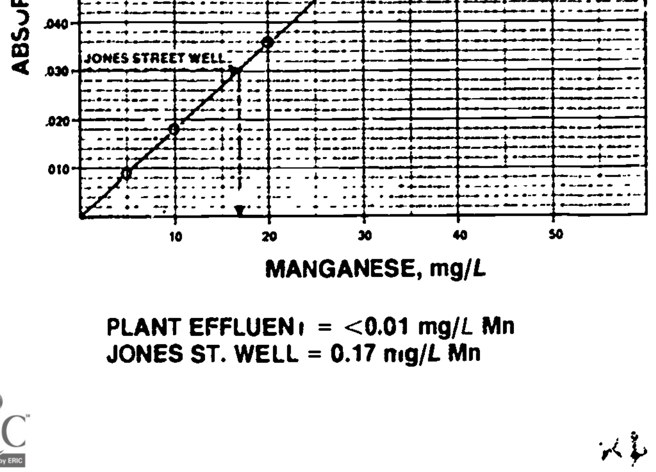


3. Concentrate to 90 mL then add 1 g ammonium persulfate. Dilute to 100 mL after cooling.



4. Measure absorbance at 525 nm with spectrophotometer.

2. Obtain concentration of unknown plant effluent and well sample from curve.



PLANT EFFLUENT = <0.01 mg/L Mn
JONES ST. WELL = 0.17 mg/L Mn

I. Notes

1. If turbidity or interfering color is present, use the following "bleaching" method: as soon as the spectrophotometer reading has been made, add 0.05 mL hydrogen peroxide solution directly to the optical cell. Mix and read again as soon as the color has faded. Deduct absorbance of bleached solution from initial absorbance to obtain absorbance due to manganese.
2. Determine manganese as soon as possible after sample collection. If this is not possible, acidify sample with nitric acid to pH less than 2.

J. Reference

See page 229, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 483.

21.1J Iron in a domestic water supply may cause what problems?

21.1K Why must all glassware be acid washed when analyzing samples for iron?

(Marble Test)

21.1L In what forms does manganese occur in surface waters?

21.1M If the manganese concentration in a sample cannot be measured immediatel what would you do?

9. **Marble Test** (Calcium Carbonate Stability Test)

A. Discussion

The Marble Test is intended to determine the degree to which a sample of water is saturated with calcium carbonate. Water in intimate contact with powdered calcium carbonate (calcite) will approach saturation. The water being tested should not be exposed to atmospheric carbon dioxide. The Marble Test must be conducted at the specific temperature because the solubility of calcium carbonate varies with temperature. However, equipment that will maintain a constant temperature (either lower or higher than room temperature) while mixing the solution is not commonly available in water treatment plants. The only other way to keep a reasonable uniform temperature is to run the test as rapidly as possible.

B. What is Tested?

Source	Common Range*
Untreated Surface Water	−1 to +1
Treated Surface Water	−0.2 to +0.2
Well Water	−0.1 to +1

* Initial pH − Final pH

C. Apparatus Required

Bottle, BOD, 300 mL
Magnetic stirrer
Stir-bar
Thermometer
Funnel, glass, 125 mm
Filter paper, Watman #50 (18.5 inch)
Equipment for determining pH and hardness

D. Reagents

1. Calcium carbonate, reagent grade.
2. Reagents for determining pH and hardness.

E. Procedure

1. Measure the temperature of the water to be tested.
2. Measure the pH, hardness and, if desired, the alkalinity of the sample being tested.
3. Insert the stirring bar in the BOD bottle and fill with the water being tested. Adjust the water temperature to within 1°C of the initial temperature. Add approximately one (1) gram of calcium carbonate and stir for five minutes at a rate high enough to keep the calcium carbonate in suspension and the sample vigorously agitated.
4. Recheck the temperature. If the temperature has changed more than one degree Celcius, repeat the stirring with a fresh sample whose temperature has been adjusted so that the final temperature will be within one degree Celcius of the initial temperature.
5. Immediately measure the final pH.
6. Filter the remaining sample. Determine the hardness and, if desired, the final alkalinity on the filtrate (water that passed through the filter).

F. Example

Results from a series of tests for the calcium carbonate precipitation potential were as follows:

	Filtered Water Sample
Initial Temperature	14°C
Final Temperature	14°C
Initial pH	8.7
Final pH	9.1
Initial Hardness	34 mg/L
Final Hardness	38 mg/L
Initial Alkalinity	24 mg/L
Final Alkalinity	27 mg/L

G. Calculation

Calcium Carbonate Precipitation Potential = Initial Hardness − Final Hardness

The Langelier Index[3] is approximately equal to the initial pH − final pH. If the value of this index is less than 0.2, this value will indicate that the water is very near the saturation level. In any event, the sign of this value will be the same as the sign of the Langelier Index. That is to say, both the Langelier Index and the calcium carbonate precipitation potential will be negative if the water is undersaturated and positive if the water is supersaturated.

---

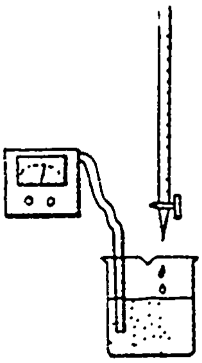
[3] *Langelier Index (L.I.). An index reflecting the equilibrium pH of a water with respect to calcium and alkalinity. This index is used in stabilizing water to control both corrosion and deposition of scale.*

Langelier Index = pH − pHs

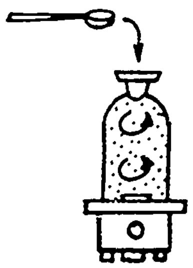
Where pH = actual pH of the water, and

pHs = pH at which water having the same alkalinity and calcium content is just saturated with calcium carbonate.

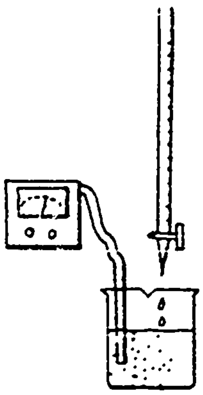
OUTLINE OF PROCEDURE FOR MARBLE TEST



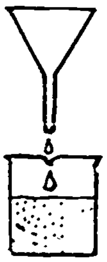
1. Measure temperature, pH hardness, and alkalinity of sample being tested.



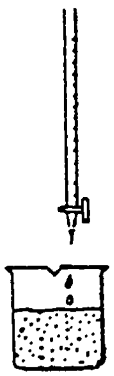
2. Transfer to BOD bottle and add 1 g calcium carbonate. Mix.



3. Measure final pH and temperature



4. Filter.



5. Determine hardness and alkalinity of filtrate.

From the example above:

Calcium Carbonate Precipitation Potential = Initial Hardness, mg/L − Final Hardness, mg/L

$= 34\ \text{mg/}L - 38\ \text{mg/}L$

$= -4$

Langelier Index $\simeq$ Initial pH − Final pH

$\simeq 8.7 - 9.1$

$\simeq -0.4$

This water is undersaturated (and therefore corrosive) with respect to calcium carbonate.

10. Metals

A. Discussion

The presence of certain metals in drinking water can be a matter of serious concern because of the toxic properties of these materials. The analyses of these metals is generally done by using atomic absorption spectroscopy or colorimetric methods. The term "metals" would include the following elements:

Aluminum
Antimony
Arsenic
Barium
Berryllium
Cadmium
Calcium
Chromium

Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Molybdenum
Nickel

Potassium
Selenium
Silver
Sodium
Thallium
Tin
Titanium
Vanadium
Zinc

B. Reference

For materials and procedures see:

Page 143, *STANDARD METHODS*, 16th Edition.

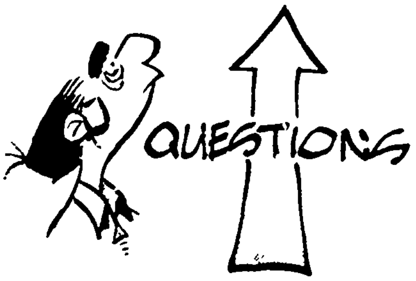
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 483.

21.1N Why is temperature important when running the Marble Test?

21.1O The results from the Marble Test produce an initial pH of 8.9 and a final pH of 8.6. Would this water be considered corrosive?

21.1P How are the concentrations of most metals in water measured?



11. Nitrate

A. Discussion

Nitrate represents the most completely oxidized form of nitrogen found in water. High levels of nitrate in water indicate biological wastes in the final state of stabilization or runoff from fertilized areas. High nitrate levels degrade water quality by stimulating excessive algal growth. Drinking water that contains excessive amounts of nitrate can cause infant methemoglobinema (blue babies). For this reason, a level of 10 mg/*L* (as Nitrogen) has been established as a maximum level. The procedure given below measures the amount of both nitrate and nitrite nitrogen present in a sample by reducing all nitrate to nitrite through the use of a copper-cadmium column. The total nitrate (any nitrite present originally plus the reduced nitrate) is then measured colorimetrically.

B. What is Tested?

Sample	Common Range, mg/*L*
Treated Surface Water	<0.1 to 5
Groundwater	0.5 to 10

C. Apparatus

Reduction column. The column in Figure 21.2 was constructed from a 100 m*L* volumetric pipet by removing the top portion. This column may also be constructed from two pieces of tubing joined end to end. A 10 cm length of 3 cm I.D. tubing is joined to a 25 cm length of 3.5 mm I.D. tubing. A column may be purchased from HACH Company. Order by Code No. 14563-00, $85.20, Post Office Box 389, Loveland, Colorado 80539.

Spectrophotometer for use at 540 nm, providing a light path of 1 cm or longer

Beakers, 125 m*L*

Glass wool

Glass fiber filter or 0.45 micron membrane filter

Filter holder assembly

Filter flask

pH meter

Separatory funnel, 250 m*L*

Pipets, volumetric, 1, 2, 5, and 10 m*L*

D Reagents

1. Granulated cadmium: 40 to 60 mesh (available from: EM Laboratories, Inc., 500 Executive Boulevard, Elmsford, New York 10523, Catalog No. 2001 Cadmium, Coarse Powder and HACH Company, Catalog No. 74560-26).
2. Copper-Cadmium: The cadmium granules (new or used) are cleaned with 6 *N* HCl and copperized with 2 percent solution of copper sulfate in the following manner:
   a. Wash the cadmium with 6 *N* HCl and rinse with distilled water. The color of the cadmium should be silver.
   b. Swirl 25 gm cadmium in 100 mg/*L* portions of a 2 percent solution of copper sulfate for 5 minutes or until the blue color partially fades, decant and repeat with fresh copper until a brown precipitate forms.
   c. Wash the copper-cadmium with distilled water at least 10 times to remove all the precipitated copper. The color of the cadmium should now be black.
3. Preparation of reaction column: Insert a glass wool plug into the bottom of the reduction column and fill with distilled water. Add sufficient copper-cadmium granules to produce a column 18.5 cm in length. Maintain a level of distilled water above the copper-cadmium granules to eliminate entrapment of air. Wash the column with 200 m*L* of dilute ammonium chloride — EDTA solution (reagent 5). The column is then activated by passing through the column 100 m*L* of solution composed of 25 m*L* of a 1.0 mg/*L* NO_2-N standard and 75 m*L* of concentrated ammonium chloride — EDTA solution. Use a flow rate of 7 to 10 m*L* per minute. Collect the reduced standard until the level of solution is 0.5 cm above the top of the granules. Close the screw clamp to stop flow. Discard the reduced standard.
4. Measure about 40 m*L* of concentrated ammonium chloride — EDTA and pass through column at 7 to 10 m*L* per minute to wash nitrate standard off column. Always leave at least 0.5 cm of liquid above top of granules. The column is now ready for use.
5. Dilute ammonium chloride — EDTA solution. Dilute 300 m*L* of concentrated ammonium chloride — EDTA solution (reagent 4) to 500 m*L* with distilled water.
6. Color reagent.
7. Zinc sulfate solution.
8. Sodium hydroxide, 6 *N*.
9. Ammonium hydroxide, concentrated.
10. Hydrochloric acid, 6 *N*. Dilute 50 m*L* concentrated HCl to 100 m*L* with distilled water.
11. Copper sulfate solution, 2 percent.
12. Nitrate stock solution. 1.0 m*L* = 1.00 mg NO_3-N. Preserve with 2 m*L* of chloroform per liter. This solution is stable for at least six months.

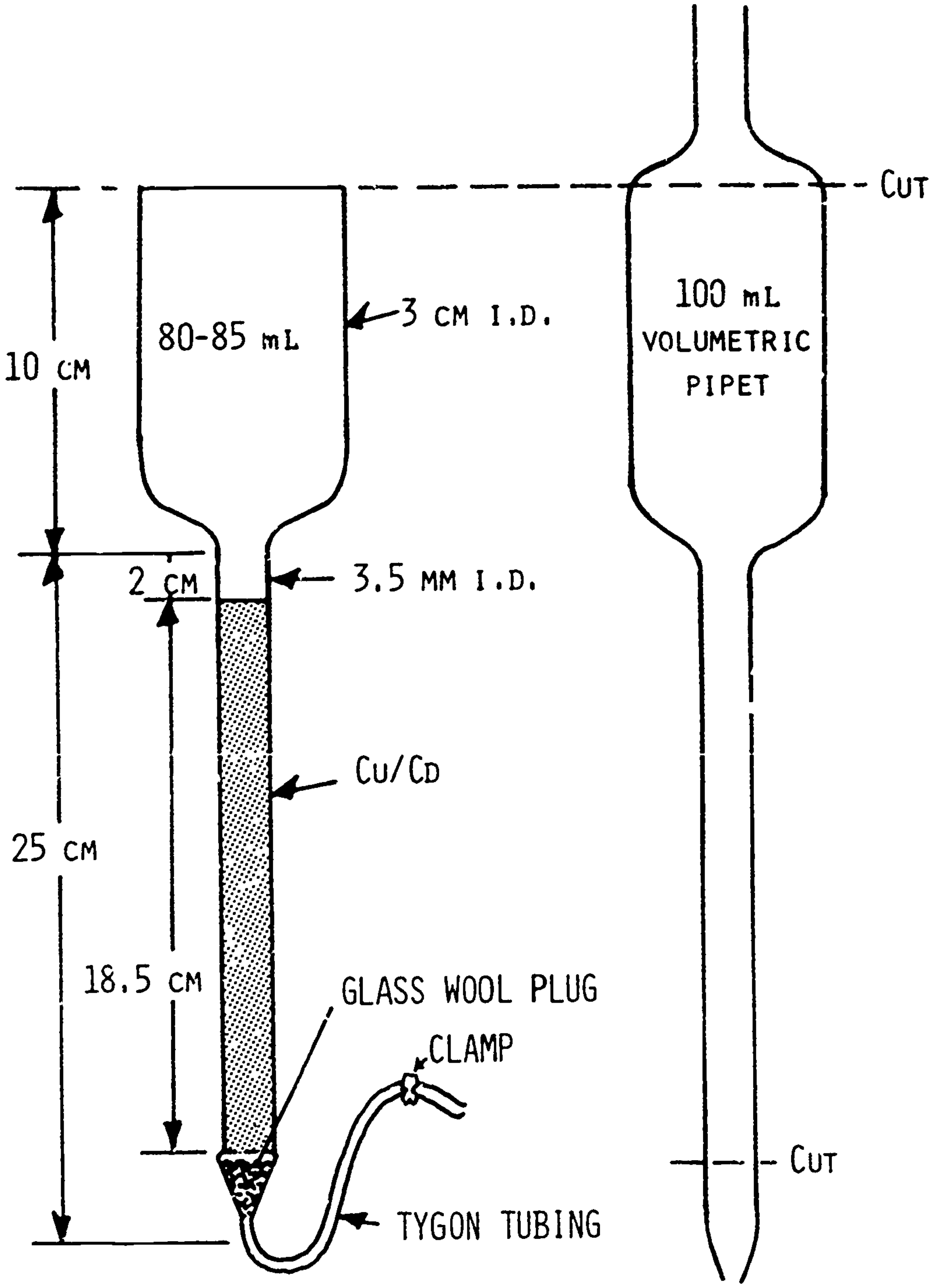


Fig. 21.2 Reduction column

(Nitrate)

13. Nitrate standard solution. 1.0 mL = 0.01 mg NO_3-N. Dilute 10.0 mL of nitrate stock solution (reagent 12) to 1000 mL with distilled water.
14. Chloroform.

E. Procedure

Removal of Interferences (if necessary).

Turbidity removal. Use one of the following methods to remove suspended matter that can clog the reduction column.

a. Filter sample through a glass fiber or a 0.45 micron pore size filter as long as the pH is less than 8, or

b. Add 1 mL zinc solution (reagent 7) to 100 mL sample and mix thoroughly. Add enough (usually 8 to 10 drops) sodium hydroxide solution (reagent 8) to obtain a pH of 10.5. Let treated sample stand a few minutes to allow the heavy flocculent precipitate to settle. Clarify by filtering through a glass fiber filter.

Reduction of Nitrate to Nitrite.

1. Using a pH meter adjust the pH of sample (or standard) to between 5 and 9 either with concentrated HCl or concentrated NH_4OH.
2. To 25 mL of sample (or standard) or aliquot diluted to 25 mL, add 75 mL of concentrated ammonium chloride -- EDTA solution and mix.
3. Pour sample into column and collect reduced sample at a rate of 7 to 10 mL per minute.
4. Discard the first 25 mL. Collect the rest of the sample (approximately 70 mL) in the original sample flask. Reduced samples should not be allowed to stand longer than 15 minutes before addition of color reagent.
5. Add 2.0 mL of color reagent to 50 mL of sample. Allow 10 minutes for color development. Within two hours measure the absorbance at 540 nm against a reagent blank (50 mL distilled water to which 2.0 mL color reagent has been added).

F. Construction of Standard Calibration Graph

1. Prepare working standards by pipeting the following volumes of nitrate standard solution into each of five 100 mL volumetric flasks.

Add this volume of Nitrate Standard Solution to 100 mL flask	Concentration of NO_3-N in mg/L
0.0	0.00
1.0	0.10
2.0	0.20
5.0	0.50
10.0	1.00

Dilute each to 100 mL with distilled water and mix.

2. Determine the amount of nitrate-nitrite as outlined above in the procedure for reduction of nitrate to nitrite.
3. Plot on a sheet of graph paper the absorbance versus concentration.

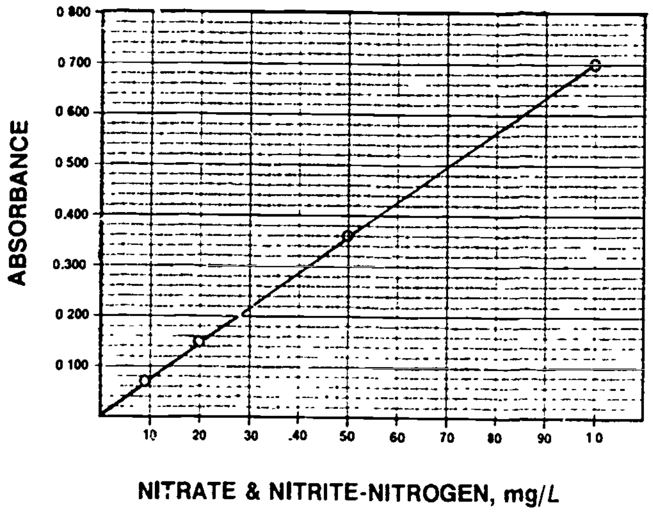
G. Example

Results from the analyses of samples and working standards for nitrate-nitrite were as follows:

Flask #		Volume	Absorbance
1	Jones St. Well	25 mL	0.440
2	Blank (distilled water)	25 mL	0.00
3	0.10 mg/L NO_3-N	25 mL	0.075
4	0.20 mg/L NO_3-N	25 mL	0.142
5	0.50 mg/L NO_3-N	25 mL	0.355
6	1.00 mg/L NO_3-N	25 mL	0.700

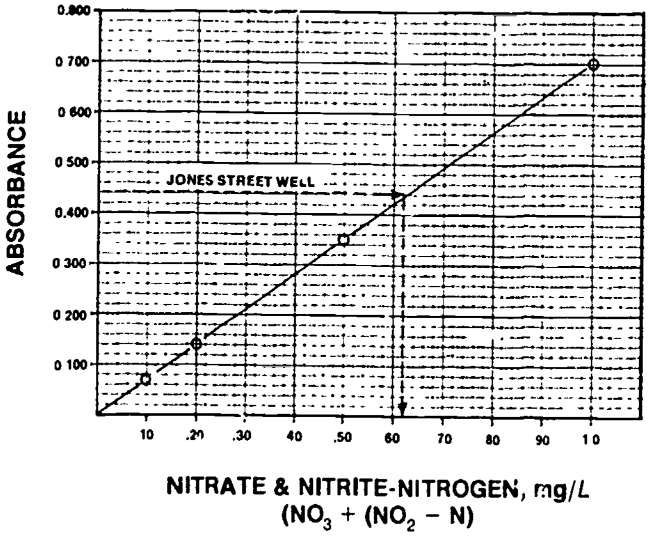
H. Calculation

1. Using graph paper, plot the absorbance values of working standards versus their known concentrations. For example, from the above data the following graph can be constructed.



2. Read concentration of $NO_3^- + NO_2^-$ nitrogen in plant effluent from graph shown below.

mg/L nitrate + nitrite nitrogen in sample = 0.62 mg/L

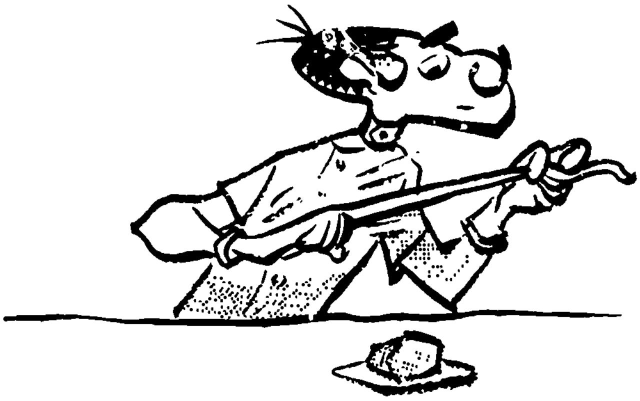


3. Determine concentration of Nitrite-Nitrogen (NO_2-N) in sample using nitrite procedure.
4. Subtract nitrite from $NO_2^- + NO_3^-$ nitrogen concentration. The result is the amount of nitrate nitrogen in sample.

5. For example, if the sample of Jones St. Well used in the above example contained no nitrite nitrogen then the nitrate nitrogen (NO_3-N) would be 0.62 mg/*L*.

I Notes

1. If concentration of nitrate in the sample is greater than 1 mg/*L*, then the sample must be diluted.
2. Cadmium metal is highly toxic thus caution must be exercised in its use. Rubber gloves should be used whenever it is handled.



J. Reference

See page 394, *STANDARD METHODS*, 16th Edition.

12. pH by Jack Rossum

DISCUSSION

This discussion is presented to give you a better understanding of what a pH value actually represents. Procedures for measuring pH are given in Chapter 11, "Laboratory Procedures."

Pure water dissociates according to the following reaction:

$$H_2O = H^+ + OH^-.$$

At 25°C and a pH of 7, the activity of the hydrogen ion is equal to the activity of the hydroxyl ion at .000 000 1 moles/liter. "Activity" is a term used by chemists to allow real atoms, molecules and ions to behave as if they were perfect particles (having zero size). Activity is obtained by multiplying the concentration by an activity coefficient. The value of the activity coefficient depends on the electrical charge on the particle, the temperature and the other substances dissolved in the water. For hydrogen ion the activity coefficient at 25°C varies from 0.996 in pure water to 0.900 in water containing 400 mg/*L* of dissolved solids. Activities are expressed in moles per liter which is assumed to be the number of grams per liter since the molecular weight of hydrogen ion is 1.008 (almost 1.0).

When the activities of the hydrogen and hydroxyl ions are equal, the solution is neutral. If hydrogen ions are in excess, the solution is acid and if hydroxyl ions are in excess, the solution is alkaline. An important property of water is that for any temperature, the product of the activities of these ions is a constant. At 25°C, this constant is .000 000 000 000 01.

In a strong solution of hydrochloric acid, the hydrogen ion activity may be as high as 1 mole per liter, while in a strong solution of lye, the hydroxyl ion concentration may be as high as 1 mole per liter. To avoid the inconvenience of writing these very small numbers, hydrogen ion activities are expressed in terms of pH, with

$$pH = \log_{10} \frac{1}{[H^+]}$$

The relation between pH, H^+ and OH at 25°C is shown in Table 21.2.

Most natural waters have pH values between 6.5 and 8.5. Human blood has a pH of 7.4 and the gastric juices in your stomach have a pH of approximately 0.9 to aid in the digestion of food.

Alum coagulates most effectively at pH values near 6.8.

The pH of natural waters is controlled by the relative amounts of carbon dioxide, bicarbonate, and carbonate ions. Rain water usually has a pH of slightly less than 7 because carbon dioxide from the air dissolves to form carbonic acid.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 483.

21.1Q How is nitrate measured in the nitrate test?

21.1R If turbidity is interfering with a nitrate analysis, how can turbidity be removed?

21.1S The pH of natural waters is usually controlled by the relative amounts of what ions?

TABLE 21.2 RELATION BETWEEN pH, H^+ AND OH^- AT 25°C

Activity of H^+ moles/*L*	Activity of OH^- moles/*L*	pH
1.	0.000 000 000 000 01	0
0.1	0.000 000 000 000 1	1
0.01	0.000 000 000 001	2
0.001	0.000 000 000 01	3
0.000 1	0.000 000 000 1	4
0.000 01	0.000 000 001	5
0.000 001	0.000 000 01	6
0.000 000 1	0.000 000 1	7
0.000 000 01	0.000 001	8
0.000 000 001	0.000 01	9
0.000 000 000 1	0.000 1	10
0.000 000 000 01	0.001	11
0.000 000 000 001	0.01	12
0.000 000 000 000 1	0.1	13
0.000 000 000 000 01	1.	14

13. Specific Conductance

A. Discussion

Specific conductance or conductivity is a numerical expression (expressed in micromhos per centimeter) of the ability of a water to conduct an electrical current. This number depends on the total concentration of the minerals dissolved in the sample (TDS) and the temperature. Changes in conductivity from normal may indicate changes in mineral composition of the water, seasonal variations in lakes and reservoirs, or intrusion of pollutants. The custom of reporting conductivity values in micromhos/cm at 25°C requires the accurate determination of each sample's temperature at the time of conductivity measurement

Specific conductance is measured by the use of a conductivity meter.

B. What is Tested?

Sample	Common Range, micromhos/cm
Raw and Treated Surface Waters	30 to 500
Groundwater	100 to 1000

C. Materials and Procedure

Follow instrument manufacturer's instructions. Also see page 76, *STANDARD METHODS*, 16th Edition.

14. Sulfate

A. Discussion

The sulfate ion is one of the major anions occurring in natural waters. Sulfate ions are of importance in water supplies because of the tendency of appreciable amounts to form hard scales in boilers and heat exchangers. The secondary maximum contaminant level for sulfate listed in the Safe Drinking Water Act is 250 mg/L.

B. What is Tested?

Sample	Common Range, mg/L
Raw or Treated Water Supply	5 - 100

C. Apparatus Required

Turbidimeter *OR* spectrophotometer
Stopwatch or timer
Measuring spoon, 0.3 mL
Magnetic stirrer
Magnetic stir-bar
Pipet, 10 mL
Flasks, Erlenmeyer, 250 mL

D. Reagents

(Note. Standardized solutions are commercially available.)

1. Conditioning reagent.
2. Barium chloride, $BaCl_2$, crystals: Sized for turbidimetric work.* To ensure uniformity of results, construct a standard curve for each batch of $BaCl_2$ crystals.
3. Standard sulfate solution: Prepare a standard sulfate solution as described in (a) or (b) below; 1.00 mL = 0.10 mg SO_4.
   (a) Dilute 10.41 mL standard 0.0200 *N* H_2SO_4 titrant specified in Alkalinity Test, Chapter 11, to 100 mL with distilled water.
   (b) Dissolve 147.9 mg anhydrous Na_2SO_4 in distilled water and dilute to 1,000 mL.

E. Procedure

1. Place 100 mL of sample or a suitable portion diluted to 100 mL into a clean 250 mL Erlenmeyer flask
2. Add 5.0 mL of conditioning reagent and mix
3. While stirring, add a spoonful of barium chloride crystals. Stir for exactly 1 minute.
4. Measure turbidity at 30-second intervals for 4 minutes. Consider turbidity to be the maximum reading obtained in the 4-minute interval.

F. Construction of Standard Calibration Curve

1. Using the standard solution prepare the following standards in 100 mL volumetric flasks.

mL of Standard Sulfate Solution Placed in 100 mL Volumetric Flask	**Sulfate Concentration, mg/L**
5.0	5.0
10.0	10.0
15.0	15.0
20.0	20.0
25.0	25.0

2. Dilute flasks to 100 mL.
3. Transfer to 250 mL Erlenmeyer flask.
4. Determine amount of sulfate as outlined previously.
5. Prepare a standard curve by plotting turbidity values of standards versus the corresponding sulfate concentrations. Set nephelometer (or spectrophotometer) at zero sulfate concentration using distilled water as a control.

G. Example

Results from a series of tests for sulfate were as follows:

Flask	**Sample**	**Volume**	**Turbidity**
1	Distilled Water	100 mL	0
2	Plant Effluent	100 mL	35
3	Jones St. Well	50 mL	45
4	5.0 mg/L SO_4 Standard	100 mL	11
5	10.0 mg/L SO_4 Standard	100 mL	29
6	15.0 mg/L SO_4 Standard	100 mL	40
7	20.0 mg/L SO_4 Standard	100 mL	53

H. Calculation

1. Prepare a standard curve by using data from prepared standards. From the above example:

Concentration Sulfate, mg/L	**Turbidity, TU**
0.0	0.0
5.0	11
10.0	29
15.0	40
20.0	53

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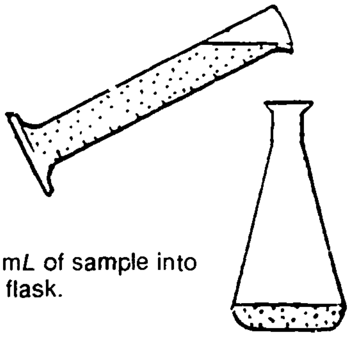
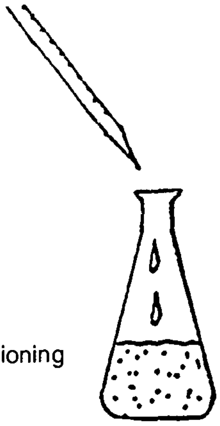
* Baker No. 0974 or equivalent.

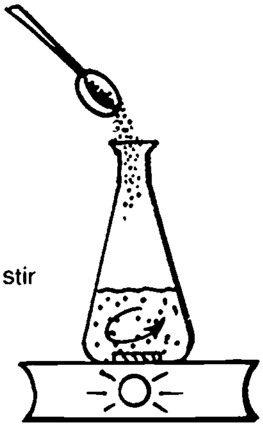
OUTLINE OF PROCEDURE FOR SULFATE



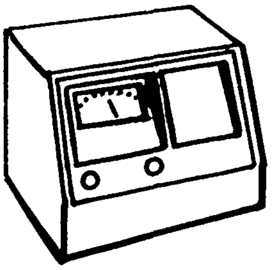
1. Measure 100 m*L* of sample into clean 250 m*L* flask.



2. Add 5.0 m*L* conditioning reagent. Mix.

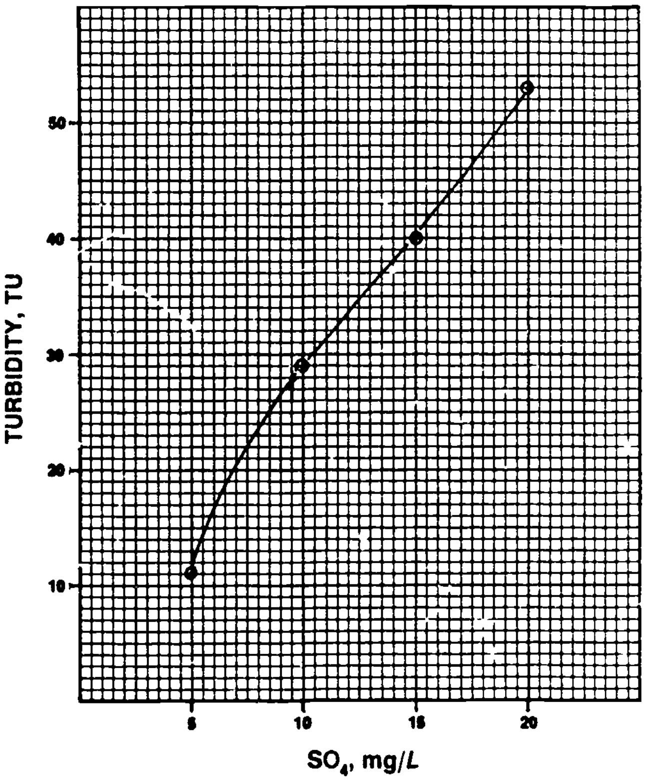


3. Add barium chloride and stir for 1 minute.

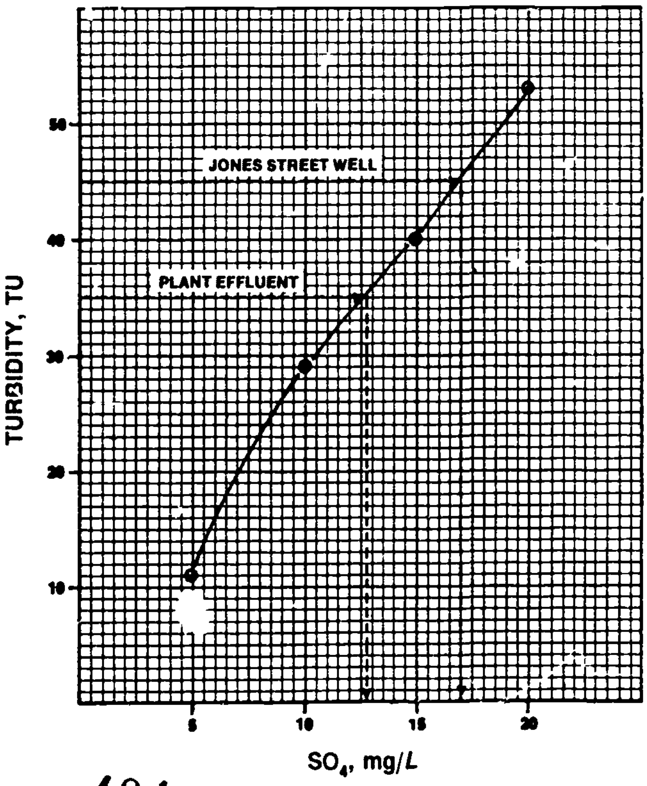


4. Measure turbidity.

The graph below is the result of plotting concentration of standards versus their corresponding turbidity.



2. Obtain concentration of unknown plant and well samples from curve.



(Taste and Odor)

3. Correct (if necessary) for samples of less than 100 mL by using the following formula:

$$\text{Sulfate, mg/}L\ SO_4 = \frac{(\text{Graph Sulfate, mg/}L)(100\ mL)}{\text{Sample Size, }mL}$$

Using data from example.

	Sample Volume	Turbidity	Concentration from Graph
Plant Effluent	100 mL	35 TU	13 mg/L

Sulfate, mg/L = 13 mg/L

	Sample Volume	Turbidity	Concentration from Graph
Jones St Well	50 mL	45 TU	17 mg/L

$$\text{Sulfate, mg/}L = \frac{(\text{Sulfate, mg/}L)(100\ mL)}{\text{Sample Size, }mL}$$

$$= \frac{(17\ mg/L)(100\ mL)}{(50\ mL)}$$

$$= 34\ mg/L\ SO_4$$

I. Notes

1. A spectrophotometer can be used to measure absorbance of barium sulfate suspension. Use at 420 nanometer (nm) wavelength.
2. Color or suspended matter will interfere when present in large amounts. Correct for these items by testing blanks from which barium chloride is withheld.
3. Analyze samples and standards with their temperatures in the range of 20 to 25°C.

J. Reference

See page 467, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 483.

21.1T What is the meaning of specific conductance or conductivity?

21.1U Sulfate ions are of concern in drinking water for what reason?

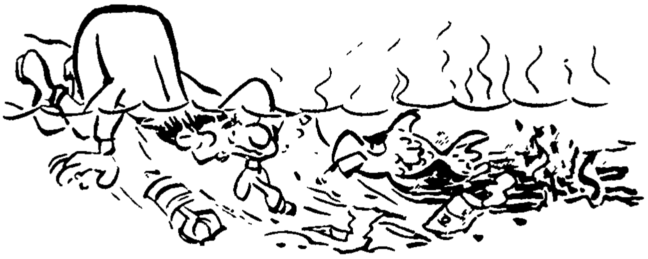
21.1V A 50 mL sample from a well produced a turbidity reading of 40 TU using a nephelometer (turbidimeter). What was the sulfate concentration in mg/L?

15. Taste and Odor

A. Discussion

Taste and odor are sensory clues that provide the first warning of potential hazards in the environment. Water, in its pure form, cannot produce odor or taste sensations. However, algae, actinomycetes, bacteria, decaying vegetation, metals, and pollutants can cause tastes and odors in drinking water. Corrective measures designed to reduce unpleasant tastes and odors include aeration or the addition of chlorine, chlorine dioxide, potassium permanganate or activated carbon.

Odor is considered a quality factor affecting acceptability of drinking water (and foods prepared with it), tainting of fish and other aquatic organisms, and aesthetics of recreational waters. Most organic and some inorganic chemicals contribute to taste and odor. These chemicals may originate from municipal and industrial waste discharges, from natural sources (such as decomposition of vegetable matter), or from associated microbial activity.



Some substances, such as certain inorganic salts, produce taste without odor. Many other sensations considered to cause taste actually cause odors, even though the sensation is not noticed until the water is in the mouth.

Taste, like odor, is one of the chemical senses. Taste and odor are different in that odors are sensed high up in our nose and tastes are sensed on our tongue. Taste is simpler than odor because there may be only four true taste sensations: sour, sweet, salty, and bitter. Dissolved inorganic salts of copper, iron, manganese, potassium, sodium, and zinc can be detected by taste.

Operators must remember that a tasteless water is not the most desirable water. Distilled water is considered less pleasant to drink than a high-quality water. The taste test must determine the taste intensity by the threshold test and also evaluate the quality of the drinking water on the basis of desirability for consumers.

B. Apparatus Required

Sample bottles, glass-stoppered or with TFE-lined closures
Constant temperature bath
Odor flasks (500 mL glass stoppered Erlenmeyer flasks)
Transfer and volumetric pipets or graduated cylinders (200, 100, 50, and 25 mL)
Measuring pipets (10 mL, graduated in 0 1 mLs)
Thermometer (0 to 110°C)

C Precautions

Use preliminary tests to select the persons to make taste or odor tests. Use only persons who want to participate in the test. Avoid distracting odors such as those caused by smoking, foods, soaps, perfumes, and shaving lotions. The testers should not have colds or allergies that affect odor response. Do not have the testers perform too many tests and allow frequent rests so the testers won't become tired and lose their sensitivity. Keep the room in which the tests are conducted free from distractions, drafts and odors.

A panel of five or more testers is recommended for precise work. Do not allow the testers to prepare the samples or to know the dilution concentrations being evaluated. Familiarize testers with the procedure before they participate in a panel test. Present most dilute sample first to avoid tiring the senses with a concentrated sample. Keep temperature of sample during test within 1°C of the specified temperature. Use opaque or darkly colored flasks to avoid biasing the results due to turbid or colored waters being tested.

D. Procedure

ODOR

1. Determine the approximate range of the threshold odor number by adding 200 mL, 50 mL, 12 mL, and 2.8 mL of sample to 500 mL glass-stoppered Erlenmeyer flasks containing odor-free water[4] to make a total volume of 200 mL. Use a separate flask containing only odor-free water as a reference for comparison. Heat dilutions and reference to desired test temperature (usually 60°C or 140°F).
2. Shake flask containing odor-free water, remove stopper, and sniff vapors. Test sample containing least amount of odor-bearing water in the same way. If an odor can be detected in this dilution, prepare more dilute samples.

To prepare more dilute samples, prepare an intermediate dilution consisting of 20 mL sample diluted to 200 mL with odor-free water. Use this dilution for the threshold determination. Multiply the threshold odor number (T O.N.) obtained by 10 to correct for the intermediate dilution.

If an odor cannot be detected in the first dilution, repeat the above procedure using sample containing the next higher concentration of odor-bearing water and continue this process until odor is detected clearly.

3. Based on the results obtained in the preliminary test, prepare a set of dilutions using Table 21.3 as a guide. Prepare the five dilutions shown in the appropriate column and the three next most concentrated in the next column to the right in Table 21.3. For example, if odor was first noted in the flask containing the 50 mL sample in the preliminary test, prepare flasks containing 50, 35, 25, 17, 12, 8.3, 5.7, and 4.0 mL sample, each diluted to 200 mL with odor-free water. This procedure is necessary to challenge the range of sensitivities of the entire panel of testers.

TABLE 21.3 DILUTIONS FOR VARIOUS ODOR INTENSITIES

PRELIMINARY TEST

Sample Volume in Which Odor First Noted

200 mL	50 mL	12 mL	3.8 mL

FINAL TEST

Volume in mL of Sample to be Diluted to 200 mL

200	50	12	(Intermediate dilution)
140	35	8.3	
100	25	5.7	
70	17	4.0	
50	12	2.8	

Insert two or more blanks near the expected threshold, but avoid any repeated patterns. Do not let the testers know which dilutions are odorous and which are blanks. Instruct each tester to smell each flask in sequence, beginning with the least concentrated sample, until odor is detected with certainty.

4. Record observations by indicating whether odor is noted in each flask. For example

mL Sample Diluted to 200 mL	12	0	17	25	0	35	50
Response	−	−	−	+	−	+	+

5. Calculate the threshold odor number (T.O.N.) as shown in E. Calculations.

TASTE THRESHOLD TEST

1. The taste threshold test is used when the purpose is quantitative measurement of detectable taste. When odor is the predominant sensation, as in the case of chlorophenols, the threshold odor test takes priority.
2. Use the dilution and random blank system described for odor tests when preparing taste samples.

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[4] *See STANDARD METHODS, 16th Edition, page 85, for directions on how to prepare odor-free water.*

3. Present each dilution and blank to the tester in a clean 50-m*L* plastic container filled to the 30-m*L* level. Use high quality clear plastic containers. Discard the plastic container when finished. Do not use glass containers because the soap used to clean the glass could leave a residue which may affect the results.

4. *STANDARD METHODS* recommends maintaining the sample presentation at 40 ± 1°C (104 ± 2°F).

   NOTE: Some operators use normal water temperatures for taste tests or a temperature of 15°C (59°F).

5. Present the series of samples to each tester. Pair each sample with a known blank.
6. Have each tester taste the sample by taking into the mouth whatever volume is comfortable, holding it in the mouth for several seconds, and discharging the sample without swallowing the water.
7. Have the tester compare the sample with the blank and record whether a taste or aftertaste is detectable in the sample.
8. Submit samples in an increasing order of concentration until the tester's taste threshold has been passed.
9. Calculate individual threshold and threshold of the panel as shown in E. Calculations.

TASTE RATING TEST

1. When the purpose of the test is to estimate the taste acceptability, use the "taste rating test" procedure described below.
2. Samples for this test usually represent treated water ready for human consumption. If experimentally treated water is tested, *BE CERTAIN THAT THE WATER IS SAFE TO DRINK* (no pathogens and no toxic chemicals present).
3. Give testers thorough instructions and trial or orientation sessions followed by questions and discussions of procedures.
4. Select panel members on basis of performance in trial sessions.
5. When testing samples testers work alone.
6. Present samples at a temperature that testers find pleasant for drinking water. Maintain this temperature by the use of a water bath apparatus. A temperature of 15°C (59°F) is recommended, but in any case, do not let the test temperature exceed tap water temperatures that are customary at the time of the test. Specify the test temperature in reporting results.
7. Present each dilution and blank to the tester in a clean 50-m*L* plastic container filled to the 30-m*L* level. Use high quality clear plastic containers. Discard the plastic containers when finished. Do not use glass containers because the soap used to clean the glass could leave a residue which may affect the results.
8. Each tester is presented with a list of nine statements about the water ranging on a scale from very favorable to very unfavorable (Table 21.4). The testers task is to select the statement that best expresses the tester's opinion. The scored rating is the scale number of the statement selected. The panel rating is the arithmetic mean (average) of the scale numbers of all testers.
9. Rating involves the following steps:
   a. Initial tasting of about half the sample by taking water into the mouth, holding it for several seconds, and discharging it without swallowing;
   b. Forming an initial judgment on the rating scale;
   c. A second tasting is made in the same manner as the first;
   d. A final rating is made for the sample and the result is recorded on the appropriate data form;
   e. Rinse mouth with taste- and odor-free water; and
   f. Rest one minute before repeating steps a through e on the next sample.

TABLE 21.4 ACTION TENDENCY RATING SCALE FOR TASTE RATING TEST

1. I would be very happy to drink this water as my everyday drinking water.
2. I would be happy to accept this water as my everyday drinking water.
3. I am sure that I could accept this water as my everyday drinking water.
4. I could accept this water as my everyday drinking water.
5. Maybe I could accept this water as my everyday drinking water.
6. I don't think I could accept this water as my everyday drinking water.
7. I could not accept this water as my everyday drinking water.
8. I could never drink this water.
9. I can't stand this water in my mouth and I could never drink it.

10. Independently randomize sample order for each tester. Allow at least 30 minutes rest between repeated rating sessions. Testers should not know the composition or source of samples.

E. Calculations

FORMULAS

1. ODOR

The threshold odor number (T.O.N.) for an individual tester is calculated using the following formula:

$$\text{T.O.N.} = \frac{A + B}{A}$$

where:

A = m*L* sample and

B = m*L* odor-free water.

The threshold odor number for a group is presented as the geometric mean of the individual tester thresholds.

$$\text{Geometric Mean} = (X_1 \times X_2 \times X_3 \times \ldots X_n)^{1/n}$$

where:

X_1 = threshold odor number for tester number 1,

X_2 = threshold odor number for tester number 2,

X_3 = threshold odor number for the nth tester, and

n = total number of testers.

2. TASTE THRESHOLD

Calculate the individual tester's threshold taste number and the threshold taste number for a panel using the same formulas that are used for the threshold odor tests.

3. TASTE RATING

Determine the taste rating for a water by calculating the arithmetic mean and *STANDARD DEVIATION*[5] of all ratings given for each sample.

$$\text{Arithmetic Mean, } \bar{X} = \frac{X_1 + X_2 + X_3 + \ldots X_n}{n}$$

where: X_1 = taste rating for tester number 1,

X_2 = taste rating for tester number 2,

X_n = taste rating for nth tester, and

n = number of testers.

$$\text{Standard Deviation} = \left[\frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \quad (X_n - \bar{X})^2}{n - 1}\right]^{1/2}$$

$$\text{or} = \left[\frac{(X_1^2 + X_2^2 + \quad X_n^2) - (X_1 + X_2 + \quad X_n)^2/n}{n - 1}\right]^{1/2}$$

EXAMPLE 1

Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 25 m*L* sample was diluted to 200 m*L* (175 m*L* of odor-free water was added to the 25 m*L* sample).

Known		Unknown
A or Sample Size, m*L*	= 25 m*L*	T.O.N.
B or Odor-Free Water, m*L*	= 175 m*L*	

Calculate the threshold odor number, T.O.N.

$$\text{T.O.N.} = \frac{A + B}{A}$$

$$= \frac{25\ mL + 175\ mL}{25\ mL}$$

$$= 8$$

EXAMPLE 2

Determine the geometric mean threshold odor number for a panel of five testers given the results shown below.

Known	Unknown
Tester 1, X_1 = 8	Geometric Mean Threshold Odor Number
Tester 2, X_2 = 6	
Tester 3, X_3 = 12	
Tester 4, X_4 = 8	
Tester 5, X_5 = 4	

Calculate the geometric mean

$$\text{Geometric Mean T.O.N.} = (X_1 \times X_2 \times X_3 \times X_4 \times \ X_5)^{1/n}$$

$$= (8 \times 6 \times 12 \times 8 \times 4)^{1/5}$$

$$= (18432)^{0.2}$$

$$= 7.1$$

EXAMPLE 3

Calculate the threshold taste number for a sample when the first detectable taste occurred when the 50 m*L* sample was diluted to 200 m*L* (150 m*L* of taste-free water was added to the 50 m*L* sample).

Known		Unknown
A or Sample Size, m*L*	= 50 m*L*	Threshold Taste Number
B or Taste-Free Water, m*L*	= 150 m*L*	

Calculate the threshold taste number.

$$\text{Threshold Taste Number} = \frac{A + B}{A}$$

$$= \frac{50\ mL + 150\ mL}{50\ mL}$$

$$= 4$$

---

[5] *Standard Deviation. A measure of the spread or dispersion of data.*

EXAMPLE 4

Determine the taste rating for a water by calculating the arithmetic mean and standard deviation for the panel ratings given below.

Known	**Unknown**
Tester 1, $X_1 = 4$	1. Arithmetic Mean, $\bar{X}$
Tester 2, $X_2 = 2$	2. Standard Deviation, S
Tester 3, $X_3 = 3$	
Tester 4, $X_4 = 5$	
Tester 5, $X_5 = 3$	
Tester 6, $X_6 = 1$	

1. Calculate the arithmetic mean, $\bar{X}$, taste rating.

$$\text{Arithmetic Mean, } \bar{X} \text{ Taste Rating} = \frac{X_1 + X_2 + X_3 + X_4 + X_5 + X_6}{n}$$

$$= \frac{4 + 2 + 3 + 5 + 3 + 1}{6}$$

$$= \frac{18}{6}$$

$$= 3$$

2. Calculate the standard deviation, S, of the taste rating.

$$\text{Standard Deviation, S} = \left[\frac{(X_1-\bar{X})^2 + (X_2-\bar{X})^2 + (X_3-\bar{X})^2 + (X_4-\bar{X})^2 + (X_5-\bar{X})^2 + (X_6-\bar{X})^2}{n-1} \right]^{1/2}$$

$$= \left[\frac{(4-3)^2 + (2-3)^2 + (3-3)^2 + (5-3)^2 + (3-3)^2 + (1-3)^2}{6-1} \right]^{1/2}$$

$$= \left[\frac{(1)^2 + (-1)^2 + 0^2 + (2)^2 + 0^2 + (-2)^2}{5} \right]^{0\,5}$$

$$= \left[\frac{1 + 1 + 0 + 4 + 0 + 4}{5} \right]^{0\,5}$$

$$= \left[\frac{10}{5} \right]^{0\,5}$$

$$= (2)^{0\,5}$$

$$= 1.4$$

or

$$\text{Standard Deviation, } S = \left[\frac{(X_1^2 + X_2^2 + X_3^2 + X_4^2 + X_5^2 + X_6^2) - (X_1+X_2+ X_3+X_4+ X_5+X_6)^2 /n}{n-1}\right]^{1/2}$$

$$= \left[\frac{(4^2+2^2+3^2+5^2+3^2+1^2) - (4+2+3+5+3+1)^2/6}{6-1}\right]^{1/2}$$

$$= \left[\frac{(16+4+9+25+9+1) - (18)^2/6}{5}\right]^{0.5}$$

$$= \left[\frac{64-54}{5}\right]^{0.5}$$

$$= \left[\frac{10}{5}\right]^{0.5}$$

$$= (2)^{0.5}$$

= 1.4 (same answer as before)

F. Reference

Odor:

See page 85, *STANDARD METHODS*, 16th Edition.

Taste:

See page 122, *STANDARD METHODS*, 16th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 483.

21.1W List the items that can cause tastes and odors in drinking water.

21.1X Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 12 *mL* sample was diluted to 200 *mL* (188 *mL* of odor-free water was added to the 12 *mL*).

16. Trihalomethanes

A. Discussion

The trihalomethanes (THMs) are members of the family of organohalogen compounds which are named as derivatives of methane. Current analytical chemistry applied to drinking water has thus far detected chloroform, bromodichloromethane, dibromochloromethane, bromoform, and dichloroiodomethane.

The principal sources of chloroform and other trihalomethanes in drinking water is the chemical interaction of chlorine added for disinfection and other purposes with the commonly present natural humic substances and other precursors produced either by normal organic decomposition or by the metabolism of aquatic organisms. Since these natural organic precursors are more commonly found in surface water, water taken from a surface source is more likely to produce high THM levels than most groundwaters.

Generally, the THM producing reaction is:

Chlorine + Precursors = Chloroform + Other THMs

Chloroform is the most common THM found in drinking water and it is usually present in the highest concentration. The presence in drinking water of chloroform and other THMs and synthetic organic chemicals may have an adverse effect on the health of consumers; therefore, human exposure to these chemicals should be reduced.

B. Reference

For materials and procedures see:

Page 591, *STANDARD METHODS*, 16th Edition.

NOTE: A gas chromatography analyzer is required for this analysis.

17. Total Dissolved Solids

A. Discussion

"Total dissolved solids" (TDS) refer to material that passes through a standard glass-fiber filter disc and remains after evaporation at 180°C. The amount of dissolved solids present in water is a consideration in its suitability for domestic use. In general, waters with a TDS content of less than 50 mg/*L* are most desirable for such purposes. The higher the TDS concentration, the greater the likelihood of tastes and odors and also scaling problems. As TDS increases, the number of times the water can be recycled and reclaimed before requiring demineralization decreases. In potable waters, TDS consists mainly of inorganic salts, small amounts of organic matter, and dissolved gases.[6]

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[6] *Reference. CHEMISTRY FOR ENVIRONMENTAL ENGINEERING, Third Edition, 1978, by Clair N. Sawyer and Perry L. McCarty. Published by McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, New York 10010. Price $50.95.*

(Total Dissolved Solids)

B. What is Tested?

Sample	Common Range, mg/L
Raw and Treated Surface Waters	20 to 700
Groundwater	100 to 1000

C. Apparatus Required

Glass-fiber filter discs (Millipore AP40; or Gelman Type A/E)
Flask, suction 500 mL
Filter holder or Gooch crucible adapter
Gooch crucibles (25 mL if 2.2 cm filter used)
Evaporating dishes, 100 mL (high-silica glass)
Drying oven, 180°C
Steam bath
Vacuum source
Disiccator
Analytical balance
Muffle furnace, 550°C

D. Procedure

Preparation of Dish

1. Ignite a clean evaporating dish at 550 ± 50°C for one hour in muffle furnace.
2. Cool in desiccator then weigh and record weight. Store in desiccator until needed.

Preparation of Glass-fiber Filter Disc

1. Place the disc on the filter apparatus or insert into the bottom of a suitable Gooch crucible. While vacuum is applied, wash the filter disc with three successive 20 mL volumes of distilled water. Continue the suction to remove all traces of water from the disc and discard the washings.

Sample Analysis

1. Shake the sample vigorously and transfer 100 to 150 mL to the funnel or Gooch crucible by means of a 150 mL graduated cylinder.
2. Filter the sample through the glass-fiber filter and continue to apply vacuum for about three minutes after filtration is complete to remove as much water as possible.
3. Transfer 100 mL of the filtrate to the weighed evaporating dish and evaporate to dryness on a steam bath.
4. Dry the evaporated sample for at least one hour at 180°C. Cool in desiccator and weigh. Repeat drying cycle until constant weight is obtained or until weight loss is less than 0.5 mg.

E. Example

Results from weighings were:

Clean dish = 47.0028 grams (47,002.8 mg)
Dissolved residue + dish = 47.0453 grams (47,045.3 mg)
Sample volume = 100 mL

F. Calculations

1. Total Dissolved Solids, mg/L = $\dfrac{(A-B) \times 1000}{mL \text{ sample volume}}$

where, A = weight of dish and dissolved material in milligrams (mg)

B = weight of clean dish in milligrams (mg)

2. From example,

$$\text{Total Dissolved Solids, mg/}L = \frac{(A-B) \times 1000}{mL \text{ sample volume}}$$

$$= \frac{(47{,}045.3 \text{ mg} - 47{,}002.8 \text{ mg})(1000 \text{ m}L/L)}{100 \text{ m}L}$$

$$= 425 \text{ mg/}L$$

G. Comments

Because excessive residue in the evaporating dish may form a water-entrapping crust, use a sample that yields no more than 200 mg of residue.

H. Reference

See page 95, *STANDARD METHODS*, 16th Edition.

QUESTIONS

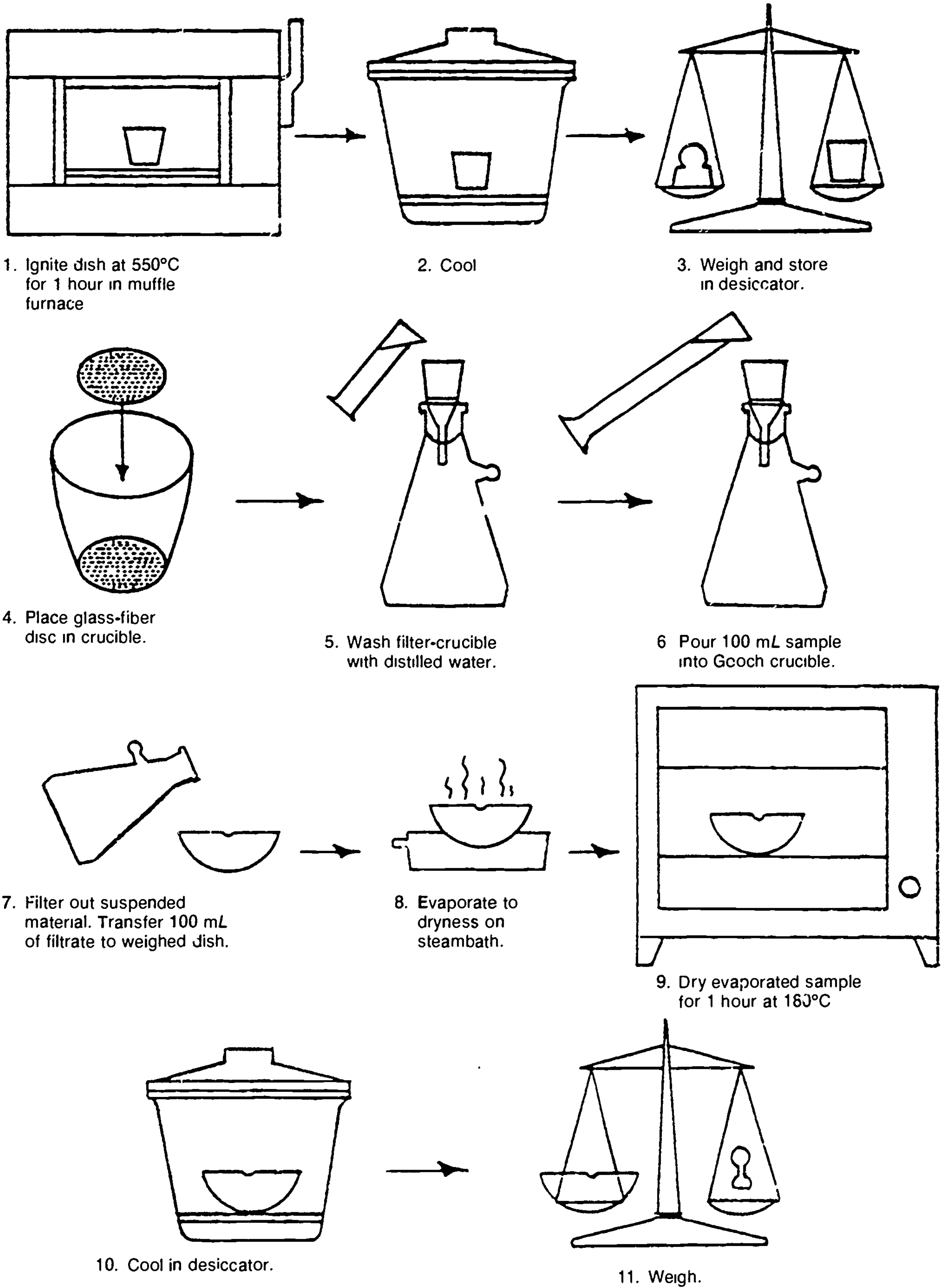
Write your answers in a notebook and then compare your answers with those on page 483.

21.1Y How are trihalomethanes produced?

21.1Z What are "total dissolved solids" (TDS)?

End of Lesson 2 of 2 Lessons
on
ADVANCED LABORATORY
PROCEDURES

OUTLINE OF PROCEDURE FOR TOTAL DISSOLVED SOLIDS



1. Ignite dish at 550°C for 1 hour in muffle furnace

2. Cool

3. Weigh and store in desiccator.

4. Place glass-fiber disc in crucible.

5. Wash filter-crucible with distilled water.

6. Pour 100 m*L* sample into Gooch crucible.

7. Filter out suspended material. Transfer 100 m*L* of filtrate to weighed dish.

8. Evaporate to dryness on steambath.

9. Dry evaporated sample for 1 hour at 180°C

10. Cool in desiccator.

11. Weigh.

DISCUSSION AND REVIEW QUESTIONS

Chapter 21. ADVANCED LABORATORY PROCEDURES

(Lesson 2 of 2 Lessons)

Please write the answers to these questions in your notebook before continuing with the Objective Test on page 484. The question numbering continues from Lesson 1.

9 Why is iron undesirable in a domestic water supply?

10. What precautions must be exercised when collecting samples to be analyzed for iron?

11. How would you obtain the manganese concentration in a sample by using a spectrophotometer if turbidity or color was interfering with the results?

12. What is the purpose of the Marble Test?

13. Why is the presence of certain metals in drinking water of serious concern?

14. How would you interpret the results of lab tests which indicate high levels of nitrate in a raw water sample?

15. When performing the nitrate determination, why should caution be exercised when using cadmium and what precautions should be used?

16. How would you interpret the meaning of changes (away from normal) in conductivity in water?

17. Why are sulfate ions of concern in water supplies?

18 How would you attempt to reduce unpleasant tastes and odors in drinking water?

19. Why should exposure to THMs be reduced?

20. Why is the amount of dissolved solids present in water a consideration in its suitability for domestic use?

SUGGESTED ANSWERS

Chapter 21. ADVANCED LABORATORY PROCEDURES

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 449.

21.0A The intensity of a blue color is measured when measuring the concentration of phosphorus in water.

21.0B The scale in spectrophotometers is usually graduated in two ways:
1. In units of percent transmittance (%T), an arithmetic scale with units graded from 0 to 100%; and
2. In units of absorbance (A), a logarithmic scale of nonequal divisions graduated from 0.0 to 2.0.

21.0C If the absorbance reading was 0.60, the unknown concentration was 0.70 mg/*L*.

Answers to questions on page 453.

21.1A Yes, the quality of water in any lake, reservoir or stream has a very direct effect on the abundance and types of aquatic organisms found.

21.1B Calcium in the form of lime or calcium hydroxide may be used to soften water or to control corrosion through pH adjustment.

21.1C Titrate sample for calcium immediately after adding sodium hydroxide (NaOH) solution.

21 1D Chloride concentrations above 250 mg/*L* are objectionable to many people due to a salty taste.

Answers to questions on page 453.

21.1E The most common colors which occur in raw water are yellow and brown.

21.1F True color is normally removed or at least decreased by coagulation and chlorination or ozonation.

21.1G Stock color standards should be protected against evaporation and contamination when not in use.

Answers to questions on page 460.

21.1H The presence of dissolved oxygen (DO) in water can contribute to corrosion of piping systems.

21.1I The common range of fluoride in fluoridated drinking water is 0.8 to 1.2 mg/*L*.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 465.

21.1J Problems that may be caused by iron in a domestic water supply include staining of laundry, concrete, and porcelain. A bitter astringent taste can be detected by some people at levels above 0.3 mg/*L*.

21.1K All glassware must be acid washed when analyzing samples for iron to remove deposits of iron oxide which could give false results.

21.1L Manganese occurs both in suspension and as a soluble complex in surface waters.

21.1M If the manganese concentration cannot be determined immediately, acidify sample with nitric acid to pH less than 2.

Answers to questions on page 468.

21.1N Temperature is important in the Marble Test because the solubility of calcium carbonate varies with temperature. Therefore, the test must be performed immediately after the sample is collected and as rapidly as possible.

21.1O Langelier Index ≃ Initial pH − Final pH

$$\simeq 8.9 - 8.6$$

$$\simeq 0.3$$

Since the Langelier Index is positive, the water is supersaturated with calcium carbonate and not considered corrosive.

21.1P The concentration of most metals in water is determined by using atomic absorption spectroscopy or colorimetric methods

Answers to questions on page 471.

21.1Q In the nitrate test, all nitrate is reduced to nitrite and then measured colorimetrically.

21.1R Removal of turbidity interfering with nitrate analyses can be accomplished by one of the following methods to remove suspended matter that can clog the reduction column.

1. Filter sample through a glass fiber or a 0.45 micron pore size filter as long as the pH is less than 8, or
2. Add 1 m*L* zinc solution to 100 m*L* of sample and mix thoroughly. Add enough sodium hydroxide solution to obtain a pH of 10.5. Let treated sample stand a few minutes to allow the heavy flocculent precipitate to settle. Clarify by filtering through a glass fiber filter.

21.1S The pH of natural waters is controlled by the relative amounts of carbon dioxide, bicarbonate, and carbonate ions.

Answers to questions on page 474.

21.1T Specific conductance or conductivity is a numerical expression (expressed in micromhos per centimeter) of the ability of a water to conduct an electrical current. This number depends on the total concentration of the mineral dissolved in the sample (TDS) and the temperature.

21.1U Sulfate ions are of importance in water supplies because of the tendency of appreciable amounts to form hard scales in boilers and heat exchangers.

21.1V A 50 m*L* sample from a well produced a turbidity reading of 40 TU using a nephelometer. What was the sulfate concentration in mg/*L*?

Known		Unknown
Sample Size, m*L*	= 50 m*L*	Sulfate, mg/*L*
Turbidity, TU	= 40 TU	

1. Determine the sulfate concentration from the graph.

   Sulfate Concentration, mg/*L* = 15 mg/*L*

2. Calculate the sulfate concentration in mg/*L*.

$$\text{Sulfate, mg}/L = \frac{(\text{Graph Sulfate, mg}/L)(100\text{ m}L)}{\text{Sample Size, m}L}$$

$$= \frac{(15\text{ mg}/L)(100\text{ m}L)}{50\text{ m}L}$$

$$= 30\text{ mg}/L$$

Answers to questions on page 479.

21.1W Tastes and odors can be caused in drinking water by algae, actinomycetes, bacteria, decaying vegetation, metals and pollutants (most organic chemicals and some inorganic chemicals). Dissolved inorganic salts of copper, iron, manganese, potassium, sodium and zinc can be detected by taste.

21.1X Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 12 m*L* sample was diluted to 200 m*L* (188 m*L* of odor-free water was added to the 12 m*L*).

Known		Unknown
A or Sample Size, m*L*	= 12 m*L*	T.O.N.
B or Odor-Free Water, m*L*	= 188 m*L*	

Calculate the threshold odor number, T.O.N.

$$\text{T.O.N.} = \frac{A + B}{A}$$

$$= \frac{12\text{ m}L + 188\text{ m}L}{12\text{ m}L}$$

$$= 17$$

Answers to questions on page 480.

21.1Y The principal source of chloroform and other trihalomethanes in drinking water is the chemical interaction of chlorine added for disinfection and other purposes with the commonly present natural humic substances and other precursors produced either by normal organic decomposition or by the metabolism of aquatic organisms.

21.1Z "Total Dissolved Solids" (TDS) refer to material that passes through a standard glass-fiber disc and remains after evaporation at 180°C.

OBJECTIVE TEST

Chapter 21. ADVANCED LABORATORY PROCEDURES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Measuring the intensity of the color enables the concentration of a substance in water to be measured.
   1. True
   2. False

2. The human eye is more precise than a spectrophotometer.
   1. True
   2. False

3 A sample which has a low color intensity will have a low percent transmittance but a high absorbance.
   1. True
   2. False

4 In most natural waters calcium is the principal anion.
   1. True
   2. False

5 Chloride usually occurs in natural waters as a basic salt.
   1. True
   2 False

6. Usually the chloride content in water increases as the mineral content decreases.
   1. True
   2. False

7 True color results from the presence of suspended materials.
   1. True
   2. False

8 The formation of a white floc during the DO test indicates that there is DO present in the sample.
   1. True
   2. False

9 As the temperature of water increases, the DO saturation value increases.
   1. True
   2. False

10. Always record temperature of water when collecting a dissolved oxygen sample.
   1. True
   2. False

11. Iron is an abundant and widespread constituent of rocks and soils.
   1. True
   2. False

12 Above a pH of 4.8 the solubility of the ferric iron species increases considerably.
   1 True
   2 False

13 Colloidal ferric hydroxide may persist in small quantities in surface waters that appear clear.
   1 True
   2. False

14. Manganese is much more abundant in the earth's crust than iron
   1. True
   2. False

15. Manganese in surface waters occurs both in suspension and as a soluble complex.
   1. True
   2. False

16. During the Marble Test, the water being tested should not be exposed to atmospheric carbon dioxide.
   1 True
   2 False

17 Nitrite represents the most completely oxidized form of nitrogen found in water.
   1. True
   2. False

18. The nitrate test measures both nitrate and nitrite.
   1. True
   2. False

19 Taste and odor are sensory clues which provide the first warning of potential hazards in the environment.
   1. True
   2 False

20 Water taken from a groundwater source is more likely to produce high THM levels than most surface waters
   1. True
   2 False

MULTIPLE CHOICE

21 Analyses of which of the following water quality characteristics are based on the measurement of color intensity?
   1. Dissolved oxygen
   2. Iron
   3. Manganese
   4. pH
   5 Phosphorus

22. Color intensities can be converted to concentrations of substances using
    1. Amperometric titration.
    2. Nessler tubes
    3. pH probes
    4. Pocket comparators.
    5. Spectrophotometers.

23. The quality of water in any lake, reservoir or stream has a very direct effect on the _____ of aquatic organisms found in the water.
    1. Absorbance
    2. Abundance
    3. Aliquots
    4. Percent transmittance
    5. Transparency

24. The recommended maximum allowable concentration of chloride in drinking water is _____.
    1. 50 mg/*L*
    2. 100 mg/*L*
    3. 150 mg/*L*
    4. 200 mg/*L*
    5. 250 mg/*L*

25. Ions that interfere with the chloride test include
    1. Iron.
    2. Orthophosphate.
    3. Sulfide.
    4. Sulfite.
    5. Thiosulfate

26. Color in water supplies may result from
    1. Copper.
    2. Hardness.
    3. Iron.
    4. Manganese.
    5. Organic matter.

27. Precautions that must be exercised when using a dissolved oxygen (DO) probe include
    1. Acidify the sample.
    2. Keep the membrane in the tip of the probe from drying out.
    3. Keep the sample iced.
    4. Periodically check the calibration of the probe.
    5. Remove reactive compounds that can interfere with the output.

28. Samples being tested for fluoride must be distilled if the samples contain excessive amounts of
    1. Aluminum.
    2. Hardness.
    3. Hexametaphosphate
    4. Nitrate.
    5. Sodium hydroxide.

29. Iron in a domestic water supply can cause
    1. Bitter tastes.
    2. Consumer complaints.
    3. Corrosion.
    4. Staining of concrete.
    5. Staining of laundry.

30. Objections to manganese in domestic waters include
    1. Corrosivity.
    2. Discolored driveways.
    3. Hardness.
    4. Stained laundry
    5. Stained plumbing fixtures

31. Metals found in drinking water include
    1. Calcium
    2. Chloride
    3. Iron
    4. Nitrogen.
    5. Sodium.

32. High levels of nitrate in a domestic water supply are undesirable because of
    1. Hardness.
    2. Health threat due to infant methemoglobinema
    3. Laundry stains.
    4. Nitrate stains.
    5. Potential for stimulating excessive algae growth.

33. Alum coagulates most effectively at pH values near _____.
    1. 4.3
    2. 5.6
    3. 6.8
    4. 7.5
    5. 8.3

34. Tastes and odors in drinking waters can be produced by
    1. Algae
    2. Bacteria
    3. Decaying vegetation.
    4. Hardness.
    5. Pollutants.

35. In potable waters TDS consists mainly of
    1. Dissolved minerals.
    2. Inorganic salts.
    3. Organic matter.
    4. Soluble acids.
    5. Vitamins.

36. Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 17 m*L* sample was diluted to 200 m*L* (183 m*L* of odor-free water was added to the 17 m*L*).
    1. 4
    2. 6
    3. 8
    4. 12
    5. 17

End of Objective Test

CHAPTER 22

DRINKING WATER REGULATIONS

by
Tim Gannon

Revised
by
Jim Sequeira

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LESSON 1

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OBJECTIVES

Chapter 22. DRINKING WATER REGULATIONS

Following completion of Chapter 22, you should be able to:

1. Identify the two basic types of water systems,
2. List the types of primary contaminants,
3. Explain the proposed Surface Water Treatment Rule (SWTR),
4. Describe the Interim Primary Drinking Water Standards,
5. List the secondary contaminants,
6. Develop and conduct a sampling program,
7. Record and report results, and
8. Comply with notification requirements.

GLOSSARY

Chapter 22. DRINKING WATER REGULATIONS

ACUTE ACUTE

When the effects of an exposure cause severe symptoms to occur quickly, the symptoms are said to be acute because they are brief and severe.

CHECK SAMPLING CHECK SAMPLING

Whenever an initial or routine sample analysis indicates that a Maximum Contaminant Level (MCL) has been exceeded, CHECK SAMPLING is required to confirm the routine sampling results. Check sampling is in addition to the routine sampling program.

CHELATING AGENT (key-LAY-ting) CHELATING AGENT

A chemical used to prevent the precipitation of metals (such as copper).

CHLORAMINATION (KLOR-ah-min-NAY-shun) CHLORAMINATION

The application of chlorine and ammonia to water to form chloramines for the purpose of disinfection.

CHRONIC CHRONIC

Effects of repeated exposures over a long period of time which eventually cause symptoms that continue for a long time.

INITIAL SAMPLING INITIAL SAMPLING

The very first sampling conducted under the Safe Drinking Water Act for each of the applicable contaminant categories.

MBAS MBAS

Methylene-Blue-Active Substances. These substances are used in surfactants or detergents.

MCL MCL

Maximum Contaminant Level. The largest allowable amount. MCLs for various water quality indicators are specified in the National Drinking Water Regulations.

pCi/L pCi/L

PicoCurie per Liter. A picoCurie is a measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second.

ROUTINE SAMPLING ROUTINE SAMPLING

Sampling repeated on a regular basis.

SURFACTANT (SIR-fac-TENT) surfactant

Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

THRESHOLD ODOR NUMBER THRESHOLD ODOR NUMBER

TON. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.

TU TU

Turbidity Units. Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in the Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

CHAPTER 22. DRINKING WATER REGULATIONS

(Lesson 1 of 2 Lessons)

All water treatment plant operators need to be thoroughly familiar with the state and federal laws and standards that apply to domestic water supply systems. These regulations are the goals and guideposts for the water supply industry. Their purpose is to assure the uniform delivery of safe and aesthetically pleasing drinking water to the public.

This chapter will introduce the major drinking water regulations and explain the monitoring and reporting requirements. For more detailed information, you will need to refer to current copies of your state's regulations and the most recent federal standards. These publications should be made readily available to all operators since operators will only know whether their system is in compliance by comparing monitoring test data with the actual current regulations.

22.0 HISTORY OF DRINKING WATER LAWS AND STANDARDS

Up until shortly after the turn of the century, there were no standards for drinking water. The first standards, established in 1914, were designed in large part to control waterborne bacteria and viruses that cause diseases such as cholera, typhoid, and dysentery. These new standards were overwhelmingly successful in curbing the spread of such diseases. However, with time and technology, other types of contaminants, this time chemicals, again stirred public concern. In 1962 the U.S. Public Health Service (the forerunner of the U.S. Environmental Protection Agency) revised the national drinking water standards to include limits on select organic chemicals.

In 1972 a series of reports detailing organic contamination in the drinking water supplied to the residents of New Orleans from the Mississippi River triggered profound changes in drinking water regulations. A study by the Environmental Defense Fund found that people drinking treated Mississippi River water in New Orleans had a greater chance of developing certain cancers than those in neighboring areas whose drinking water came from groundwater sources. Heightened public awareness and concern regarding cancer became major factors behind the push for legislative action on the issue of drinking water contamination. The finding of suspected carcinogens in drinking water established a widespread sense of urgency that led to the passage and signing into law of the Safe Drinking Water Act in December, 1974.

The Safe Drinking Water Act (SDWA) gave the federal government, through the U.S. Environmental Protection Agency (EPA), the authority to:

- Set national standards regulating the levels of contaminants in drinking water;
- Require public water systems to monitor and report their levels of identified contaminants; and
- Establish uniform guidelines specifying the acceptable treatment technologies for cleansing drinking water of unsafe levels of pollutants.

While the SDWA gave EPA responsibility for promulgating drinking water regulations, it gave state regulatory agencies the opportunity to assume primary responsibility for enforcing those regulations.

Over the past decade, implementation of the SDWA has greatly improved compliance with basic drinking water purity across the nation. However, recent EPA surveys of surface water and groundwater indicate the presence of synthetic organic chemicals in 20 percent of the nation's water sources, with a small percentage at levels of concern. In addition research studies suggest that some naturally occurring contaminants may pose even greater risks to human health than the synthetic contaminants. Further, there is growing concern about microbiological and radon contamination.

In the years following passage of the SDWA, Congress felt that EPA was slow to regulate contaminants and states were lax in enforcing the law. Consequently, in 1986 Congress enacted amendments designed to strengthen the 1974 SDWA. These amendments included language modifications, set deadlines for the establishment of maximum contaminant levels, placed greater emphasis on enforcement, authorized penalties for tampering with drinking water supplies and mandated the complete elimination of lead from drinking water. In addition, the SDWA amendments placed considerable emphasis on the protection of underground drinking water sources.

22.1 1986 AMENDMENTS TO THE SAFE DRINKING WATER ACT

22.10 Major Aspects

The 1986 SDWA amendments require that the EPA, the states, and the water supply industry undertake significant new programs in the very near future to clean up the country's drinking water supplies. The major aspects of the 1986 Amendments to the SDWA include:

1. Compulsory revisions to the regulations for new contaminants (as described below),
2. Definition of an approved treatment technique for each regulated contaminant,
3. Filtration requirement for surface water supplies,
4. Disinfection of all water supplies, and
5. Prohibition of the use of lead products in materials used to convey drinking water.

The 1986 Amendments require the regulation of many more contaminants. The Amendments state that:

- The EPA must regulate nine contaminants within a year of enactment (1987), another 40 within two years (1988), and the rest within three years (1989) for a total of 83. These 83 contaminants (shown in Table 22.1) include 14 volatile organic chemicals (VOCs), five microbiological parameters and turbidity, 23 inorganics (IOCs), and five radionuclides.
- In addition to the promulgation of standards for the 83 contaminants, EPA must develop at least 25 more primary standards by 1991 and 25 additional standards every three years thereafter.

TABLE 22.1. CONTAMINANTS REQUIRED TO BE REGULATED BY THE SDWA AMENDMENTS OF 1986

VOLATILE ORGANIC CHEMICALS

Trichloroethylene
Tetrachloroethylene
Carbontetrachloride
1,1,1-Trichloroethane
1,2-Dichloroethane
Vinyl chloride
Methylene chloride
Chlorobenzene
Dichlorobenzene
Trichlorobenzene
1,1-Dichloroethylene
trans-1,2-Dichloroethylene
cis-1,2-Dichloroethylene
Benzene

MICROBIOLOGICAL AND TURBIDITY

Total coliforms
Turbidity
Giardia lambli
Viruses
Standard plate count
Legionella

INORGANICS

Arsenic
Barium
Cadmium
Chromium
Lead
Mercury
Nitrate
Selenium
Silver
Fluoride
Aluminum
Antimony
Molybdenum
Asbestos
Sulfate
Copper
Vanadium
Sodium
Nickel
Zinc
Tahllium
Baryllium
Cyanide

TABLE 22.1. CONTAMINANTS REQUIRED TO BE REGULATED BY THE SDWA AMENDMENTS OF 1986 (continued)

ORGANICS

- Endrin
- Lindane
- Methoxychlor
- Toxaphene
- 2,4-D
- 2,4,5-TP
- Aldicarb
- Chlorodane
- Diaquat
- Endothall
- Glyphosate
- Carbofuran
- Alachlor
- Epichlorohydrin
- Toluene
- Adipates
- 2,3,4,8-TCDD (Dioxin)
- 1,1,2-Trichloroethane
- Vydate
- Simazine
- PAHs
- PCBs
- Atrazine
- Phthalates
- Acrylamide
- Dibromochloropropane (DBCP)
- 1,2-Dichloropropane
- Pentachlorophenol
- Picloram
- Dinoseb
- Ethylene dibromide (EDB)
- Dalapon
- Dibromomethane
- Xylene
- Hexachlorocyclopentadiene

RADIONUCLIDES

- Radium 226 and 228
- Beta particle and photon radioactivity
- Gross alpha particle activity
- Uranium
- Radon

Contaminants on the above list of 83 for which maximum contaminant level goals (MCLGs) were not proposed as of November 13, 1985.[a]

- Methylene chloride
- Antimony
- Endrin
- Dalapon
- Diaquat
- Endothall
- Glyphosate
- Adipates
- 2,3,4,8-TCDD (Dioxin)
- Trichlorobenzene
- Standard plate count
- *Legionella*
- Sulfate
- Thallium
- Beryllium
- Cyanide
- 1,1,2-Trichloroethane
- Vydate
- Simazine
- PAHs
- Atrazine
- Phthalate
- Picloram
- Dinoseb
- Hexachlorocyclopentadiene
- Nickel

[a] Note. MCLGs have also not been proposed for the seven contaminants EPA is proposing to delete from the list of 83 contaminants. These seven are zinc, silver, aluminum, sodium, dibromomethane, molybdenum, and vanadium.

- EPA can substitute up to seven other contaminants for those on the list if it finds this will provide greater health protection.
- By 1988, EPA must specify criteria for filtration of surface water supplies.
- By 1990, EPA must specify criteria for disinfection of surface and groundwater supplies.

Even prior to the passage of the 1986 Amendments, the EPA used a regulatory approach when reviewing drinking water contaminants. This type of approach, coincides with the regulation requirements imposed by the Amendments, considers pollutants in four phases:

Phase I: Volatile Organic Chemicals (VOCs)

Phase II: Synthetic Organic Chemicals (SOCs), inorganic chemicals, and microbiological contaminant regulations

Phase III: Radionuclide Contaminants Regulations

Phase IV: Disinfectant By-Product Contamination Regulations

22.11 Schedule

The EPA's schedule for compliance with the SDWA Amendments of 1986 is listed below.

June 1987- Promulgate MCLs for at least 9 chemicals. EPA has prepared MCLs for 8 VOCs, fluoride, and lead.

December 1987- Promulgate criteria for the mandatory filtration of surface water sources. This has been delayed until 1988.

January 1988 - Publish a list of contaminants which may require regulation by EPA. Begin monitoring of 33 unregulated VOCs.

June 1988- Promulgate MCLs for at least 40 contaminant chemicals in water.

June 1989- Promulgate MCLs for at least 34 contaminant chemicals in water.

January 1991- Promulgate MCLs for 25 contaminant chemicals in water. This is the first of a triannual promulgation of 25 MCLs.

At first glance, this schedule for setting standards appears reassuring. Keep in mind, however, that protection from regulated contaminants does not occur the instant a regulation is published. The Act requires the regulation of nine contaminants within 12 months of its passage. These Phase I contaminant limits were promulgated in 1987, but because the drinking water program is a federal-state partnership, states are allowed 18 additional months to adjust their own regulations. Therefore, water systems will more than likely not be required to meet Phase I regulations until two-and-a-half years after the law was passed.

All public water systems must comply with the regulations. This includes all public and privately owned systems that:

1. Have at least 15 service connections which are used at least 60 days out of the year, or
2. Serve an average of at least 25 people at least 60 days out of the year.

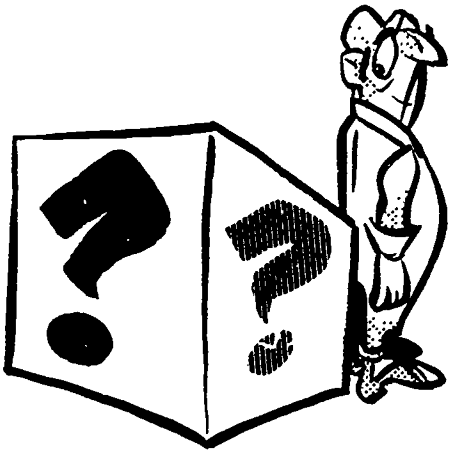
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 527.

22.0A What were the first drinking water standards designed to control?

22.1A List the major aspects of the 1986 Amendments to the SDWA.

22.1B Why will water systems not be required to meet Phase I regulations until two-and-a-half years after the law was passed?



22.2 DISINFECTANTS AND DISINFECTION BY-PRODUCTS

The EPA's initial draft list of 25 regulated compounds (the first of three such lists to be issued at three year intervals) emphasizes limits on the concentration of disinfection residuals and disinfection by-products. These new regulations are expected to set lower MCLs for trihalomethanes (THMs) plus limit disinfectants (chlorine, chlorine dioxide, chloramines, hypochlorite ion, and ozone), inorganic by-products (chlorite), and organic by-products which are principally other chlorinated compounds (halogenated acids, alcohols, aldehydes, and ketones and halonitriles). Compliance with these standards is likely to radically alter current water treatment disinfection practices by curtailing the use of chlorine and increasing the use of alternatives such as ozone and chloramines.

Of the substances mentioned above, only trihalomethanes (THMs) are regulated at the present time.. THMs are the product of chlorine combining with organic material in the water. They are suspected of being carcinogenic. The MCL established for total trihalomethanes (TTHMs) is 0.10 milligrams per liter or 100 micrograms per liter. EPA is expected to strengthen this standard by reducing the MCL and considering whether additional standards of this type are necessary.

22.3 SURFACE WATER TREATMENT RULE (SWTR)

In 1987, the EPA prepared a draft Surface Water Treatment Rule (SWTR) that specifies which water supplies that must be filtered and provides performance criteria for both filtered water sources and those treated by disinfection only. The draft SWTR specifically requires that:

1. All surface water systems must disinfect.
2. All surface water systems must filter unless they meet source water quality criteria and site-specific conditions. States will determine which systems will need to install filtration or upgrade existing filtration and disinfection.

3. All systems will need to achieve the removal or inactivation criteria of Giardia and enteric viruses.
4. Only qualified operators will be entitled to operate the systems.

The general performance criteria to be met by surface water systems are primarily directed toward acute health risks from waterborne microbiological contaminants. The requirements are:

1. At least 99.9 percent removal and/or inactivation of *Giardia lamblia* cysts, and
2. At least 99.99 percent removal and/or inactivation of enteric viruses.

In general, compliance by the surface water purveyor could be through one of the following alternatives:

1. Meeting the criteria for which filtration is not required and providing disinfection according to the specific requirements in the SWTR, or
2. Providing filtration and meeting disinfection criteria required for those supplies that are filtered.

Mandatory filtration is expected to affect the small and medium-sized water systems most severely. A few large surface water systems do not filter their water; more than nine million people drink unfiltered water in Seattle, New York City, and Boston alone. However, most of the unfiltered surface water systems serve communities with fewer than 10,000 residents.

22.30 Requirement for Non-Filtered Systems

To avoid mandatory filtration, a water utility must meet:

1. Source water quality criteria (coliforms and turbidity levels), and
2. Certain site-specific conditions,
   (a) has disinfection that achieves 99.9 percent inactivation of Giardia and 99.99 percent inactivation of viruses.
   (b) watershed control or sanitary surveys that satisfy regulatory requirements.
   (c) no history of waterborne disease outbreak without making treatment corrections.
   (d) compliance with long-term coliform maximum contaminant level (MCL).
   (e) compliance with total trihalomethanes MCL, if the system serves more than 10,000 people.

If a system cannot meet the source water quality criteria and site-specific conditions listed above, then the system must install and operate appropriate filtration facilities.

22.31 Requirements for Filtered Water Systems

For systems that filter, the primary concern is adequate disinfection and filtration performance. The requirements are:

1. For conventional or direct filtration systems, the filtered water turbidity must be less than or equal to 0.5 *TU*[1] for at least 95 percent of each month's measurements. For slow sand or diatomaceous earth filtration, the filtered water turbidity must be less than 1 NTU in at least 95 percent of the measurements taken each month.
2. Filtered water must never exceed five TUs.
3. A disinfectant residual in the distribution system of 0.2 mg/*L* in 95 percent of the samples be maintained.

As a further measure of filtration/disinfection performance, the SWTR refers to the use of CT (residual concentration x time) values for various disinfectants. Conformance with CT values could be the means of meeting Giardia and virus inactivation limits. It is expected that most states will follow EPA recommendations and include CT analysis for evaluating disinfection effectiveness.

22.32 Monitoring Requirements of the SWTR

Unfiltered surface water systems must:

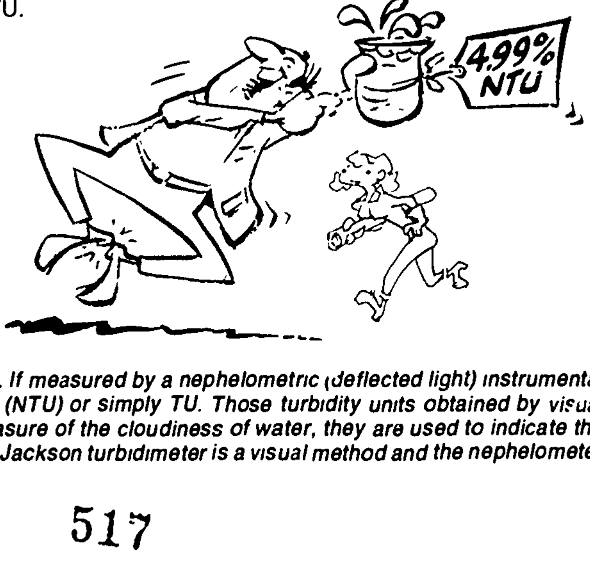
1. Monitor raw water for coliforms (frequency is dependent on system size) and turbidity every 4 hours (continuous monitoring allowed with measurement every 4 hours);
2. Continuously monitor the disinfectant residual entering the distribution system;
3. Sample the distribution system for disinfectant residuals (frequency depends on system size);
4. Monitor daily to demonstrate that the level of disinfection achieved is 99.9 percent inactivation of Giardia and 99.99 percent inactivation/removal enteric viruses.

Filtered systems must:

1. Perform turbidity measurements of representative water every 4 hours (which can be continuous monitoring);
2. Continuously monitor the disinfectant residual entering the distribution system;
3. Sample in the distribution system for disinfectant residuals (sampling frequency depends on system size).

22.33 Turbidity Requirements of the SWTR

To avoid filtration, the level of a system's unfiltered water turbidity would have to be less than 5 TU. For filtered water systems, the filtered water must be less than either 0.5 TU or less than 1 TU for 95 percent of the time, depending upon the technology being used, and must at no time exceed 5 TU.



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[1] *Turbidity Units. Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.*

Unfiltered systems are required to begin with a clean source water and have a watershed that is protected from human activities that might otherwise have an adverse impact on water quality. Unfiltered systems would have very little, if any, virus contamination. For these systems, the major concern is Giardia contamination from animal activities that cannot be prevented by watershed protection. The purpose of the turbidity limit for unfiltered water is to ensure a high probability that turbidity does not interfere with disinfection of Giardia cysts. The turbidity limit of 5 TU serves this purpose.

For filtered water systems, the major burden for Giardia removal rests with filtration. With conventional treatment and direct filtration, low turbidity levels (<0.5 TU) are needed to ensure effective Giardia cyst removals. Disinfection of either Giardia or viruses will not be hampered at these turbidity levels.

For slow sand filtration and diatomaceous earth filtration, effective Giardia removal does not necessarily correlate with low treated water turbidities. However, to ensure effective virus inactivation, a low filtered water turbidity is needed. Viruses are much smaller than Giardia, and thus a lower turbidity limit of 1 TU is needed compared with the turbidity level of 5 TU for unfiltered supplies to ensure effective disinfection.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 527.

22.2A What are THMs?

22.3A What does the draft Surface Water Treatment Rule (SWTR) specifically require?

22.3B How can a water utility avoid mandatory filtration?

22.4 TYPES OF WATER SYSTEMS

All the drinking water regulations apply to two types of public water systems: (1) community water systems, and (2) non-community water systems.

22.40 Community Water Systems

A community water system is defined as follows:

1. Has at least 15 service connections used by all-year residents, or
2. Services at least 25 all-year residents.

22.41 Non-Community Water Systems

A non-community water system is defined as follows:

1. Has at least 15 service connections used by travelers or intermittent users at least 60 days a year, or
2. Services a daily average of at least 25 people at least 60 days a year.

Any water system that provides services for fewer connections or persons listed above is not covered by the SDWA. However, regardless of size, all operators must strive to provide consumers with a potable drinking water.

22.5 INTERIM PRIMARY DRINKING WATER STANDARDS

22.50 Establishment of Drinking Water Standards

The drinking water standards established by EPA reflect the best scientific and technical judgment available. They were refined by the suggestions and advice of the 15-member National Drinking Water Advisory Council, made up of representatives of the general public, state and local agencies, and experts in the field of public water supply. The Department of Health and Human Services as well as other agencies and organizations contributed to the development of the National Interim Primary Drinking Water Regulations.

The regulations set achievable levels of drinking water quality to protect your health. They are called "interim" regulations because research continues on drinking water contaminants. The existing standards may be strengthened and new standards may be established for other substances based on studies being conducted by the National Academy of Sciences, EPA, and others.

EPA has established standards (maximum contaminant levels) for ten chemicals, six pesticides, bacteria, radioactivity, turbidity, and trihalomethanes. Most of these substances occur naturally in our environment and in the foods we eat The national drinking water standards set by EPA reflect the levels we can safely consume in our water, taking into account the amounts we are exposed to from these other sources

22.51 Types of Contaminants

Five types of primary contaminants are considered to be of public health importance:

1 *INORGANIC CONTAMINANTS*, such as lead and mercury,

2. *ORGANIC CONTAMINANTS*, which now include pesticides, herbicides and trihalomethanes, but may be expanded to include solvents and other synthetic organic compounds;

3. *TURBIDITY*, such as small particles suspended in water which interfere with light penetration and disinfection;

4. *MICROBIOLOGICAL CONTAMINANTS*, such as bacteria, virus, and protozoa; and

5 *RADIOLOGICAL CONTAMINANTS*, which include natural and man-made sources of radiation.

22.52 Immediate Threats to Health

Only two substances for which standards have been set pose an immediate threat to health whenever they are exceeded, (1) bacteria, and (2) nitrate.

22.520 Bacteria

Coliform bacteria from human and animal wastes may be found in drinking water if the water is not properly treated. These bacteria usually do not themselves cause diseases transmitted by water, but indicate that other harmful organisms may be present in the water. Waterborne diseases such as typhoid, cholera, infectious hepatitis, and dysentery have been traced to improperly disinfected drinking water. Certain coliforms have been identified as the cause of "travelers" diarrhea.

22.521 Nitrate

Nitrate in drinking water above the national standard of 100 mg/*L* (as N) poses an immediate threat to children under three months of age. In some infants, excessive levels of nitrate have been known to react with intestinal bacteria which change nitrate to nitrite which reacts with the hemoglobin in the blood This reaction will reduce the oxygen carrying ability of the blood and produce an anemic condition commonly known as "blue baby."

Non-community systems *MAY* be allowed to serve water containing up to 90 mg/*L* nitrate if.

1. The water is not available to infants six months of age and younger.
2. Posting of the potential health hazard is maintained;
3 State and local health authorities are notified and agree; and
4. No threat to health will result

22.53 Setting Standards

The process by which EPA establishes drinking water standards is both long and complicated. A standard is the maximum level of a substance that EPA has deemed acceptable in drinking water. The first step in the setting of a standard is to study the human and animal health effects of a given chemical. These studies are normally performed using rats or mice. Based on these studies, EPA establishes a "no observed adverse effect" level (abbreviated as "NOAEL"). A safety factor is added to the NOAEL and the result is an acceptable daily intake limit of the chemical in question. The limit is adjusted to take into account the average weight and water consumption of the consumer, and the resulting figure is called a maximum contaminant level goal, or MCLG .

The maximum contaminant level goal represents what EPA believes to be a safe level of consumption based solely on its studies of health effects. It is, however, a goal rather than an immediately achievable constituent limit. To develop more realistic, enforceable limits, EPA further revises the MCLG to take into account existing laboratory detection technology, costs, and reasonableness. After adjusting for these factors, EPA sets the maximum contaminant level (MCL) as close to the MCLG as is realistically feasible. The important difference between the two levels is that the MCLG is a nonenforceable goal and the MCL is an enforceable standard.

The Maximum Contaminant Levels (MCLs) are the highest permissible concentration of a particular substance in water. The MCLs apply whether the contaminant is from naturally occurring sources or from man-made pollution. More types of contaminents must be monitored by community than by non-community systems as shown on Table 22.2.

TABLE 22.2 CONTAMINANTS MONITORED BY COMMUNITY AND NON-COMMUNITY WATER SYSTEMS

Community Water Systems

Contaminant	Period of Exposure Which May Affect Health
Inorganic Chemicals (except nitrate)	Long-term
Inorganic Chemicals (nitrate only)	Short-term
Organic Chemicals	Long-term
Turbidity	Short-term
Microbiological Contaminants	Short-term
Radiological Contaminants	Long-term

Non-Community Water Systems

Contaminant	Period of Exposure Which May Affect Health
Inorganic Chemicals (nitrate only)	Short-term
Turbidity	Short-term
Microbiological Contaminants	Short-term

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 528.

22.4A Define a community water system.

22.5A List the five types of primary contaminants which are considered to be of public health importance.

22.5B Why is nitrate considered an immediate threat to public health?

End of Lesson 1 of 2 Lessons on DRINKING WATER REGULATIONS

DISCUSSION AND REVIEW QUESTIONS

Chapter 22. DRINKING WATER REGULATIONS

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. What will be the impact of the 1986 Amendments to the SDWA on water treatment disinfection practices?
2. Why are THMs regulated?
3. Mandatory filtration is expected to affect what sized water systems most severely?
4. What is a community water system?
5. What is the difference between a community and a non community water system?
6. What are Maximum Contaminant Levels (MCLs)?
7. Why is turbidity undesirable in a finished or treate water?
8. How do coliform bacteria get into drinking water ar what does their presence indicate?

CHAPTER 22. DRINKING WATER REGULATIONS

(Lesson 2 of 2 Lessons)

22.6 PRIMARY STANDARDS

Primary Standards or MCLs are set for substances that are thought to pose a threat to health when present in drinking water at certain levels. Because these substances are of health concern, primary standards are enforceable by law. (In contrast, secondary standards relate to cosmetic factors and are not federally enforceable.) A primary standard can also be referred to as a maximum contaminant level (MCL). In July 1987 EPA finalized MCLs for eight volatile organic chemicals bringing the number of primary standards to 30. Table 22.3 lists the current (January, 1988) primary standards and health concerns associated with the contaminants.

22.60 Inorganic Chemical Standards

Inorganic chemicals are metals, salts, and other chemical compounds that do not contain carbon. The health concerns about inorganic chemicals are not centered on cancer, but rather on their suspected links to several different human disorders. For example, lead is suspected of contributing to mental retardation in children.

Presently, only ten inorganic chemicals are regulated but several others are being studied and considered possible candidates. They are: aluminum, antimony, molybdenum, asbestos, sulfate, copper, vanadium, sodium, nickel, zinc, thallium, beryllium, and cyanide. The following paragraphs briefly discuss each of the inorganic contaminants regulated by the national drinking water standards. Waters exceeding the MCL for these elements for short periods of time will pose no immediate threat to health. However, studies show that these substances must be controlled because consumption of drinking water that exceeds these standards over long periods of time may prove harmful.

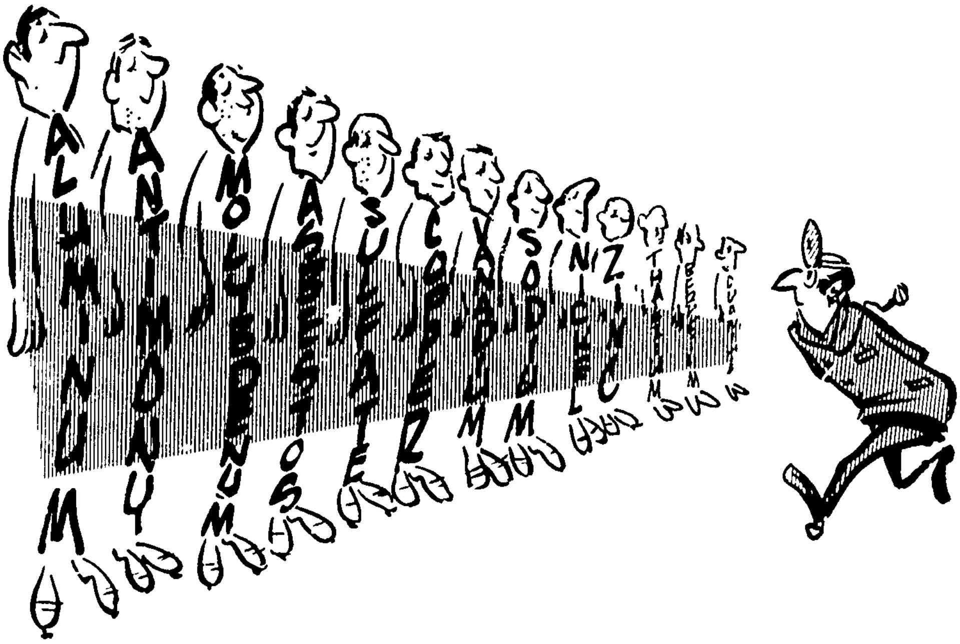

TABLE 22.3 PRIMARY DRINKING WATER STANDARDS

CONTAMINANT	MCL (mg/L)	HEALTH EFFECT
Inorganics		
Arsenic	0.05	dermal/nervous system toxicity
Barium	1.00	circulatory system effects
Cadmium	0.01	kidney effects
Chromium	0.05	liver and kidney effects
Lead	0.05	nervous system/kidney damage toxic to infants & pregnant women
Mercury	0.002	nervous system/kidney disorders
Nitrate	10.0	Methemoglobinemia ("blue-baby" syndrome)
Selenium	0.01	gastrointestinal effects
Silver	0.05	skin discoloration
Fluoride	4.00	skeletal damage
Organics		
Endrin	0.0002	nervous system/kidney effects
Lindane	0.004	nervous system/liver effects
Methoxychlor	0.10	nervous system/kidney effects
2,4-D	0.1	liver/kidney effects
2,4,5-TP Silvex	0.01	liver/kidney effects
Toxaphene	0.005	cancer risk
Benzene	0.005	cancer
Carbon Tetrachloride	0.005	possible cancer
p-Dichlorobenzene	0.075	possible cancer
1,2-Dichloroethane	0.005	possible cancer
1,1-Dichloroethylene	0.007	liver/kidney effects
1,1,1-Trichloroethane	0.2	nervous system effects
Trichloroethylene (TEC)	0.005	possible cancer
Vinyl Chloride	0.002	cancer risk
Trihalomethanes	0.10	cancer risk
Microbiological		
Total Coliforms	1 per 100mL	indicators of disease-causing organisms
Physical		
Turbidity	1-5 TU	interferes with disinfection
Radionuclides		
Gross alpha particles	15 pCi/L	cancer
Gross beta particles	4 mrem/yr	cancer
Radium 226 & 228	5 pCi/L	bone cancer

22.600 Arsenic

This element occurs naturally in the environment, especially in the western United States and it is also used in insecticides Arsenic is found in foods, tobacco, shellfish, drinking water and in the air in some locations. The national standard for arsenic is 0 05 milligrams per liter of water Water that continuously exceeds the national standard by a substantial amount over a lifetime may cause fatigue and loss of energy Extremely high levels can cause poisoning

22.601 Barium

Although not as widespread as arsenic, this element also occurs naturally in the environment in some areas Barium can also enter water supplies through industrial waste discharges Small doses of barium are not harmful However, it is quite dangerous when consumed in large quantities and will bring on increased blood pressure, nerve damage, and even death. The maximum amount of barium allowed in drinking water by the national standard is one milligram per liter of water.

22.602 Cadmium

Only extremely small amounts of this element are found in natural waters in the United States Waste discharges from the electroplating, photography, insecticide, and metallurgy industries can increase cadmium levels, however The most common source of cadmium in our drinking water is from galvanized pipes and fixtures The maximum amount of cadmium allowed in drinking water by the national standard is 0 010 milligrams per liter of water

22.603 Chromium

This metal is found in cigarettes, some of our foods, and the air. Some studies suggest that in very small amounts, chromium may be essential to human beings, but this has not been proven The national standard for chromium is 0 05 milligrams per liter of water.

22.604 Fluoride

This is a natural mineral and many drinking waters contain some fluoride. Fluoride produces two effects, depending on its concentration, and EPA has set both primary and secondary limits to regulate it. At levels of 6 to 8 mg/*L* fluoride may cause skeletal fluorosis which is a brittling of the bones and stiffening of the joints. On the basis of this health hazard, fluoride has been added to the list of primary standards.

At levels of 2 mg/*L* and greater fluoride may cause dental fluorosis which is discoloration and mottling of the teeth, especially in children. EPA has recently reclassified dental fluorosis as a cosmetic effect raised the primary drinking water standard from 1.4 - 2 mg/*L* to 4 mg/*L*, and established a secondary standard of 2 mg/*L* for fluoride.

22.605 Lead

This metal is found in the air and in our food. Lead comes from galvanized pipes, solder used with copper pipes, auto exhausts, and other sources. The maximum amount of lead permitted in drinking water by the national standards is 0 05 milligrams per liter of water. Excessive amounts well above this standard may result in nervous system disorders or brain or kidney damage.

22.606 Mercury

Mercury is found naturally throughout the environment. Large increases in mercury levels in water can be caused by industrial and agricultural use. The health risk from mercury is greater from mercury in fish than simply from waterborne mercury. Mercury poisoning may be *ACUTE*[2] in large doses, or *CHRONIC*[3] from lower doses taken over an extended time period.

22.607 Selenium

This mineral occurs naturally in soil and plants, especially in western states Selenium is found in meat and other foods. Although it is believed to be essential in the diet, there are indications that excessive amounts of selenium may be toxic. Studies are under way to determine the amount required for good nutrition and the amount that may be harmful.

The national standard for selenium is 0.01 milligrams per liter of water. If a person's intake of selenium came only from drinking water, it would take an amount many times greater than the standard to produce any ill effects.

22.608 Silver

This metal should pose no problem Silver is sometimes used in proprietary water treatment devices for disinfecting water The maximum amount of silver allowed in drinking water by the national standard is 0 05 milligrams per liter of water

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[2] *Acute. When the effects of an exposure cause severe symptoms to occur quickly, the symptoms are said to be acute because they are brief and severe.*

[3] *Chronic. Effects of repeated exposures over a longer period of time which eventually cause symptoms that continue for a long time*

QUESTIONS

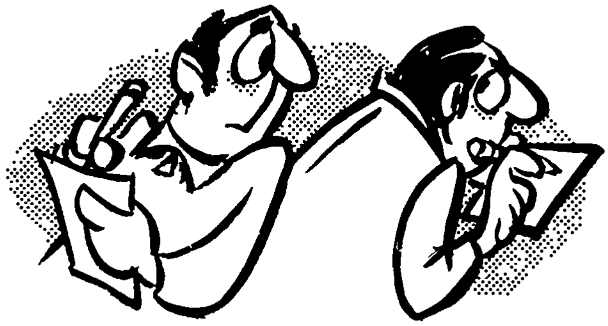
Write your answers in a notebook and then compare your answers with those on page 528.

22.6A What are inorganic chemicals?

22.6B Why is arsenic listed as a primary contaminant?

22.6C What are two detrimental effects of excessive levels of fluoride?

22.6D What are the sources of lead in drinking water?



22.61 Organic Chemical Standards

Organic chemicals are either natural or synthetic chemical compounds that contain carbon. Synthetic organic chemicals (SOCs) are man-made compounds and are used throughout the world as pesticides, paints, dyes, solvents, plastics, and food additives. Volatile organic chemicals (VOCs) are a subcategory of organic chemicals. These chemicals are termed "volatile" as they evaporate easily. The most commonly found VOCs are trihalomethanes (THMs), trichloroethylene (TCE), tetrachloroethylene, and 1,1-dichloroethane. THMs were the first regulated VOC when EPA finalized regulations in 1979.

The most common sources of organic contamination of drinking water are pesticides and herbicides, industrial solvents, and disinfection by-products (trihalomethanes). Millions of pounds of pesticides are used on croplands, forests, lawns, and gardens in the United States each year. They drain off into surface waters or seep into underground water supplies. Spills, poor storage, and haphazard disposal of organic chemicals have resulted in widespread groundwater contamination. This is a critical problem since groundwater, once contaminated, may remain that way for a long time.

Many organic chemicals pose health problems if they get into drinking water and the water is not properly treated. The maximum limits for pesticides in drinking water are shown on Table 22.3 (page 502). Based on a review of the available toxicological data, EPA has categorized the eight regulated VOCs as shown on Table 22.4.

As directed by Congress in the 1986 Amendments, the EPA will regulate 83 contaminants by 1989 (including 14 VOCs and 35 SOCs) and will undertake studies of at least 25 additional contaminants for potential regulation by 1990.

TABLE 22.4 HEALTH EFFECTS CATEGORIES OF THE VOCS

Category I: Known or Probable Human Carcinogens

Benzene
Vinyl Chloride
Carbon Tetrachloride
1,2-Dichloroethane
Trichloroethylene

Category II: Limited But Insufficient Evidence of Carcinogenicity

1,1-Dichloroethylene - causes liver and kidney damage in animals at high doses; also affects central nervous system and heart

Category III: Inadequate or No Evidence of Carcinogenicity

1,1,1-Trichloroethane - causes depression of central nervous system and changes in the cardiovascular system and liver in humans and animals

p-Dichlorobenzene - causes liver damage and is suspected of being an animal carcinogen

22.610 Trichloroethylene (TCE)

Although the use of trichloroethylene is declining because of stringent regulations, it was, for many years, a common ingredient in household products (spot removers, rug cleaners, air fresheners), dry cleaning agents, industrial metal cleaners and polishers, refrigerants, and even anesthetics. Its wide range of use is perhaps why TCE is the organic contaminant most frequently encountered in groundwater. The MCL for TCE is 0.005 mg/*L*.

22.611 1,1-Dichloroethylene

This solvent is used in manufacturing plastics and, more recently, in the production of 1,1,1-trichloroethane. The MCL for this chemical is 0.2 mg/*L*.

22.612 Vinyl Chloride

Billions of pounds of this solvent are used annually in the United States to produce polyvinyl chloride (PVC), the most widely used ingredient for manufacturing plastics throughout the world. There is also evidence that vinyl chloride may be a biodegradation end-product of tri- and tetrachloroethylene under certain environmental conditions. The MCL for vinyl chloride is 0.002 mg/*L*.

22.613 1,1,1-Trichloroethane

This chemical has replaced TCE in many industrial and household products. It is the principal solvent in septic tank degreasers, cutting oils, inks, shoe polishes, and many other products. Among the VOCs found in groundwaters, 1,1,1-trichloroethane and TCE are encountered most frequently and in the highest concentrations. The MCL for this contaminant is 0.2 mg/*L*

22.614 1,2-Dichloroethane

1,2-Dichloroethane is used as a solvent for fats, oils, waxes, gums, and resins. The MCL for this chemical is 0.005 mg/*L*.

22.615 Carbon Tetrachloride

Carbon tetrachloride was once a popular household solvent, a frequently used dry cleaning agent, and a charging agent for fire extinguishers. Since 1970, however, carbon tetrachloride has been banned from all use in consumer goods in the United States and in 1978, it was banned as an aerosol propellant. Currently its principal use is in the manufacture of fluorocarbons which are used as refrigerants. The MCL for carbon tetrachloride is 0.005 mg/*L* (5 ug/*L*).

22.616 Benzene

Benzene is used primarily in the synthesis of styrene (for plastics), phenol (for resins), and cyclohexane (for nylon). Other uses include the production of detergents, drugs, dyes, and insecticides. Benzene is still being used as a solvent and as a component of gasoline. The MCL for benzene is 0.005 mg/*L* (5 ug/*L*).

22.617 1,4-Dichlorobenzene (p-dichlorobenzene)

The principal uses of this chemical are in moth control (balls, powders) and as lavatory deodorants. The MCL is 0.075 mg/*L* (75 ug/*L*).

22.62 Turbidity Standards

Turbidity is undesirable in a finished or treated water because it causes cloudiness resulting in an unattractive water. However, the major reason that turbidity is undesirable is because it causes a health hazard by:

1. Interfering with disinfection by reducing the ability of the disinfectant to inactivate or kill disease-causing organisms.
2. Exerting a chlorine demand which makes it difficult to maintain a residual throughout the distribution system.
3. Interfering with the bacteriological examination of the water, and
4. Not satisfactorily reducing "tastes and odors" and "asbestos fibers."

The MCLs for turbidity which apply to surface water only are shown on the poster provided with this manual and are:

- The monthly average turbidity MCL may not exceed 1 TU. At state option this may be raised to 5 TU. Some states require 0.5 TU where there is a major hazard of wastewater (sewage) contamination of the water supply.
- Five turbidity units based on an average for two consecutive days.

The 5 TU MCL was included as a state option because there are certain types of turbidity that do not interfere with bacteriological effectiveness of disinfection. In such cases, the state may authorize the 5 TU MCL for a water system on a case-by-case basis.

The two-day-average turbidity limit is designed to protect against the presence of a high turbidity during certain periods, such as periods of heavy runoff, when the adequacy of the treatment is particularly critical to protect the public.

Daily turbidity sample requirements from non-community systems using surface water can be relaxed by the state or local health agency provided certain criteria are met.

The turbidity standards are currently being reviewed and revised under the Surface Water Treatment Rules recently drafted. These are discussed in Section 22.33, "Turbidity Requirements of the SWTR."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 528.

22.6E What are organic chemicals?

22.6F What have been the common uses of trichloroethylene (TCE)?

22.6G What is the MCL for turbidity?

22.63 Microbiological Standards

Bacteria, viruses, and other organisms have long been recognized as serious contaminants of drinking water. Organisms such as Giardia cause almost immediate gastrointestinal illness when people consume them in water. Even though most recent attention has been focused on the chemical contaminants of drinking water, the EPA has continued to pay special attention to improving treatment effectiveness with regard to microbiological contaminants. Currently only total coliforms are regulated. EPA, however, is considering creating MCLs for Giardia, viruses, standard plate count, and *Legionella.* In addition, EPA will publish final rules for filtration in 1988 and disinfection by June 1991. Filtration and disinfection of water should effectively control the threat posed by microbiological contaminants.

22.630 Coliform

Coliform bacteria are an indication of possible disease-producing organisms being present in the water supply. MCLs have been established to indicate when a coliform concentration could indicate the likely presence of disease-causing bacteria These MCLs have been established for both the membrane filter method and the multiple-tube fermentation method of testing.

22.631 Multiple-Tube Fermentation Method

The multiple-tube fermentation method of testing for coliforms determines the presence and the number of coliforms by the multiple-tube dilution method. This is a process whereby 10 m*L* of the sample is added to each of five tubes. The tubes contain a culture media and an inverted vial. If gas accumulates in the inverted vial, it indicates presumptive evidence of coliform organisms in that portion of the sample. Should no gas form in the vial, that portion of the sample is negative.

For all systems, regardless of the number of samples taken per month, coliforms must not be present in more than 10 percent of the portions per month. For systems required to take fewer than 20 samples per month, not more than one monthly sample can have three or more portions positive. For systems required to take 20 or more samples per month, not more than five percent of the monthly samples can have three or more portions positive. For water systems that regularly take 10 or fewer samples per month, *ONE* positive sample may be discarded if:

1. The system chlorinates and maintains a residual,
2. The system takes two check samples on consecutive days, and
3. This exclusion has *NOT* been used in the previous month.

22.632 Membrane Filter Method

This method provides for filtering a 100 m*L* water sample through a thin, porous, cellulose membrane filter under a partial vacuum The filter is placed in a sterile container and incubated in contact with a special liquid called a "culture medium" which the bacteria use as a food source. Colonies of bacteria then grow on the media The coliform colonies are visually identified, counted, and recorded as the number of coliform colonies per 100 m*L* of sample.

The coliform MCLs using the membrane filter method are such that the numbers of colonies shall not exceed any of the following:

1. One per 100 m*L* as the arithmetic mean of all samples examined per month,
2. Four per 100 m*L* in more than one sample when fewer than 20 samples are examined per month, and
3. Four per 100 m*L* in more than five percent of the samples when 20 samples or more are examined per month.

22.633 Chlorine Residual Substutution

At the discretion of the state and based upon a review of the water system, chlorine residual testing may be substituted for some of the bacteriological testing. Chlorine residual testing could give the operator a quicker indication of the condition of the system. However, the following requirements must be met:

1. Samples must be taken at points which are representative of conditions within the distribution system,
2. Chlorine residual testing can replace only up to 75 percent of the bacteriological testing,
3. At least four chlorine residual tests must be taken to substitute for one bacteriological sample,
4. A free chlorine residual of at least 0.2 mg/*L* must be maintained throughout the distribution system,
5. If free chlorine residual falls below 0.2 mg/*L* check samples must be taken for bacteriological testing and a report must be submitted to the state within 48 hours, and
6. Chlorine residual must be determined daily.

In order to meet the total trihalomethanes (TTHM) MCL, some water treatment plants practice *CHLORAMINATION.*[4] Chloramination is the application of chlorine and ammonia to form chloramines. Experience has shown that satisfactory chlorine residuals and bacteriological test results can be obtained at remote locations in distribution systems provided

$C \times T > 120$ after filtration

where C is the chlorine residual in mg/*L*, and

T is the chlorine contact time in minutes.

For example, if a clear well provides a minimum contact time of 120 minutes, then the chlorine residual should be at least one mg/*L* after 120 minutes.

22.634 Draft Coliform Rule

The EPA has also prepared a draft coliform rule which was published in November of 1987. The Total Coliform Rule proposes to revise the MCL for total coliform and establishes a nonenforceable health goal, termed maximum contaminant level goal of zero. The Rule also proposes changes in monitoring requirements, analytical methodology, and required responses to a positive coliform test. These proposed changes are summarized below.

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[4] Chloramination (KLOR-ah-min-NAY-shun). The application of chlorine and ammonia to water to form chloramines for the purpose of disinfection.

Monitoring Frequency. For systems which service 3,300 persons or fewer, five samples per month are required. Fewer samples will be required if the system filters and disinfects surface water and groundwater. For systems which service more than 3,300 persons, the sampling frequency is based on population. The population size categories have been reduced yet the minimum number of samples required has not changed substantially from the existing regulations.

Analytical Methodology. The proposed MCL for coliform will be based on the presence or absence of total coliforms in a sample, rather than on estimates of coliform density. The total coliform analyses must be conducted in accordance with *STANDARD METHODS*,[5] Method 908, "Multiple-Tube Fermentation Technique for Members of the Coliform Group," with a standard sample volume of 100 *mL*.

Response to Positive Coliform Testing. The monthly MCL for systems that analyze fewer than 40 samples per month requires that no more than one sample per month can be coliform positive. For water systems that collect more than 40 samples per month, no more than five percent of the samples collected can be coliform positive. The long-term MCL for systems that analyze fewer than sixty samples per year is that no more than five percent of the most recent 60 samples can be coliform positive. For systems with at least sixty samples per year, no more than five percent of all samples in the most recent 12-month period can be coliform positive.

If coliforms are detected in any sample, the water purveyor must collect a set of five repeat samples on the same day from the same location. If coliforms are detected in a repeat sample, the system must analyze the coliform positive culture medium to determine if fecal coliforms are present. If fecal coliforms are present, the coliform MCL has been violated and the appropriate health agency must be notified immediately. If the MCL has not been violated, another set of five repeat samples must be collected and analyzed.

22.635 Giardia

The protozoan *Giardia lamblia* is presently the organism most implicated in waterborne disease outbreaks in the United States. These microscopic creatures are found mainly in mountain streams. Once inside the body, they cause a painful and disabling illness. The infection caused by Giardia is called Giardiasis. The symptoms of Giardiasis are usually severe diarrhea, gas, cramps, nausea, vomiting, and fatigue.

Giardia and viruses have been added to the traditional coliform and turbidity indicators of microbiological quality. In this case, the Recommended Maximum Contaminant Levels (RMCLs) are zero because the organisms are pathogens, or indicators of pathogens, and should not be present in drinking water.

22.64 Radiological Standards

Radon, radium, and uranium are three radioactive elements sometimes found in drinking water. These materials occur naturally in the ground and dissolve into groundwater supplies. Because these radioactive materials are frequently occurring potent carcinogens, EPA will regulate radon and strengthen the standard for radium in water supplies by June 1989.

Radioactivity is the only contaminant for which standards have been set that has been shown to cause cancer. However, the possible exposure to radiation in drinking water is only a fraction of the exposure from all natural sources. The main source of radioactive material in surface water is fallout from nuclear testing. Other sources could be nuclear power plants, nuclear fuel processing plants and uranium mines. Those sources are monitored constantly and there is no great risk of contamination, barring accidents.

Alpha and radium radioactivity occur naturally in parts of the West, Midwest, and Northeast in groundwater. Standards for those types of radioactivity and for man-made, or beta radiation have been set at levels of safety comparable to other contaminants.

The MCLs for radiological contaminants are divided into two categories: (1) natural radioactivity which results from well water passing through deposits of naturally occurring radioactive materials; and (2) man-made radioactivity such as might result from industrial wastes, hospitals or research laboratories. Table 22.5 summarizes the MCLs for radioactivity.

TABLE 22.5 MCLs FOR RADIOACTIVITY

Constituent	Maximum Contaminant Level, pCi/*L*[a]
Combined Radium 226 and Radium 228	5
Gross Alpha Activity (including Radium 226 but excluding Radium and Uranium)	15
Tritium	20,000
Strontium-90	8
Gross Beta Particle Activity	50

[a] pCi/*L* PicoCurie per Liter. A picoCurie is a measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second

Monitoring for natural radioactivity contamination is required every four years for both surface water and groundwater community systems. Routine monitoring procedures to follow are.

1. Test for gross alpha activity, if gross alpha exceeds 5 pCi/*L*, then
2. Test for radium 226, if radium 226 exceeds 3 pCi/*L*, then
3. Test for radium 228

The following MCLs apply for natural radioactivity

1 Gross alpha activity 15 pCi/*L*, and

2 Radium 226 and radium 228 . . . . 5 pCi/*L*.

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[5] *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 16th Edition, 1985. Order No. 10035. Available from Computer Services, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members, $72.00, nonmembers, $90.00.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 528.

22.6H EPA is considering the creation of microbiological standard MCLs for what factors?

22.6I For water systems that regularly take 10 or fewer samples per month, under what circumstances may *ONE* positive sample be discarded?

22.6J The MCLs for radiological contaminants are divided into what two categories?

22.7 SECONDARY DRINKING WATER STANDARDS

22.70 Enforcement of Regulations

The National Secondary Drinking Water Regulations control contaminants in drinking water that primarily affect the aesthetic qualities relating to the public acceptance of drinking water. At considerably higher concentrations of these contaminants, health implications may also exist as well as aesthetic degradation. These regulations are not federally enforceable; however, some states have passed laws requiring the state health agency to enforce the regulations.

22.71 Secondary Maximum Contaminant Levels

Secondary Maximum Contaminant Levels (SMCLs) apply to public water systems and, in the judgment of the EPA Administrator, are necessary to protect the public welfare or for public acceptance of the drinking water. The SMCL means the maximum permissible level of a contaminant which is delivered to the free-flowing outlet of the ultimate user of a public water system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded by definition. Currently there are 13 secondary standards (see Table 22.6).

TABLE 22.6 SECONDARY DRINKING WATER STANDARDS

CONTAMINANT	MCL	EFFECT
Chloride	250 mg/*L*	taste and corrosion of water pipes
Color	15 Color Units	aesthetic
Copper	1 mg/*L*	taste and staining of porcelain
Corrosivity	Non-Corrosive	aesthetic and health related as corrosive water can leach pipe materials into drinking water
Fluoride	2 mg/*L*	dental fluorosis (a brownish discoloration of the teeth)
Foaming Agents	0.5 mg/*L*	aesthetic
Iron	0.3 mg/*L*	taste and staining
Manganese	0.05 mg/*L*	taste and staining
Odor	3 Threshold Odor Number[a]	aesthetic
pH	6.5 to 8.5	corrosion control
Sulfate	250 mg/*L*	taste and laxative effects
Total Dissolved Solids	500 mg/*L*	taste and possible relationship between low hardness and heart disease
Zinc	5 mg/*L*	taste

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[a] *Threshold Odor Number (TON). The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.*

States may establish higher or lower levels depending on local conditions, providing that public health and welfare are adequately protected.

Aesthetic qualities are important factors in public acceptance and confidence in a public water system. States are encouraged to implement SMCLs so that the public will not be driven to obtain drinking water from potentially lower quality, higher risk sources. Many states have chosen to enforce both Primary and Secondary MCLs to assure that the consumer is provided with the best quality water available.

22.72 Monitoring

Collect samples for secondary contaminants at a free-flowing outlet of water being delivered to the consumer. Monitor contaminants in these regulations at intervals no less frequent than the monitoring performed for inorganic chemical contaminants (every three years) listed for the Interim Primary Drinking Water Regulation or applicable to community water systems. Collect monthly distribution system physical water quality monitoring samples for color and odors. More frequent monitoring would be appropriate for specific contaminants such as pH, color, odor or others under certain circumstances as directed by the state.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 528.

22.7A Under what conditions are secondary drinking water regulations enforceable?

22.7B List the secondary drinking water contaminants.

22.7C How frequently should the contaminants in the secondary regulations be monitored?

22.73 Secondary Contaminants

22.730 Chloride

The MCL for chloride is 250 mg/L.

UNDESIRABLE EFFECTS

1 Objectionable salty taste in water.
2. Corrosion of the pipes in hot water and other systems.

STUDIES ON THE MINERALIZATION OF WATER INDICATE THE FOLLOWING

1. Major taste effects are producted by anions (where TDS was studied).
2. Chloride produces a taste effect somewhere between the milder sulfate and the stronger carbonate.
3 Laxative effects are caused by high levels of sodium and magnesium sulfate.

CORROSION EFFECT

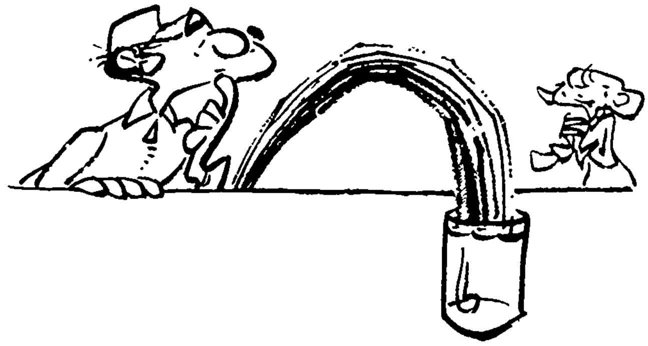
1 Studies indicate that corrosion depends on concentration of TDS (TDS may contain 50 percent chloride ions).
2 Domestic plumbing, water heaters and municipal waterworks equipment will deteriorate when high concentrations of chloride ions are present.

EXAMPLE:

Where the TDS = 200 mg/L (Chloride = 100 mg/L), water heater life will range from 10 to 13 years. Water heater life declines uniformly as a function of TDS — 1 year shortened life per 200 mg/L additional TDS.

22.731 Color

The MCL for color is 15 color units. The level of this water quality indicator is not known to be a measure of the safety of water However, high color content may indicate:



1 High organic chemical contamination.
2. Inadequate treatment, and
3 High disinfectant demand and the potential for production of excess amounts of disinfectant by-products.

Color may be caused by:

1. Natural color-causing solids such as aromatic, polyhydroxy, methoxy and carboxylic acids,
2. Fluvic and humic acid fractions, and
3. Presence of metals such as copper, iron, and manganese.

Rapid changes in color levels may provoke more citizen complaints than relatively high, constant color levels.

22.732 Copper

The MCL for copper is 1.0 mg/*L*. Copper in drinking water usually results from the reaction of aggressive water on copper plumbing. Treatment of surface water in storage reservoirs to control algae may also cause high levels of copper

UNDESIRABLE EFFECTS

1 Imparts some taste to water (astringent taste)

2 Blue or blue-green staining of porcelain at low levels (0 5 mg/*L* in soft waters). At higher levels, 4 mg/*L* causes staining of clothing and blond hair

3. Larger doses will produce Wilson's Disease.

4. Prolonged doses result in liver damage.

5 Concentrations greater than one mg/*L* can produce insoluble green curds when reacting with soap

DIETARY REQUIREMENTS

1. Adults require 2.0 mg daily.

2 Children of preschool age require 0.1 mg for normal growth.

3. Water provides an additional supplement to ensure an adequate intake.

4. Excess copper intake or inability to metabolize copper is called Wilson's Disease and can be arrested by the use of *CHELATING AGENTS*.[6]

22.733 Corrosivity

A drinking water should be non-corrosive. However, a significant level of corrosion is very difficult to define and explain The corrosivity of water depends on the complex characteristics of water which are related to pH, alkalinity, dissolved oxygen, and total dissolved solids plus other factors. A number of different measurements have been proposed to determine the degree of corrosivity of water, but none is completely satisfactory (see Chapter 8, Corrosion Control).

ADVERSE EFFECTS

1. Affects the aesthetic quality (turbid waters promote deposits under stagnant conditions encouraging bacteriological growths), and causes taste and odor problems in the water supply.

2. Serious economic impact (loss of system piping, water loss from deteriorating distribution system).

3 Health implications (toxic corrosion products such as lead, cadmium and copper).

22.734 Fluoride

Fluoride as recently been added to the list of secondary drinking water standards. Fluoride produces two effects, depending on its concentration. At levels of 6-8 mg/*L* fluoride may cause skeletal fluorosis which is a brittling of the bones and stiffening of the joints. For this reason fluoride has been added to the list of primary standards (those that have health effects).

At levels of 2 mg/*L* and greater fluoride may cause dental fluorosis which is discoloration and mottling of the teeth, especially in children. EPA has recently reclassified dental fluorosis as a cosmetic effect, raised the primary drinking water standard from 1,4-2 mg/*L* to 4 mg/*L*, and established a secondary standard of 2 mg/*L* for fluoride.

22.735 Foaming Agents

The MCL for foaming agents is 0 5 mg/*L*

UNDESIRABLE EFFECTS

1 Causes frothing and foaming which are associated with contamination (greater than 1.0 mg/*L*).

2. Imparts an unpleasant taste (oily, fishy, perfume-like) (less than 1.0 mg/*L*).

INFORMATION ITEMS

1. Because no convenient foamability test exists and because *SURFACTANTS*[7] are one major class of substances that cause foaming, this property is determined indirectly by measuring the anionic surfactant concentration in the water (*MBAS*).[8]

2 Surfactants are synthetic organic chemicals and are the principal ingredient of modern household detergents.

3 The requirement for biodegradability led to the widespread use of Linear Alkyl Benzene Sulfonate (LAS), an anionic surfactant.

4 Concentrations of anionic surfactants found in drinking waters range from 0 to 2 6 mg/*L* in well supplies and 0 to 5 mg/*L* in surface water supplies.

5 LAS are essentially odorless. The odor and taste characteristics are likely to arise from the degradation of waste products rather than the detergents.

6 If water contains an average concentration of 10 mg/*L* surfactants, the water is likely to be entirely of wastewater origin.

7 From a toxicological standpoint an MCL of 0.5 mg/*L*, assuming a daily adult human intake of 2 liters, would give a safety factor of 15,000.

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[6] *Chelating Agent (key-LAY ting) A chemical used to prevent the precipitation of metals (such as copper)*

[7] *Surfactant (sir-FAC-tent) Abbreviation for surface-active agent The active agent in detergent that possesses a high cleaning ability*

[8] *MBAS Methylene-Blue-Active Substances. These substances are used in surfactants or detergents.*

22.736 Iron and Manganese

1. Iron and manganese are frequently found together in natural waters and produce similar adverse environmental effects and color problems. Excessive amounts of iron and manganese are usually found in groundwater and in surface water contaminated by industrial waste discharges.
2. Prior to 1962, both were covered by a single recommended limit.
3. In 1962, the U.S Public Health Service recommended separate limits for both iron and manganese to reflect more accurately the levels at which adverse effects occur for each.
4. Both are highly objectionable in large amounts in water supplies for either domestic or industrial use.
5. Both impart color to laundered goods and plumbing fixtures
6. Taste thresholds in drinking water are considerably higher than the levels which produce staining effects.
7. Both are part of our daily nutritional requirements, but these requirements are not met by the consumption of drinking water.

22.737 Iron

The MCL for iron is 0.3 mg/*L*.

UNDESIRABLE EFFECTS

1. At levels greater than 0.05 mg/*L* some color may develop, staining of fixtures may occur, and precipitates may form
2. The magnitude of the staining effect is directly proportional to the concentration.
3. Depending on the sensitivity of taste perception, a bitter, astringent taste can be detected from 0.1 mg/*L* to 1.0 mg/*L*.
4. Precipitates that are formed create not only color problems but also lead to bacterial growth of slimes and of the iron-loving bacteria, *CRENOTHRIX*, in wells and distribution piping.

NUTRITIONAL REQUIREMENTS

1. Daily requirement is one to two mg, but intake of larger quantities is required as a result of poor absorption.
2. The limited amount of iron permitted in water (because of objectionable taste or staining effects) constitutes only a small fraction of the amount normally consumed and does not have toxicologic (poisonous) significance.

22.738 Manganese

The MCL for manganese is 0.05 mg/*L*

UNDESIRABLE EFFECTS

1. A concentration of more than 0.02 mg/*L* may cause buildup of coatings in distribution piping.
2. If these coatings slough off, they can cause brown blotches in laundry items and black precipitates.
3. Manganese imparts a taste to water above 0.15 mg/*L*.
4. The application of chlorine increases the likelihood of precipitation of manganese at low levels
5. Unless the precipitate is removed, precipitates reaching pipelines will promote bacterial growth

TOXIC EFFECTS

1. Toxic effects are reported as a result of inhalation of manganese dust or fumes.
2. Liver cirrhosis has arisen in controlled feeding of rats.

3. Neurological effects have been suggested, however, these effects have not been concretely determined.

NUTRITIONAL REQUIREMENTS

1. Daily intake of manganese from a normal diet is about 10 mg.
2. Manganese is essential for proper nutrition.
3. Diets deficient in manganese will interfere with growth, blood and bone formation, and reproduction.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 528.

22.7D Why is chloride a secondary contaminant?

22.7E How does copper usually get into drinking water?

22.7F Why are corrosive waters undesirable as drinking water?

22.7G What is the impact of chlorine on manganese?

22.739 Odor

The MCL for odor is a *THRESHOLD ODOR NUMBER (TON)*[9] of 3. Important facts to remember when dealing with odors include:

1. Taste and odor go hand-in-hand
2. Absence of taste and odor helps to maintain the consumers' confidence in the quality of their water, even though it doesn't guarantee that the water is safe.
3. Research indicates that there are only four true taste sensations:
   a. Sour,
   b. Sweet,
   c. Salty, and
   d. Bitter.

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[9] *Threshold Odor Number (TON). The greatest dilution of a sample with odor-free water that still yields a just detectable odor.*

4 All other sensations ascribed to the sense of taste are actually odors even though the sensation is not noticed until the material is taken into the mouth.

5 Odor tests are less fatiguing to people testing for tastes and odors than taste tests.

6. Taste and odor tests are useful:
   a. As a check on the quality of raw[10] and treated water, and
   b. To help control odor throughout the plant.

7. Odor is a useful test:
   a. For determining the effectiveness of different kinds of treatment, and
   b. As a means for tracing the source of contaminants

22.740 pH

The MCL for pH is defined as pH values beyond the acceptable range from 6.5 to 8.5 A wide range of pH values in drinking water can be tolerated by consumers.

UNDESIRABLE EFFECTS

1 When the pH increases, the disinfection activity of chlorine falls significantly.

2. High pH may cause increased production of chloroform and other trihalomethanes during chlorination.

3 Both excessively high and low pHs may cause increased corrosivity which can in turn create taste problems, staining problems, and significant health hazards.

4. Metallic piping in contact with low pH water will impart a metallic taste.

5. If the piping is iron or copper, high pH will cause oxide and carbonate compounds to be deposited leaving red or green stains

6. At a high pH drinking water acquires a bitter taste.

7. The high degree of mineralization often associated with basic waters results in encrustation of water pipes and water-using appliances

22.741 Sulfate

The MCL for sulfate is 250 mg/L

UNDESIRABLE EFFECTS AT HIGH LEVELS

1. Tends to form hard scales in boilers and heat exchangers.

2. Causes taste effects.

3. Causes laxative effect. This effect is commonly noted by newcomers or casual or intermittent users of water high in sulfate. Water containing more than 750 mg/L of sulfate usually produces the laxative effect while water with less than 600 mg/L sulfate usually does not An individual can become acclimated to sulfate in drinking water.

4. Sodium sulfate and magnesium sulfate are more active as laxatives, whereas calcium sulfate is less active.

5. When the magnesium content is 200 mg/L, the most sensitive person will feel the laxative effect, however, magnesium sulfate levels between 500 mg/L and 1000 mg/L will induce diarrhea in most individuals.

6 Tastes may sometimes be detected at 200 mg/L of sulfate, but generally are detected in the range of 300 to 400 mg/L

22.742 Total Dissolved Solids (TDS)

The MCL for total dissolved solids is 500 mg/L.

UNDESIRABLE EFFECTS

1 TDS imparts adverse taste effects at greater than 500 mg/L

2 Highly mineralized water influences the deterioration of distribution systems as well as domestic plumbing and appliances (the life of a hot water heater will decrease one year with each additional 200 mg/L of TDS above a typical 200 mg/L value).

3. Mineralization can also cause precipitates to form in boilers and other heating units, sludge in freezing processes, rings on utensils and precipitates in food being cooked.

4. There may be a great difference between a detectable concentration and an objectionable concentration of the neutral salts. Many people can become acclimated to high levels.

5. Studies show that the temperature of mineralized waters influences their acceptability to the public.

22.743 Zinc

The MCL for zinc is 5 mg/L.

UNDESIRABLE EFFECTS

1. High concentrations of zinc produce adverse physiological effects.

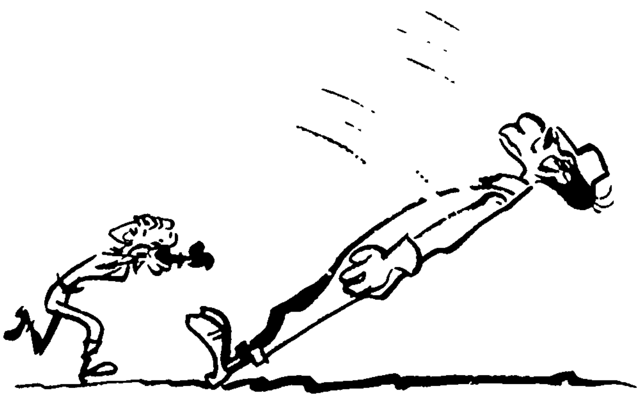
2 Zinc imparts a bitter, astringent taste which is distinguishable at 4 mg/L Also at 4 mg/L a metallic taste will exist

3 Zinc will cause a milky appearance in water at 30 mg/L.

4. Zinc may increase lead and cadmium concentrations.

5 The activity of several enzymes is dependent on zinc.

6. Cadmium and lead are common contaminants of zinc used in galvanizing steel pipe. Even if the MCL of five mg/L of zinc were dissolved from galvanized water pipe, to produce five mg/L, the cadmium dissolved would be less than 0.01 mg/L and the lead dissolved would be less than the 0.05 mg/L MCL.



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[10] *When testing raw water, be sure there are no pathogens or toxic chemicals present.*

PHYSIOLOGICAL EFFECTS

1 A concentration of 30 mg/*L* can cause nausea and fainting.

2 Zinc salts act as gastrointestinal irritants. This symptom of illness is acute and transitory.

3 The vomiting concentration range is 675 to 2,280 mg/*L*

4 A wide margin of safety exists between normal food intake and concentrations in water high enough to cause oral toxicity

DIETARY REQUIREMENTS

1. The daily requirement for preschool children is 0 3 mg Zn/kg of weight.
2. Total zinc in an adult human body averages two grams.
3. Zinc most likely concentrates in the retina of the eye and in the prostate.
4. Zinc deficiency in animals leads to growth retardation.

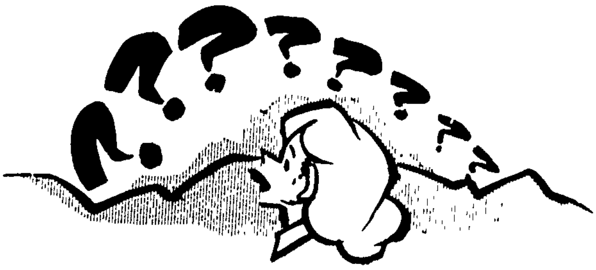
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 529.

22.7H What are the undesirable effects of abnormal pH values?

22.7I Why are high levels of sulfate undesirable in drinking water?

22.7J Why are high levels of zinc undesirable in drinking water?



22.8 SAMPLING PROCEDURES

22.80 Safe Drinking Water Regulations

The Safe Drinking Water Act and accompanying regulations require that you must take the following actions to comply:

1. Sampling,
2. Testing,
3. Recordkeeping, and
4. Reporting.

Understanding and implementing each of these steps will help ensure the success of your operation.

22.81 Initial Sampling

"Initial sampling" refers to the very first sampling you do under the SDWA for each of the applicable contaminant categories When you start and when you complete this sampling depends on:

1. The type of contaminant being monitored,
2. Whether the system is a community or non-community water system, and
3. Whether the water source is a surface or groundwater supply.

The poster inside the back cover of this manual outlines the Interim Primary Drinking Water Standards and summarizes the initial sampling program for each contaminant category (also see Table 22.7 for required sampling program). In column 7 in the poster and column 5 in Table 22.7 as well as in other places, several state options are listed. You should be familiar with the requirements of your particular state.

22.82 Routine Sampling

Routine sampling refers to sampling repeated on a regular basis. Table 22.7 and column 5 on the poster summarize the routine sampling requirements for each contaminant category.

22.83 Check Sampling

Whenever an initial or routine sample analysis indicates that an MCL has been exceeded, check sampling is required to confirm the routine sampling results. Check sampling is in addition to the routine sampling program. Although check sampling cannot be scheduled in advance, there are specific check sampling procedures to follow. The number of samples, sampling points, and frequency of sampling vary according to the particular contaminant. For example, the regulations specify that wherever a coliform bacteria check sample is required, the location from which the sample was taken cannot be eliminated from future routine sampling without prior state approval.

22.84 Sampling Points

Some of the samples required to determine compliance with the primary regulations can be taken from the routine sampling points. By coordinating the present sampling points with the sampling program required by the regulations, additional monitoring costs can be minimized. Table 22.7 summarizes what, where and how often you need to sample for both community and non-community water systems. The number of sampling points required will depend on the specific size of the population served and layout of each water system.

As noted in Table 22.7, samples for turbidity must be taken at the points where water enters the distribution system and samples collected for coliform bacteria. inorganics, organics and radiochemicals must be taken from the consumers' faucets at representative points within the distribution system.

TABLE 22.7 REQUIRED SAMPLING

What Tests[a] (Community System)	What Tests[a] (Non-Community System)	Where Samples Taken	How Often[a] (Community System)	How Often[a] (Non-Community System)
Inorganics	Inorganics (at state option)	At the consumer's faucet[b]	Systems using surface water EVERY YEAR Systems using groundwater only· EVERY THREE YEARS	All Systems STATE OPTION
Organics	Organics (at state option)	At the consumer's faucet[b]	Systems using surface water. EVERY THREE YEARS Systems using groundwater only STATE OPTION	All systems. STATE OPTION
Turbidity	Turbidity	At the point(s) where water enters the distribution system	Systems using surface water. DAILY Systems using groundwater only: STATE OPTION	Systems using surface or surface and groundwater: DAILY Systems using groundwater only: STATE OPTION
Coliform Bacteria	Coliform Bacteria	At the consumer's faucet[b]	Depends on number of people served by the water system (see Appendix at end of chapter)	All systems: ONE PER QUARTER (for each quarter water is served to public)
Radiochemicals (Natural)	Radiochemicals (Natural) — (at state option)	At the consumer's faucet[b]	Systems using surface water. EVERY FOUR YEARS Systems using groundwater only. EVERY FOUR YEARS	All systems. STATE OPTION
Radiochemicals (Man-made)	Radiochemicals (Man-made) — (at state option)	At the consumer's faucet[b]	Systems using surface water serving populations greater than 100,000: EVERY FOUR YEARS All other systems· STATE OPTION	All systems. STATE OPTION

[a] This information is summarized on the poster inside the back cover

[b] The faucets selected must be representative of conditions within the distribution system.

At the very minimum, a small system (with population of 25 to 1000) must sample for turbidity and coliform bacteria and also must have two sampling points.

1. One where the water enters the distribution system, and
2. One at a consumer faucet at a representative point in the distribution system.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 529.

22.8A What do the words "Initial Sampling" mean?

22.8B What is routine sampling?

22.8C What is check sampling?

22.8D What are the minimum sampling requirements for a small system with a population of 100 people?

22.85 Sampling Point Selection

The two major considerations in determining the number and location of sampling points are that they should be:

1. Representative of each different surface water source entering the system, and
2. Representative of conditions within the system such as deadends, loops, storage facilities and pressure zones.

22.86 Sampling Schedule

A sampling schedule should be prepared which indicates all of the samples that will be collected during a yearly period The schedule should include the following information

1 Sampling frequency,
2. Sampling point designation,
3 Location (address),
4. Type of test,
5. Sample volume, and
6 Special handling instructions.

This schedule should be reviewed with your state health department to determine adequacy to meet the SDWA regulations

22.87 Sampling Route

After selection of the sampling points and preparation of the sampling schedule, the next step is to select a route. Arrange your route so that samples that must be analzyed immediately are not delayed while other sampling is done. Field data forms must be completed by the person doing the sampling and submitted to the laboratory with the samples.

22.88 Sample Collection

Good sampling techniques are the key to a meaningful and useful sampling program. The following eight steps are necessary to the collection of an acceptable sample:

1 Obtain a sample that is truly representative of the existing condition,
2 Flush the line before sample collection,
3 Fill the sample bottle without leaving any air pocket,
4. Analyze residual chlorine when the sample is taken;
5 Handle and store the sample so that it does not become contaminated before it reaches the laboratory,
6. Use preservation techniques. These preservation methods are generally.
   a. pH control, and
   b. Refrigeration;
7 Keep accurate records of every sample collected including.
   a Date and time sampled,
   b. Location sampled,
   c. Name of sample collected,
   d. Bottle number,
   e. Type of sample, and
   f Name of person collecting sample. Any person collecting samples should be required to complete a form providing the above information at the time of sample collection. This form should be supplied by the laboratory; and
8. Keep the time between the collection of the sample and analysis as short as possible.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 529.

22.8E List the information that should be included in a sampling schedule.

22.8F List the elements necessary to the collection of an acceptable sample.

22.9 REPORTING PROCEDURES

The primary purpose of the SDWA is to protect the public's health There are two general categories of reporting called for by the Act:

1 Reporting to the public (public notification), and
2 Reporting to the state

There are three types of reports that must be sent to the state:

1. Routine sampling reports,
2. Check sample reports, and
3. Violation reports

Tables 22.9 through 22.21 outline reporting procedures for various contaminants.

22.10 NOTIFICATION FOR COMMUNITY SYSTEMS

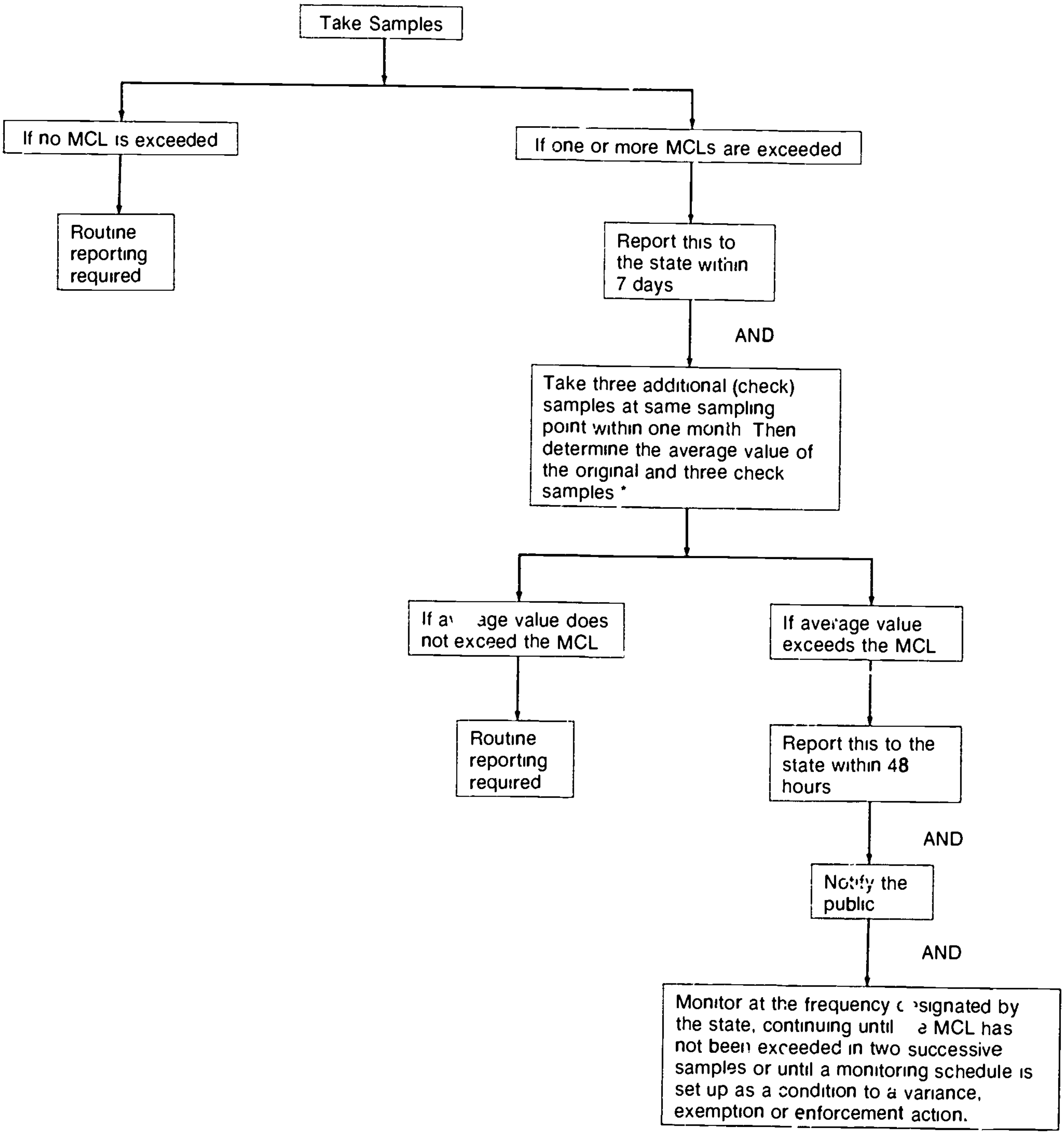
In general, public notification for community systems is only required in the circumstances shown in Table 22.8.

TABLE 22.8 PUBLIC NOTIFICATION

	Required Notification		
Type of Violation	Mail	Newspaper	Broadcast
Violation of Primary MCL	x	x	x
Failure to comply with testing procedure	x		
Variance or exception granted	x		
Monitoring failure	x		
Compliance schedule not followed	x		

Currently, public notification of violations of the drinking water regulations is cumbersome, but the 1986 Amendments to the Safe Drinking Water Act (SDWA) provide greater flexibility. The EPA must amend its existing notification regulations within 18 months of enactment and must specify the types of notice to be used to provide information to consumers as promptly and effectively as possible, taking into account both the seriousness of any potential adverse health effects and the likelihood of reaching all affected people.

TABLE 22.9 REPORTING PROCEDURES
INORGANIC CHEMICALS (EXCEPT NITRATE) AND ORGANIC CHEMICALS



$$* \text{ Average value } = \frac{\text{TOTAL of Original Sample + 3 check samples}}{4}$$

TABLE 22.10 REPORTING PROCEDURES — NITRATE

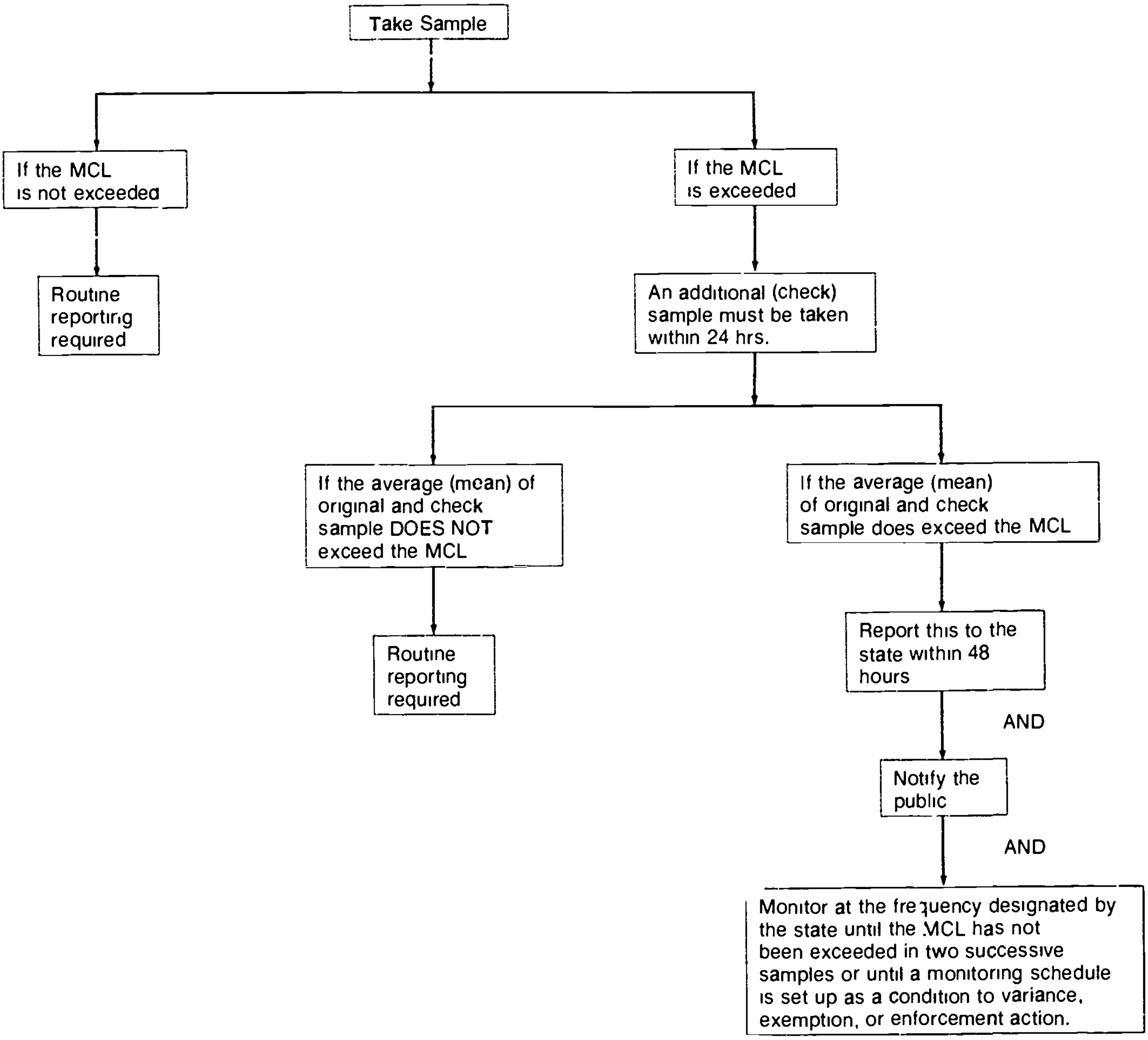
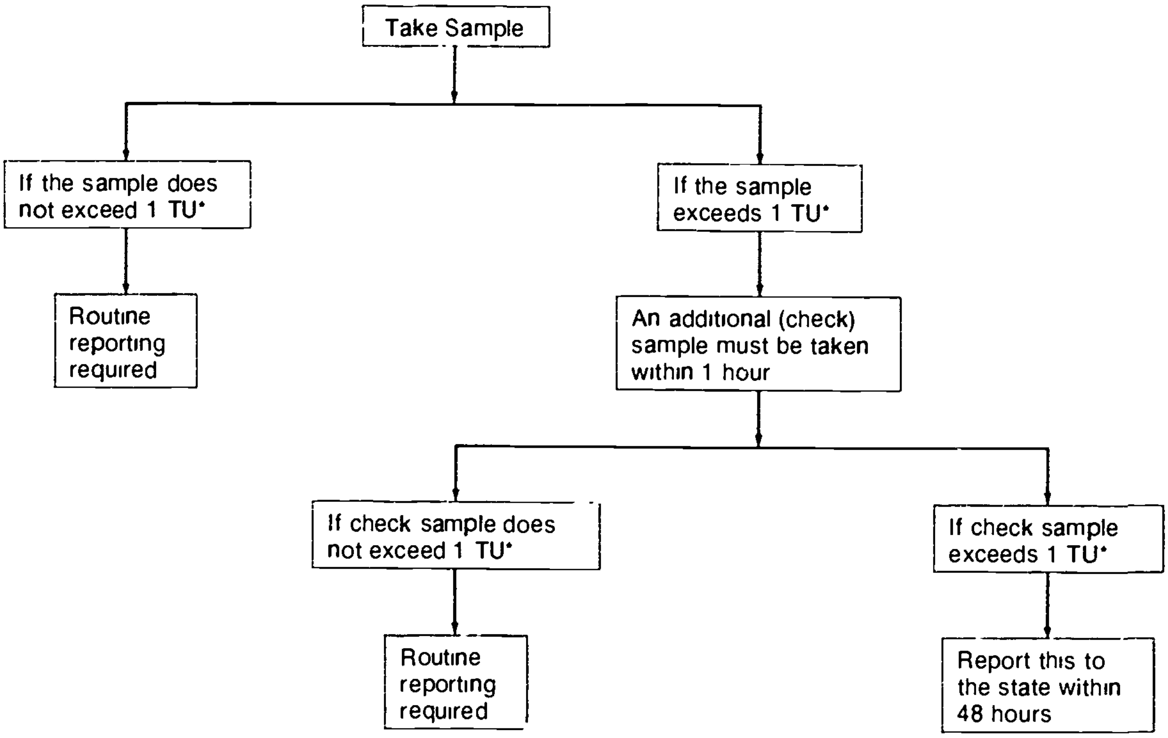
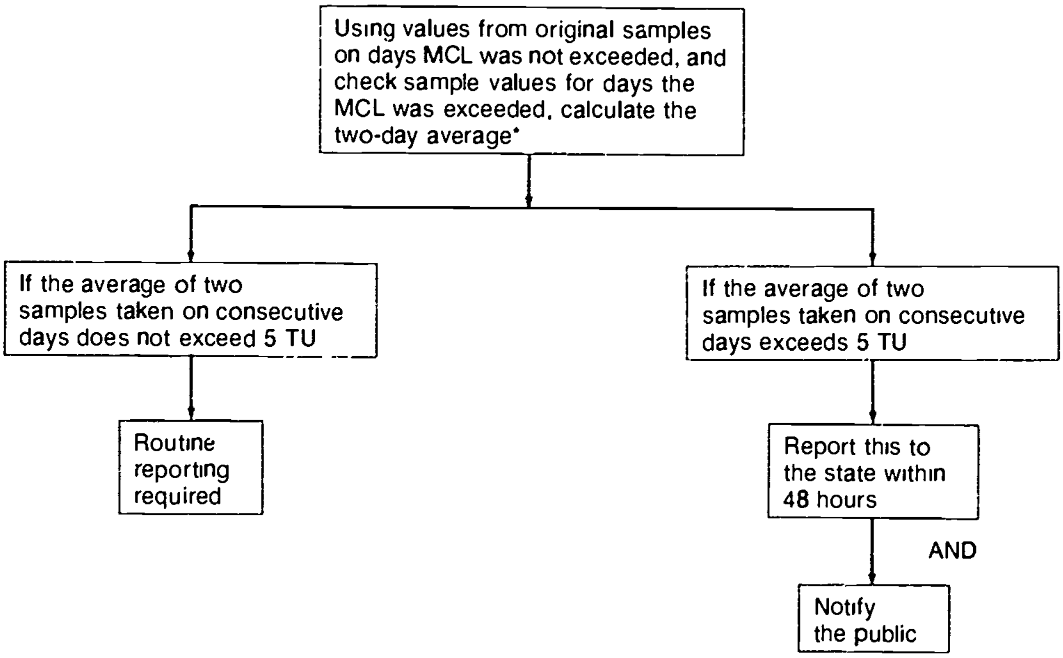


TABLE 22.11 REPORTING PROCEDURES — DAILY TURBIDITY MONITORING



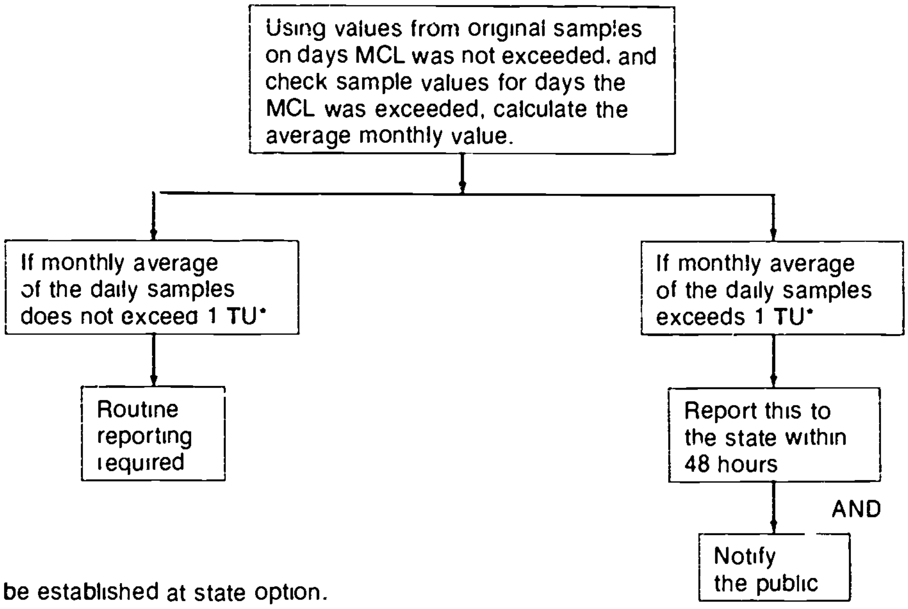
* MCL of 5 TU may be established at state option

TABLE 22.12 REPORTING PROCEDURES — WHEN CALCULATING TWO-DAY TURBIDITY AVERAGES



* The average is based on the results of samples taken on *CONSECUTIVE DAYS.*

TABLE 22.13 REPORTING PROCEDURES — WHEN CALCULATING MONTHLY AVERAGE TURBIDITY VALUES



* MCL of 5 TU may be established at state option.

TABLE 22.14 REPORTING PROCEDURES MICROBIOLOGICAL CONTAMINANTS — MEMBRANE FILTER METHOD

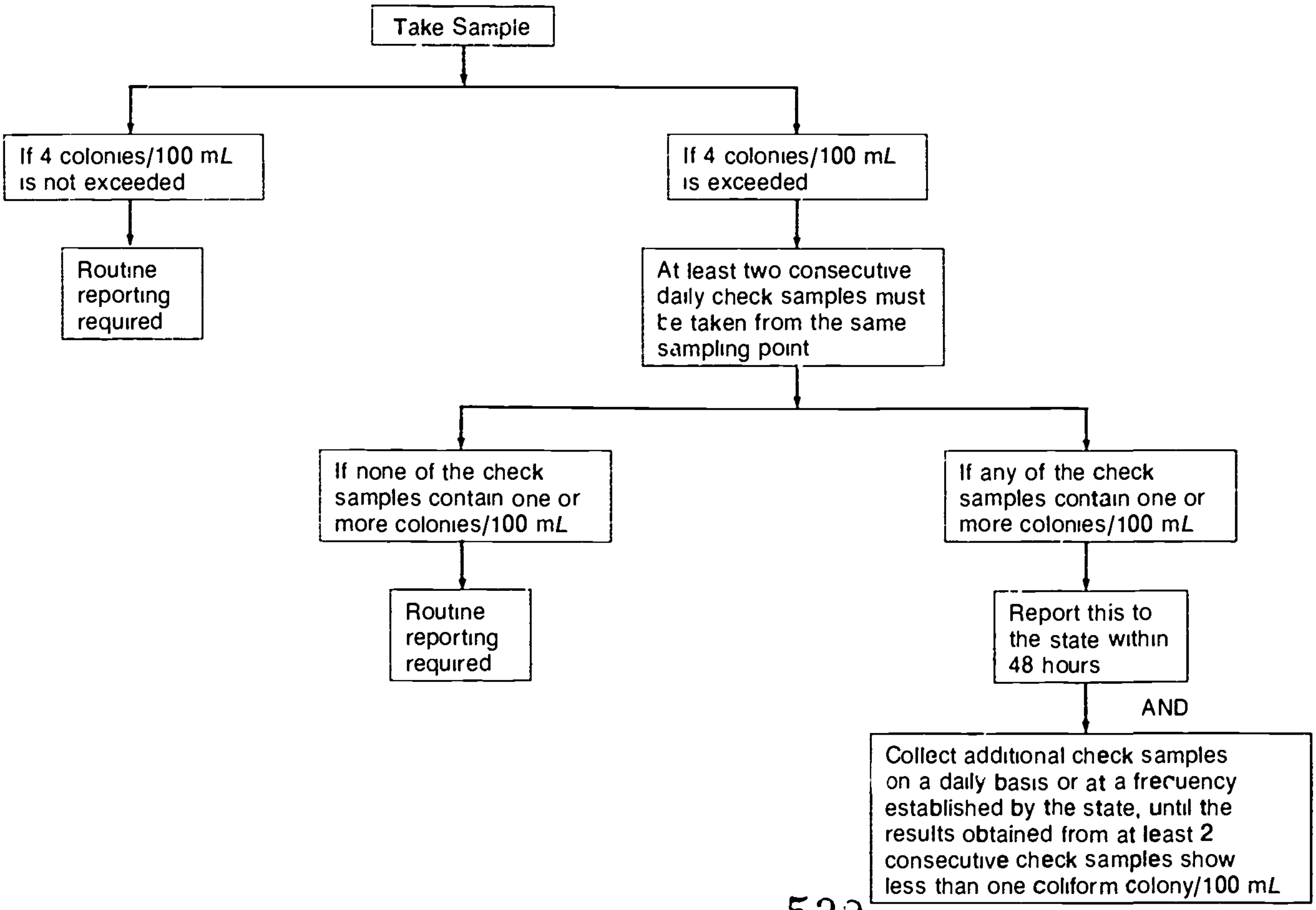
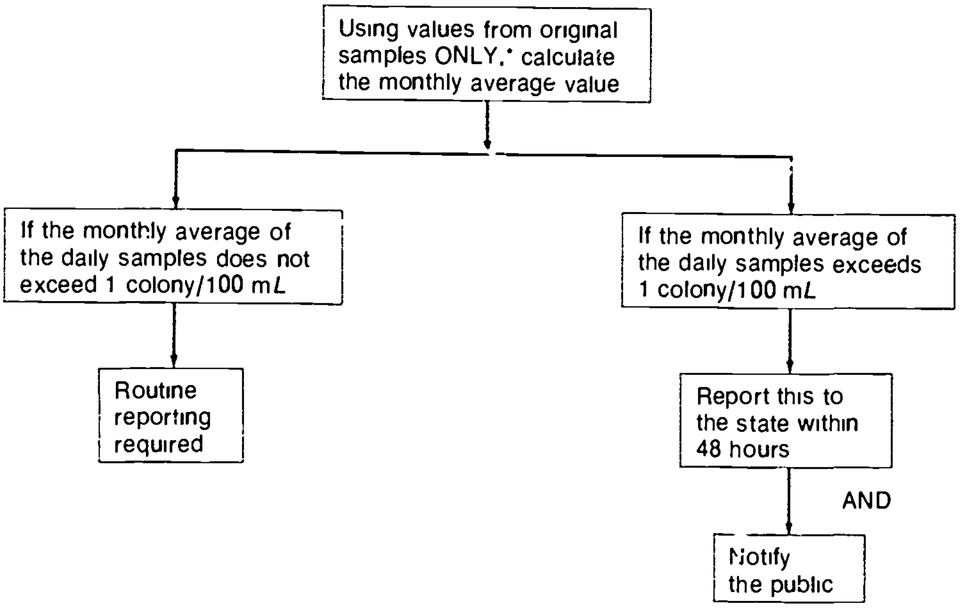
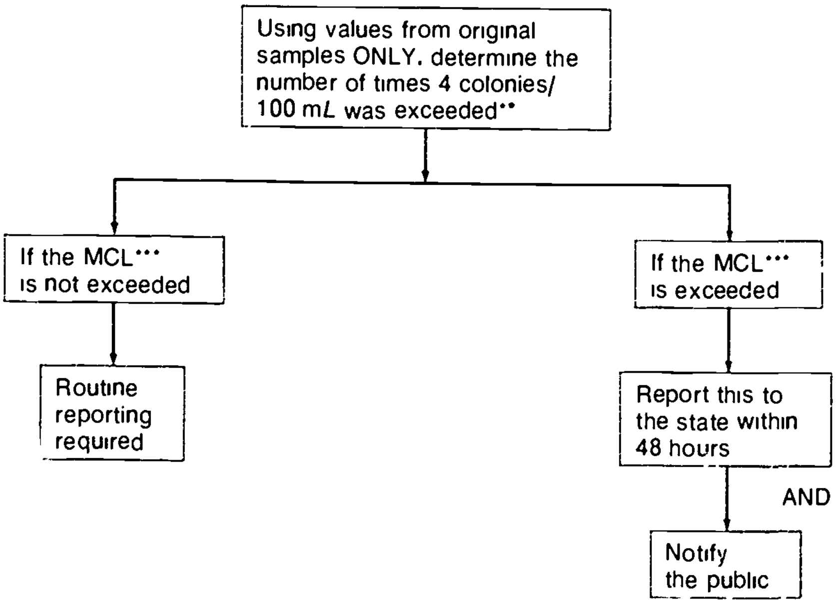


TABLE 22.15 REPORTING PROCEDURES WHEN CALCULATING MONTHLY MEMBRANE FILTER RESULTS

I. CALCULATE THE MONTHLY AVERAGE VALUE



II. DETERMINE THE NUMBER OF TIMES 4 COLONIES/100 mL WAS EXCEEDED



* Check sample values are not to be used when calculating the monthly average.

** For systems taking *FEWER THAN 20 SAMPLES PER MONTH,* merely count the number of samples exceeding 4 colonies/100 mL.

For systems taking *20 OR MORE SAMPLES PER MONTH,* calculate the percentage of samples exceeding 4 colonies/100mL.

*** The MCL states that coliform presence shall not exceed 4 colonies/100 mL in more than one sample if fewer than 20 samples collected per month or 4 colonies/100 mL in more than 5% of the samples if 20 or more are examined per month.

TABLE 22.16 REPORTING PROCEDURES — MICROBIOLOGICAL CONTAMINANTS-MULTIPLE-TUBE FERMENTATION METHOD (10 m*L*)

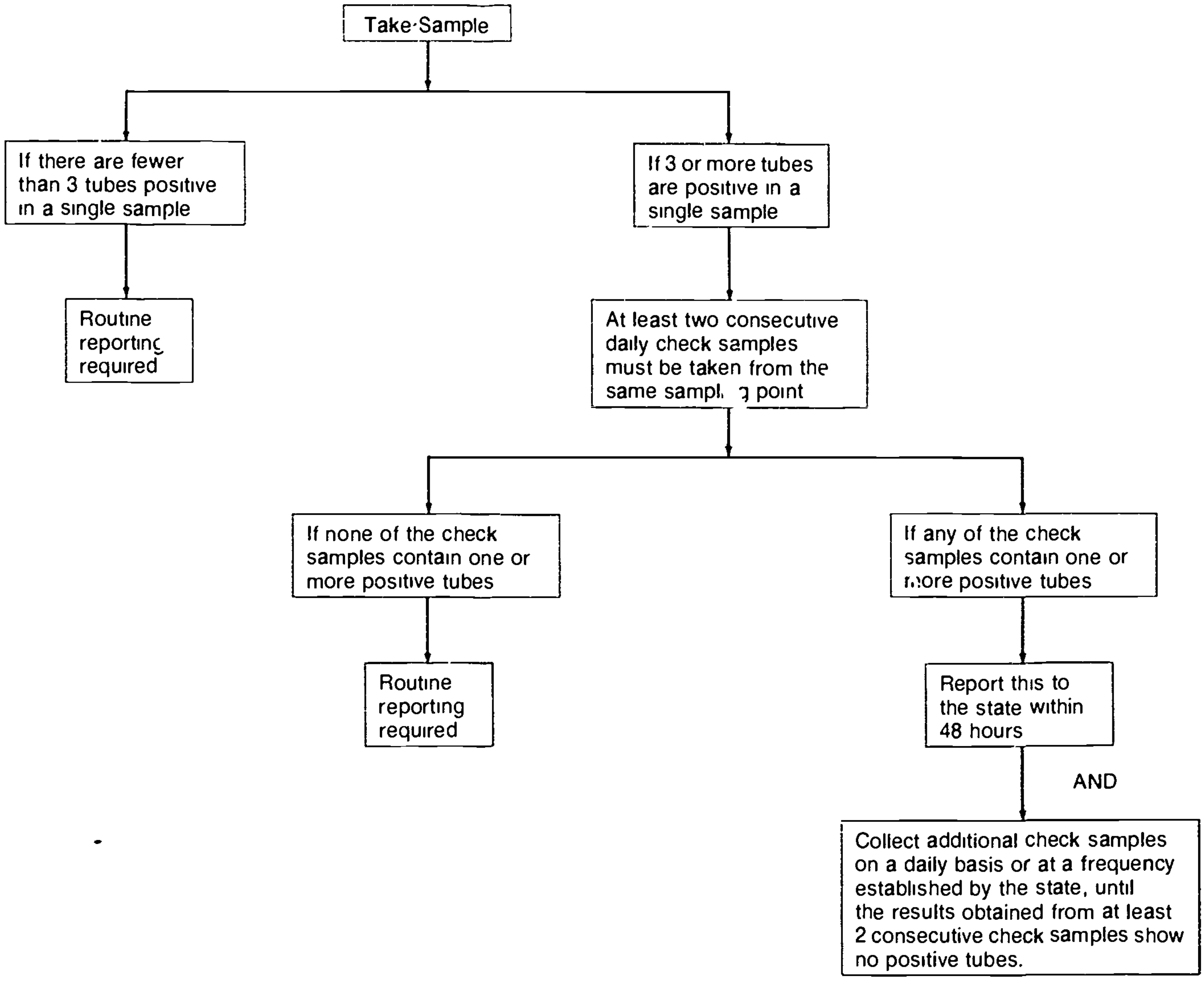
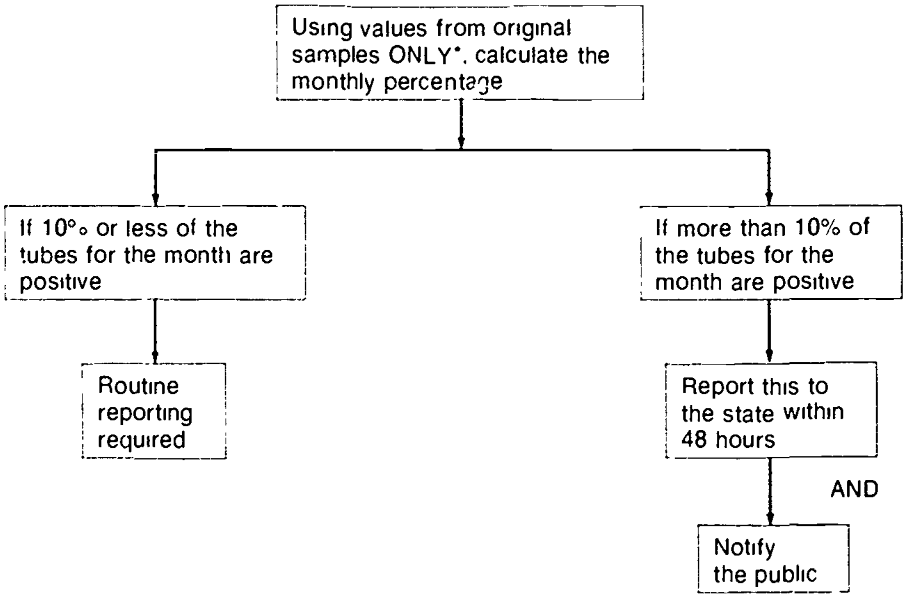
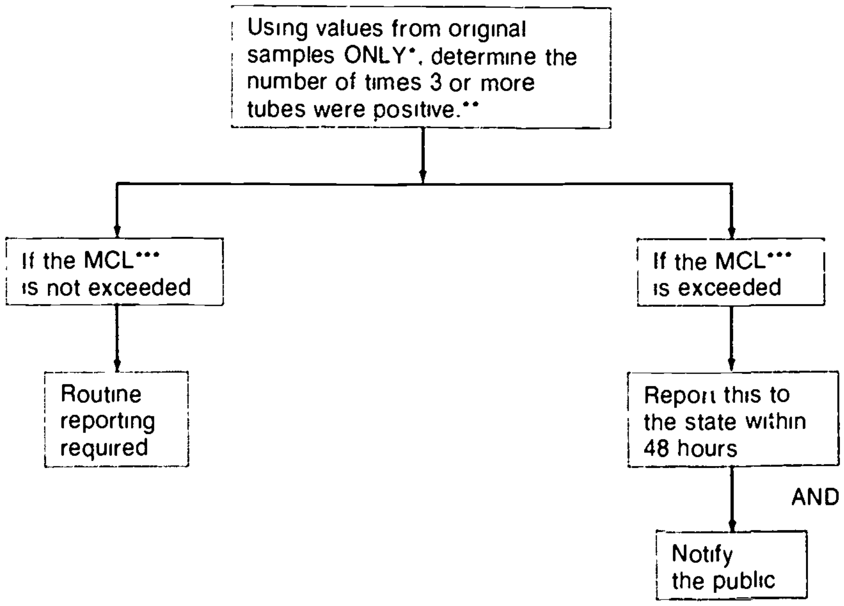


TABLE 22.17 REPORTING PROCEDURES — WHEN CALCULATING MONTHLY MULTIPLE-TUBE FERMENTATION (10 mL) RESULTS

I. CALCULATE THE MONTHLY PERCENTAGE



II. DETERMINE THE NUMBER OF TIMES 3 OR MORE TUBES WERE POSITIVE



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* Check sample values are not to be used when calculating the monthly percentages.

** For systems taking *FEWER THAN 20 SAMPLES PER MONTH*, merely count the number of samples which contained 3 or more positive portions.

For systems taking *20 OR MORE SAMPLES PER MONTH*, calculate the percentage of samples containing 3 or more positive portions.

*** The MCL states that not more than 1 sample may have 3 or more portions positive when fewer than 20 samples are examined per month OR not more than 5% of the samples may have 3 or more portions positive when 20 or more samples are examined per month.

TABLE 22.18 REPORTING PROCEDURES — MICROBIOLOGICAL CONTAMINANTS — CHLORINE RESIDUAL

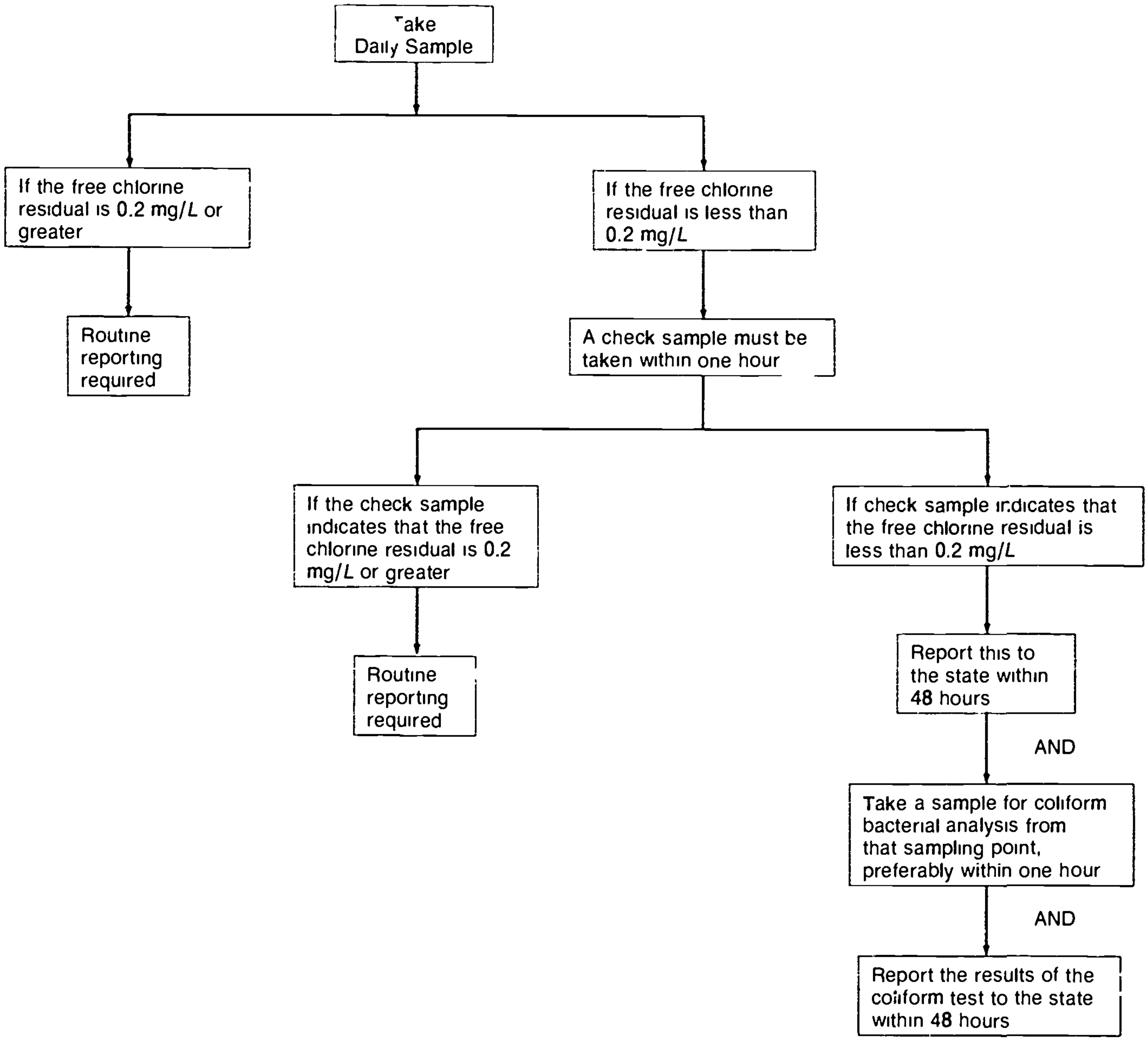
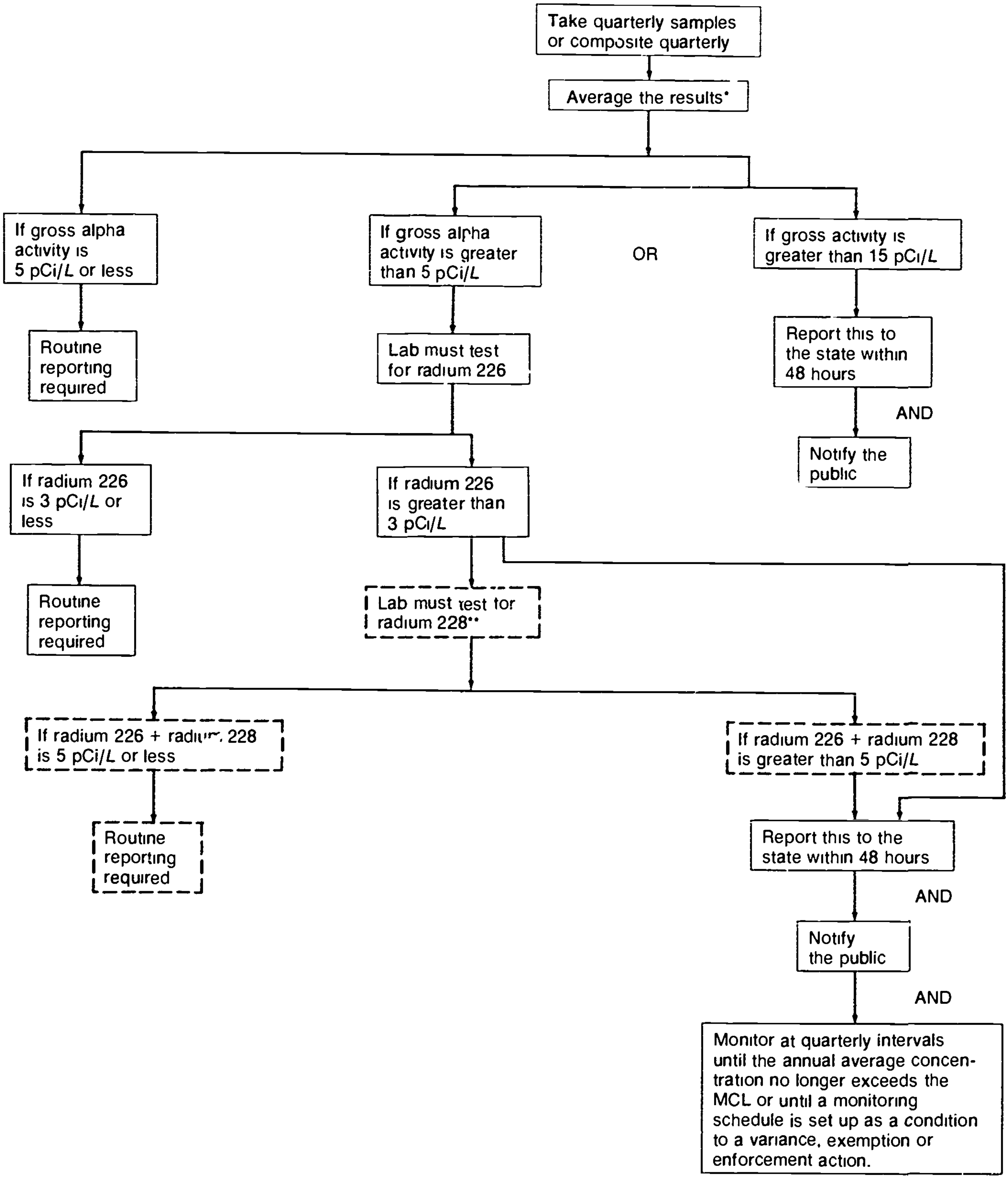


TABLE 22.17 REPORTING PROCEDURES — RADIOLOGICAL CONTAMINANTS — NATURAL
(Test for gross alpha activity)



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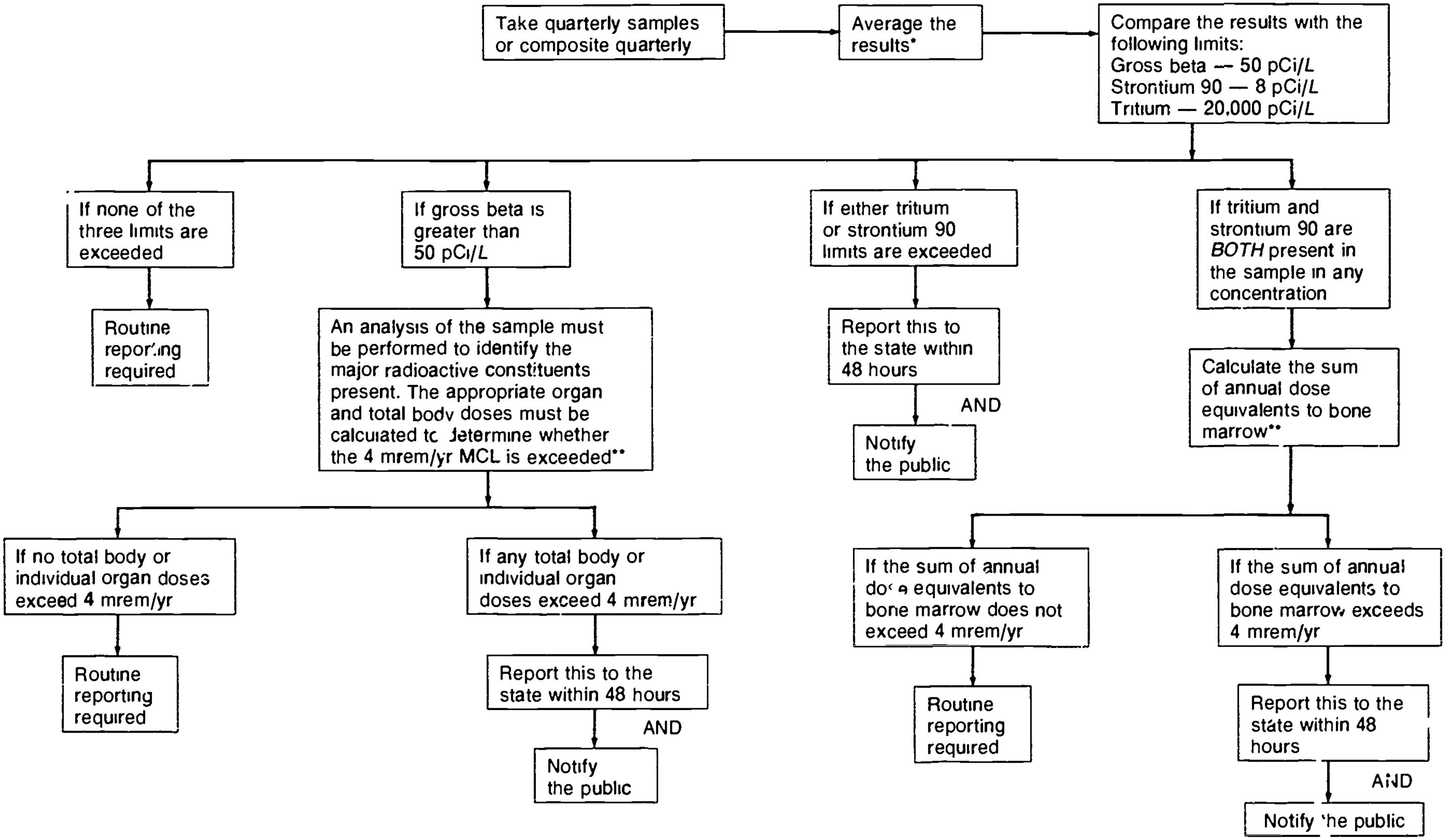
* $\text{Average} = \dfrac{\text{Sum of four values}}{4}$

No averaging is required if the quarterly samples were composited. In that case, use the results of the single sample.

** This step is required only for the initial monitoring period and not for routine monitoring, *EXCEPT AS REQUIRED BY THE STATE.*

TABLE 22.20 REPORTING PROCEDURES — RADIOLOGICAL CONTAMINANTS — MAN-MADE

(Applicable Only to Surface Water Systems Serving Populations of 100,000 or More)

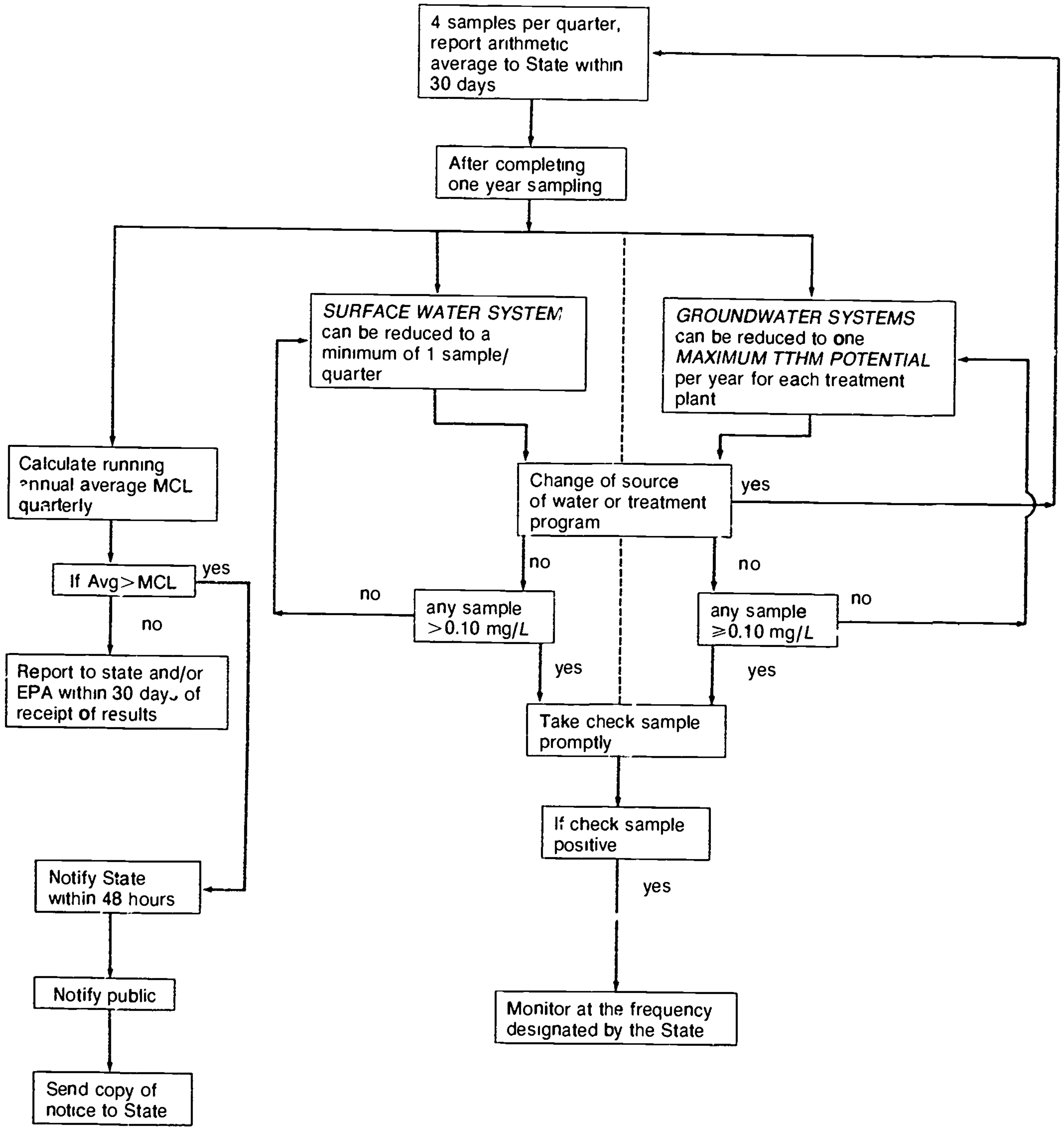


* Average = $\frac{\text{Sum of four values}}{4}$

No averaging is required if the quarterly samples were composited. In that case, use the results of the single sample.

** It is likely that the laboratory will not make these calculations. You will probably have to get help from state water supply personnel in making these calculations.

TABLE 22.21 REPORTING PROCEDURES — TOTAL TRIHALOMETHANES
(Applicable to Community Surface Water Systems
Serving Populations of 10,000 or More)



MCL.
Total trihalomethanes (the sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane (bromoform) and trichloromethane (chloroform)) 0.10 mg/L

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 529.

22.9A What are the two general categories of reporting called for by the SDWA?

22.9B What are the three types of reports that must be sent to the state?

22.10A If an MCL is violated, what is the required public notification?

End of Lesson 2 of 2 Lessons
on
DRINKING WATER REGULATIONS

DISCUSSION AND REVIEW QUESTIONS

Chapter 22. DRINKING WATER REGULATIONS

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 530. The problem numbering continues from Lesson 1.

9. Why is there a primary drinking water standard for turbidity?
10. What are the most common sources of organic contamination if drinking water?
11. What do secondary drinking water regulations control?
12. Why are secondary drinking water regulations important?
13. How may color be caused in water?
14. Why are iron and manganese undesirable in drinking water?
15. Why is the absence of tastes and odors in drinking water important?
16. Why are high levels of total dissolved solids undesirable in drinking water?
17. Why wasn't hydrogen sulfide listed under the Secondary Drinking Water Standards?
18. How is the number of sampling points determined?
19. What are the major considerations in determining the number and location of sampling points?
20. How is a sampling route selected?
21. How can samples be preserved?

SUGGESTED ANSWERS

Chapter 22. DRINKING WATER REGULATIONS

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 496.

22.0A The first drinking water standards were designed to control waterborne bacteria and viruses that can cause diseases such as cholera, typhoid, and dysentery.

22.1A The major aspects of the 1986 Amendments to the SDWA include:

1. Compulsory revisions to the regulations for new contaminants,
2. Definition of an approved treatment technique for each regulated contaminant,
3. Filtration requirement for surface water supplies,
4. Disinfection of all water supplies, and
5. Prohibition of the use of lead products in materials used to convey drinking water.

22.1B Water systems will not be required to meet Phase I regulations until two-and-a-half years after the law was passed because the Act requires promulgation of regulations within 12 months and an additional 18 months must be given for the states to adjust their own regulations.

Answers to questions on page 498.

22.2A Trihalomethanes (THMs) are the product of chlorine combining with organic material in the water; they are suspected carcinogens.

22.3A The draft Surface Water Treatment Rule (SWTR) specifically requires that

1. All surface water systems must disinfect,

2. All surface water systems must filter unless they meet source water quality criteria and site-specific conditions,
3. All systems will need to achieve the removal or inactivation criteria of Giardia and enteric viruses, and
4. Only qualified operators will be entitled to operate the systems.

22.3B A water utility can avoid mandatory filtration by meeting (1) source water quality criteria (coliforms and turbidity levels), and (2) certain site-specific conditions regarding disinfection, watershed control, lack of waterborne disease outbreaks, compliance with coliform MCL, and total THM MCL.

Answers to questions on page 500.

22.4A A community water system is defined as follows:

1. Has at least 15 service connections used by all-year residents, or
2. Services at least 25 all-year residents.

22.5A The five types of primary contaminants which are considered to be of public health importance are:

1. Inorganic contaminants,
2. Organic contaminants,
3. Turbidity,
4. Microbiological contaminants, and
5. Radiological contaminants.

22.5B Nitrate in drinking water above the national standard poses an immediate threat to children under three months of age. In some infants, excessive levels of nitrate have been known to react with intestinal bacteria which change nitrate to nitrite which reacts with hemoglobin in the blood to produce an anemic condition commonly known as "blue baby."

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 504.

22.6A Inorganic chemicals are metals, salts, and other chemical compounds that do not contain carbon.

22.6B Arsenic is listed as a primary contaminant because water that continuously exceeds the national standard by a substantial amount over a lifetime may cause fatigue and loss of energy. Extremely high levels can cause poisoning.

22.6C At levels of 6 to 8 mg/*L* fluoride may cause skeletal fluorosis which is a brittling of the bones and stiffening of the joints. At levels of 2 mg/*L* and greater fluoride may cause dental fluorosis which is discoloration and mottling of the teeth, especially in children.

22.6D Lead may enter drinking water from galvanized pipes, solder used with copper pipes, and through the air from auto exhausts.

Answers to questions on page 505.

22.6E Organic chemicals are either natural or synthetic chemical compounds that contain carbon. Synthetic organic chemicals (SOCs) are man-made compounds that are widely used as pesticides, paints, dyes, solvents, plastics, and food additives.

22.6F Trichloroethylene (TCE) has been widely used as an ingredient in many household products (spot removers, rug cleaners, air fresheners), dry cleaning agents, industrial metal cleaners and polishes, refrigerants, and even anesthetics.

22.6G The monthly average turbidity MCL may not exceed 1 TU. At state option this may be raised to 5 TU. Some states require 0.5 TU where there is a major hazard of wastewater (sewage) contamination of the water supply.

Answers to questions on page 508.

22.6H EPA is considering the creation of MCLs for Giardia, viruses, standard plate count, and *Legionella.*

22.6I For water systems that regularly take 10 or fewer samples per month, *ONE* positive sample may be discarded if:

1. The system chlorinates and maintains a residual,
2. The system takes two check samples on consecutive days, and
3. This exclusion has NOT been used in the previous month.

22.6J The MCLs for radiological contaminants are divided into two categories: (1) natural radioactivity which results from well water passing through deposits of naturally occurring radioactive materials; and (2) man-made radioactivity such as might result from industrial wastes, hospitals or research laboratories.

Answers to questions on page 509.

22.7A Secondary drinking water regulations are enforceable after a state has passed a law requiring the state health agency to enforce the regulations.

22.7B The secondary drinking water contaminants include:

1. Chloride
2. Color
3. Copper
4. Corrosivity
5. Foaming Agents
6. Fluoride
7. Iron
8. Manganese
9. Odor
10. pH
11. Sulfate
12. Total Dissolved Solids
13. Zinc

22.7C Contaminants in the secondary regulations should be monitored at intervals no less frequent than the monitoring performed for inorganic contaminants listed in the Interim Primary Drinking Water Regulations or applicable to community water systems. More frequent monitoring would be appropriate for specific contaminants such as pH, color, odor or others under certain circumstances as directed by the state.

Answers to questions on page 511.

22.7D Chloride is a secondary contaminant because it affects the aesthetic quality of water by imparting an objectionable salty taste in water and because it causes corrosion of the pipes in hot water and other systems.

22.7E Copper usually gets into drinking water from the reaction of aggressive water on copper plumbing.

22.7F Reasons why corrosive waters are undesirable as drinking water include:

1. Affects the aesthetic quality (turbid waters), and causes taste and odor problems in the water supply;
2. Has serious economic impact (loss of piping systems and water loss from leaks); and
3. Presents health implications (toxic corrosion products such as lead, cadmium and copper).

22.7G The application of chlorine to waters containing manganese increases the likelihood of precipitation at low levels. Unless the precipitate is removed, precipitates reaching pipelines will promote bacterial growth.

Answers to questions on page 513.

22.7H The undesirable effects of abnormal pH values include:

1. When the pH increases, the disinfection activity of chlorine falls significantly;
2. High pH may cause increased halogen reactions, which produce chloroform and other trihalomethanes during chlorination;
3. Both excessively high and low pHs may cause increased corrosivity which can in turn create taste problems, staining problems, and significant health hazards;
4. Metallic piping in contact with low pH water will impart a metallic taste;
5. If piping is iron or copper, oxide and carbonate compounds will be deposited leaving red or green stains;
6. At high pH, drinking water acquires a bitter taste, and
7. The high degree of mineralization often associated with basic waters results in encrustation of water pipes and water-using appliances.

22.7I High levels of sulfate are undesirable because they:

1. Tend to form hard scales in boilers and heat exchangers,
2. Cause taste effects, and
3. Cause a laxative effect.

22.7J High levels of zinc are undesirable in drinking water because they:

1. Produce adverse physiological effects,
2. Impart undesirable tastes,
3. Cause a milky appearance in the water, and
4. May increase lead and cadmium concentrations.

Answers to questions on page 514.

22.8A "Initial Sampling" refers to the very first sampling you do under the Safe Drinking Water Act for each of the applicable contaminant categories.

22.8B Routine sampling refers to sampling repeated on a regular basis.

22.8C Whenever an initial or routine sample analysis indicates that an MCL has been exceeded, *CHECK SAMPLING* is required to confirm the routine sampling results. Check sampling is in addition to the routine sampling program.

22.8D At the very minimum, a small system with a population of 100 people must sample for turbidity and coliform bacteria and also must have two sampling points.

1. One where the water enters the distribution system, and
2. One at a consumer faucet at a point representative of the distribution system.

Answers to questions on page 515.

22.8E Information that should be specified in a sampling program includes:

1. Sampling frequency,
2. Sampling point designation,
3. Location,
4. Type of test,
5. Sample volume, and
6. Special handling instructions.

22.8F The following elements are necessary to the collection of an acceptable sample:

1. Obtain a sample that is truly representative of the existing condition,
2. Flush the line before sample collection,
3. Fill the sample bottle without leaving any air pocket,
4. Analyze residual chlorine when the sample is taken,
5. Maintain the sample so that it does not become contaminated before it reaches the laboratory,
6. Use preservation techniques (pH control and refrigeration),
7. Keep accurate records of every sample collected (date, time, location, name of sample, bottle number, type of sample, and name of person collecting sample), and
8. Keep the time between the collection of the sample and analysis as short as possible.

Answers to questions on page 527.

22.9A The two general categories of reporting called for by the SDWA are:

1. Reporting to the public (public notification), and
2. Reporting to the state.

22.9B The three types of reports that must be sent to the state are:

1. Routine sample reports,
2. Check sample reports, and
3. Violation reports.

22.10A Required public notification for the violation of an MCL includes mail, newspaper and broadcast.

OBJECTIVE TEST

Chapter 22. DRINKING WATER REGULATIONS

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. All public water systems must comply with the regulations of the Safe Drinking Water Act
   1. True
   2. False
2. MCLs apply only to contaminants from man-made pollution.
   1. True
   2. False
3. More types of contaminants must be monitored by noncommunity than community systems.
   1. True
   2. False
4. MCLs have been established to indicate when a coliform concentration could indicate the likely presence of disease-causing bacteria.
   1. True
   2. False
5. Monitoring for natural radioactivity is required only for groundwater community systems.
   1. True
   2. False
6. The concerns with inorganic chemicals in drinking water are centered on cancer.
   1. True
   2. False
7. Coliform bacteria in water are used to indicate the potential presence of pathogens
   1. True
   2. False
8. Barium can enter drinking water through natural sources in the environment or industrial waste discharges
   1. True
   2. False
9. The health risk from mercury is greater from waterborne mercury than simply from eating fish.
   1. True
   2. False
10. Secondary drinking water regulations are federally enforceable
    1. True
    2. False
11. Major taste effects in water are produced by cations.
    1. True
    2. False
12. The level of color in water is a measure of the safety of water
    1. True
    2. False
13. Rapid changes in color levels may produce more citizen complaints than relatively high, constant color levels.
    1. True
    2. False
14. EPA drinking water regulations are called "interim" regulations because research continues on drinking water contaminants.
    1. True
    2. False
15. Taste tests are less fatiguing than odor tests.
    1. True
    2. False
16. If a water doesn't have any taste or odor, then it is safe to drink
    1. True
    2. False
17. Consumers can tolerate a wide range of pH values in drinking water
    1. True
    2. False
18. At low pH levels drinking water acquires a bitter taste.
    1. True
    2. False
19. Samples should be collected from consumers' faucets which are representative of conditions within the distribution system.
    1. True
    2. False
20. Check sampling is part of the routine sampling program.
    1. True
    2. False
21. When samples are delivered to the lab, lab personnel must complete the field data forms upon acceptance of the samples.
    1. True
    2. False
22. The primary purpose of the Safe Drinking Water Act is to protect the public's health.
    1. True
    2. False

23 Sampling points must include representative locations of each different water source entering the system

1. True
2 False

24 Sample lines should be flushed before collecting a sample

1. True
2 False

25 Failure to comply with a testing procedure requires notification of consumers by newspaper

1 True
2 False

MULTIPLE CHOICE

26. The regulations of the Safe Drinking Water Act which operators must deal with extensively include

1 Maximum Contaminant Levels.
2. Reporting requirements.
3. Sampling and testing requirements.
4. Siting requirements.
5. Variations in the regulations.

27 Types of primary contaminants which are considered to be of public health importance include

1. Corrosivity contaminants.
2. Foaming contaminants.
3. Inorganic contaminants.
4. Microbiological contaminants.
5 Turbidity

28. Contaminants which may affect public health after a short-term exposure include

1. Microbiological contaminants.
2. Nitrate.
3 Organic chemicals.
4. Radiological chemicals.
5. Trihalomethanes.

The MCLs for organic chemicals presently include

1. Herbicides.
2. Oils.
3 Pesticides.
4. Solvents.
5 Trihalomethanes.

30. The MCL established for total trihalomethanes (TTHMs) is

1. 0.1 micrograms per liter.
2. 1.0 microgram per liter.
3. 0.10 milligrams per liter.
4. 1.0 milligram per liter.
5. 10 milligrams per liter.

31. A state may allow a water utility to reduce the frequency of sampling for THMs after taking into consideration

1. Age of persons living in community.
2. Health of community.
3. Level of natural organics in water.
4. Quality and stability of raw water.
5. Type of treatment.

32. The Safe Drinking Water Act gave the U.S. Environmental Protection Agency the authority to

1. Establish uniform guidelines of drinking water technologies.
2. Issue NPDES permits to water purveyors.
3. Promulgate pretreatment effluent standards for POTWs.
4. Require monitoring and reporting for public water systems.
5. Set national standards for regulating levels of contaminants in drinking water.

33. The draft Surface Water Treatment Rule (SWTR) requires that a disinfection residual of ______ mg/*L* in 95 percent of the samples be maintained.

1. 0.2
2. 0.5
3. 1.0
4. 2.0
5. 5.0

34. Substances for which drinking water standards have been set and which pose an immediate threat to health whenever the standards are exceeded include

1. Arsenic.
2. Coliform bacteria.
3. Lead.
4. Mercury.
5. Nitrate.

35. Arsenic is commonly found in

1. Beverages.
2. Candy.
3. Food.
4. Shellfish.
5. Tobacco.

36. Cadmium can enter drinking water from

1. Canneries.
2. Electroplating.
3. Insecticides.
4. Metallurgy
5. Photographic processes.

37. Water with a high color content may indicate

1 High disinfection demand.
2 High organic chemical contamination.
3. High pH.
4. Inadequate treatment.
5. Potential for production of excess amounts of disinfection by-products.

38. Reasons why copper is undesirable in drinking water include

1. Causes blue or green staining of porcelain.
2. Imparts some taste to water.
3. Kills algae.
4. Results in liver damage after prolonged doses.
5. Stains blond hair.

39. True taste sensations include
    1. Bitter.
    2. Rotten.
    3. Salty
    4 Sour.
    5. Sweet.

40. Undesirable effects from high levels of sulfate in drinking water include causing
    1. Formation of hard scales in boilers and heat exchangers.
    2. Laxative effects.
    3. Precipitation of calcium sulfate.
    4. Taste effects.
    5. Undesirable odors in water.

41 High levels of total dissolved solids are undesirable in drinking water because they cause
    1. Adverse tastes.
    2 Deterioration of distribution systems.
    3. Precipitates to form in boilers.
    4. Sludge in freezing processes
    5. Water to be reused more often.

42. Which of the following actions are required of operators by the Safe Drinking Water Act?
    1. Organizing
    2. Recordkeeping
    3. Reporting
    4. Sampling
    5. Testing

43. When you start and when you finish your "Initial Sampling" program depends on
    1. Available budget.
    2. Option exercised by state.
    3. Type of contaminant being monitored.
    4. Whether the system is a community or non-community water system.
    5. Whether the water source is a surface or a groundwater supply.

44. Samples should be collected at the consumers' faucet for which of the following contaminants?
    1. Coliform bacteria
    2 Inorganics
    3. Organics
    4. Radiochemicals
    5. Turbidity

45. Community systems must sample for radiochemicals every
    1. Six months.
    2 Year.
    3 Two years.
    4. Three years.
    5 Four years.

46. To collect an acceptable sample you must
    1. Flush the line before sample collection.
    2. Keep the time between sample collection and analysis as long as possible.
    3. Obtain a sample truly representative of the existing condition.
    4. Use preservation techniques.
    5. Use the proper reporting form.

End of Objective Test

APPENDIX

Coliform Samples Required Per Population Served

Population Served	Minimum Number of Samples per Month
25 to 1,000	1†
1,001 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 9,400	10
9,401 to 10,300	11
10,301 to 11,100	12
11,101 to 12,000	13
12,001 to 12,900	14
12,901 to 13,700	15
13,701 to 14,600	16
14,601 to 15,500	17
15,501 to 16,300	18
16,301 to 17,200	19
17,201 to 18,100	20
18,101 to 18,900	21
18,901 to 19,800	22
19,801 to 20,700	23
20,701 to 21,500	24
21,501 to 22,300	25
22,301 to 23,200	26
23,201 to 24,000	27
24,001 to 24,900	28
24,901 to 25,000	29
25,001 to 28,000	30
28,001 to 33,000	35
33,001 to 37,000	40
37,001 to 41,000	45
41,001 to 46,000	50
46,001 to 50,000	55
50,001 to 54,000	60
54,001 to 59,000	65
59,001 to 64,000	70
64,001 to 70 000	75
70,001 to 76,000	80
76,001 to 83,000	85
83,001 to 90,000	90
90,001 to 96,000	95
96,001 to 111,000	100
111,001 to 130,000	110
130,001 to 160,000	120
160,001 to 190,000	130
190,001 to 220,000	140
220,001 to 250,000	150
250,001 to 290,000	160
290,001 to 320,000	170
320,001 to 360,000	180
360,001 to 410,000	190
410,001 to 450,000	200
450,001 to 500,000	210
500,001 to 550,000	220
550,001 to 600,000	230
600,001 to 660,000	240
660,001 to 720,000	250
720,001 to 780,000	260
780,001 to 840,000	270
840,001 to 910,000	280
910,001 to 970,000	290
970,001 to 1,050,000	300
1,050,001 to 1,140,000	310
1,140,001 to 1,230,000	320
1,230,001 to 1,320,000	330
1,320,001 to 1,420,000	340
1,420,001 to 1,520,000	350
1,520,001 to 1,630,000	360
1,630,001 to 1,730,000	370
1,730,001 to 1,850,000	380
1,850,001 to 1,970,000	390
1,970,001 to 2,060,000	400
2,060,001 to 2,270,000	410
2,270,001 to 2,510,000	420
2,510,001 to 2,750,000	430
2,750,001 to 3,020,000	440
3,020,001 to 3,320,000	450
3,320,001 to 3,620,000	460
3,620,001 to 3,960,000	470
3,960,001 to 4,310,000	480
4,310,001 to 4,690,000	490
More than 4,690,001	500

Source: EPA

† A community water system serving 25 to 1,000 persons, with written permission from the state, may reduce this sampling frequency, except in no case shall it be reduced to less than one per quarter The decision by the state will be based on a history of no coliform bacterial contamination for that system and on a sanitary survey by the state showing the water system to be supplied solely by a protected groundwater source, free of sanitary defects.

CHAPTER 23

ADMINISTRATION

by
Tim Gannon

Revised
by
Jim Sequeira

TABLE OF CONTENTS

Chapter 23. Administration

OBJECTIVES

Chapter 23. ADMINISTRATION

Following completion of Chapter 23, you should be able to.

1. Organize the general operation, maintenance and administrative activities of a water utility,
2. Explain the importance of and need for operator certification,
3. Develop and implement a public relations program,
4. Prepare a contingency plan for emergencies,
5. Collect, organize, file, retrieve, use and dispose of plant records, and
6. Successfully operate and maintain the water supply and water treatment facilities of your utility agency.

CHAPTER 23. ADMINISTRATION

Administering the operation and maintenance of a water treatment plant involves more than just the technical aspects of plant operations. Supervision, recordkeeping, emergency planning, public relations, and ordering supplies, for example, are all necessary parts of the overall operation of a water treatment plant facility. Whether an individual is a chief operator or novice, he or she should at least have a general idea of the administrative procedures associated with treatment plant operations.

23.0 OFFICE PROCEDURES

23.00 Budgeting

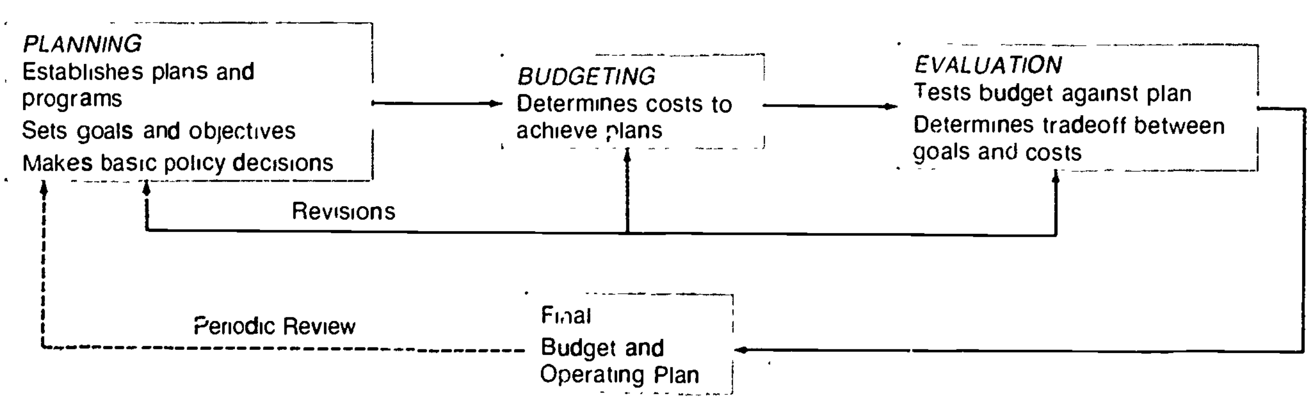
Budgeting is the art of predicting the amount of money necessary to achieve an organization's goals. Preparation of a budget requires effective planning. Planning and budgeting are both essential administrative functions. Planning identifies your goals, and budgeting identifies how much money is needed to achieve these goals.

Planning involves designing programs, setting goals and objectives, and making basic policy decisions for the organization as a whole. Budgeting, on the other hand, involves analyzing the many functions that the organization must perform to implement each program. Table 23.1 illustrates the relationship between planning and budgeting. Notice that a third component, evaluation, is needed to determine whether the goals and plans that have been set are reasonable and achievable in terms of the money available. Ideally, these three components form a dynamic process in which your goals and the budget are periodically reviewed and revised to reflect a realistic assessment of your organization's priorities and financial resources.

In preparing a budget, value judgments must be made about the efficiency of your operations. You should constantly re-evaluate your operating procedures to consider more efficient use of personnel and materials. When making these value judgments, examine how better operating results can be attained through more efficient operating procedures. In examining personnel requirements, determine if personnel could be reassigned to perform more tasks more efficiently. Look for ways to reduce the expenses for power and fuel. All phases of your operation and maintenance should be carefully examined to prepare an accurate and realistic budget. Failure to do so will generally result in waste and inefficiency. Preparation of the budget should not be viewed as a paper exercise but as a means of achieving specified goals, improving performance standards, and raising the quality of services to your community.

Budget preparation should be a group project and effort. Preparing a budget with staff involvement will create an

TABLE 23.1 PLANNING AND BUDGETING RELATIONSHIP



atmosphere of interest and a feeling of active participation in one of the most important annual activities of a water utility. Staff personnel can actively participate in the budget process by providing information on operating requirements. Moreover, new programs, positions, and equipment that are contemplated should be thoroughly researched and justified by staff to facilitate the budgetary process.

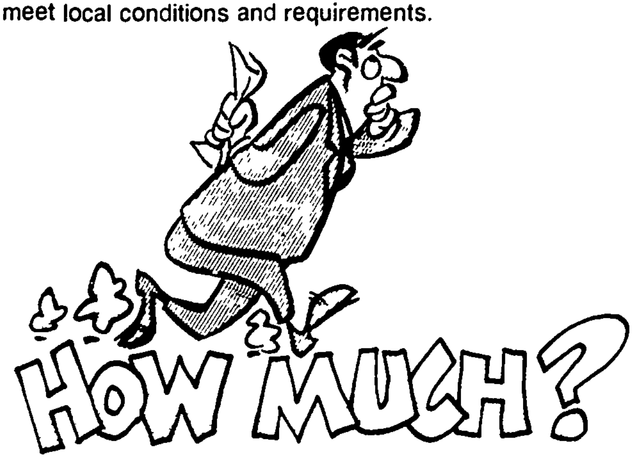
For large and small utilities alike, the amount of anticipated income is also an important factor in budgeting. Using the previous year's budget and actual income for that year can give you a good idea of what program increases might be feasible for the future.

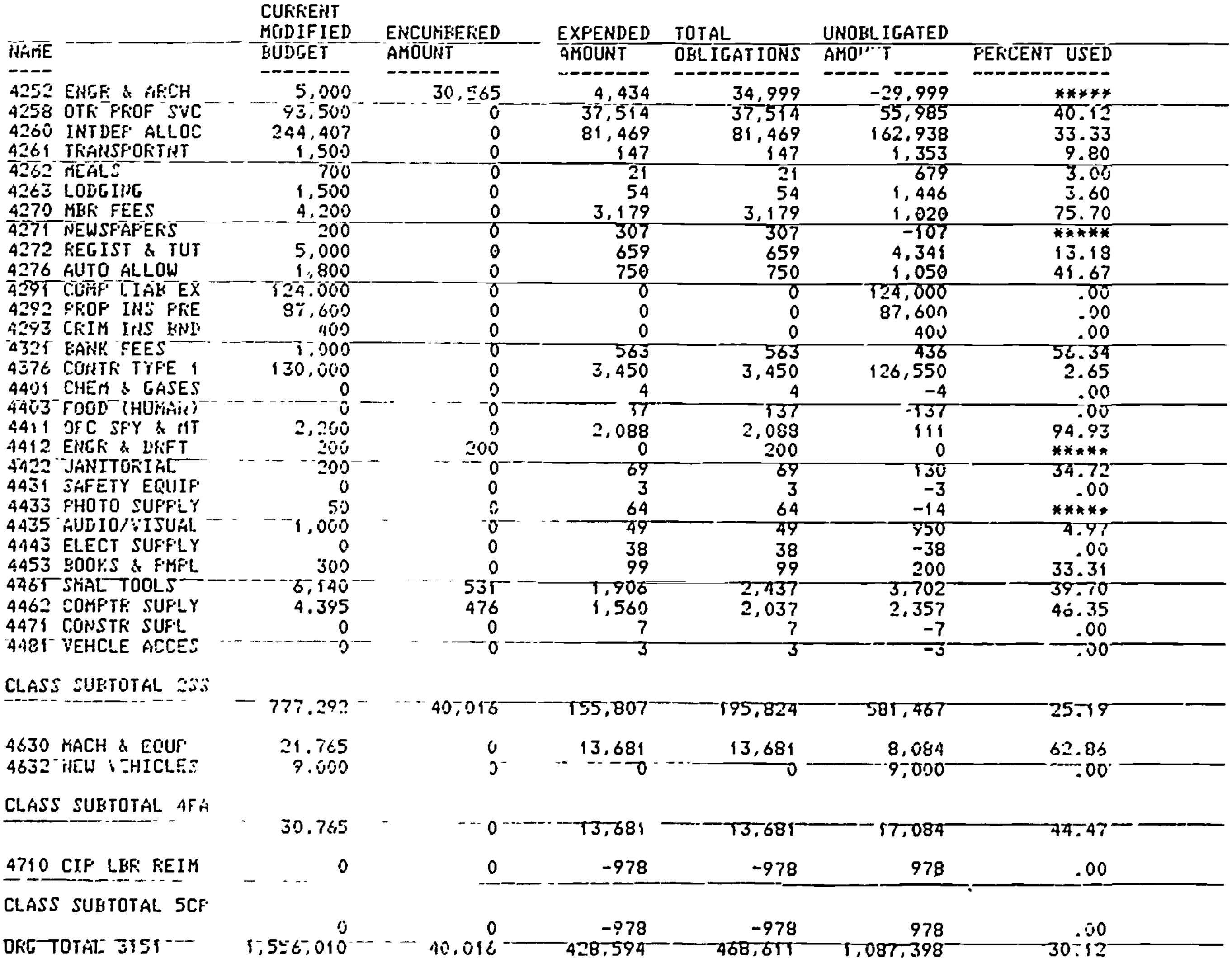
After the budget is approved, it should be reviewed by staff members who have budget-related responsibilities to give them a clear understanding of the organization's financial constraints for the upcoming year.

An excellent tool to help you control and monitor the organization's operations is the monthly budget status report. It is good management practice to compare expenditures with budgeted amounts at frequent regular intervals. Also evaluate your present financial status in terms of the amount of the year that has passed and the pace of expenditures. Figure 23.1 is an example of a budget status report. A prudent administrator will always take care to thoughtfully analyze expenditures so that the budget is not exceeded.

23.01 Water Rates

The process of determining the cost of water and establishing a water rate schedule for customers is a subject of much controversy. There is no single set of rules for determining water rates. The establishment of a rate schedule involves many factors including the form of ownership (investor or publicly owned), differences in regulatory control over the water utility (state commission or local authority), and differences in individual viewpoints and preferences concerning the appropriate philosophy to be followed to meet local conditions and requirements.





NAME	CURRENT MODIFIED BUDGET	ENCUMBERED AMOUNT	EXPENDED AMOUNT	TOTAL OBLIGATIONS	UNOBLIGATED AMOUNT	PERCENT USED
4252 ENGR & ARCH	5,000	30,565	4,434	34,999	-29,999	*****
4258 OTR PROF SVC	93,500	0	37,514	37,514	55,985	40.12
4260 INTDEP ALLOC	244,407	0	81,469	81,469	162,938	33.33
4261 TRANSPORTNT	1,500	0	147	147	1,353	9.80
4262 MEALS	700	0	21	21	679	3.00
4263 LODGING	1,500	0	54	54	1,446	3.60
4270 MBR FEES	4,200	0	3,179	3,179	1,020	75.70
4271 NEWSPAPERS	200	0	307	307	-107	*****
4272 REGIST & TUT	5,000	0	659	659	4,341	13.18
4276 AUTO ALLOW	1,800	0	750	750	1,050	41.67
4291 COMP LIAB EX	124.000	0	0	0	124,000	.00
4292 PROP INS PRE	87,600	0	0	0	87,600	.00
4293 CRIM INS BND	400	0	0	0	400	.00
4321 BANK FEES	1,000	0	563	563	436	56.34
4376 CONTR TYPE 1	130,000	0	3,450	3,450	126,550	2.65
4401 CHEM & GASES	0	0	4	4	-4	.00
4403 FOOD (HUMAN)	0	0	137	137	-137	.00
4411 OFC SPY & MT	2,200	0	2,088	2,088	111	94.93
4412 ENGR & DRFT	200	200	0	200	0	*****
4422 JANITORIAL	200	0	69	69	130	34.72
4431 SAFETY EQUIP	0	0	3	3	-3	.00
4433 PHOTO SUPPLY	50	0	64	64	-14	*****
4435 AUDIO/VISUAL	1,000	0	49	49	950	4.97
4443 ELECT SUPPLY	0	0	38	38	-38	.00
4453 BOOKS & PMPL	300	0	99	99	200	33.31
4461 SMAL TOOLS	6,140	531	1,906	2,437	3,702	39.70
4462 COMPTR SUPLY	4.395	476	1,560	2,037	2,357	46.35
4471 CONSTR SUPL	0	0	7	7	-7	.00
4481 VEHCLE ACCES	0	0	3	3	-3	.00
CLASS SUBTOTAL 2SS						
	777,292	40,016	155,807	195,824	581,467	25.19
4630 MACH & EQUP	21.765	0	13,681	13,681	8,084	62.86
4632 NEW VEHICLES	9.000	0	0	0	9,000	.00
CLASS SUBTOTAL 4FA						
	30.765	0	13,681	13,681	17,084	44.47
4710 CIP LBR REIM	0	0	-978	-978	978	.00
CLASS SUBTOTAL 5CP						
	0	0	-978	-978	978	.00
ORG TOTAL 3151	1,556,010	40,016	428,594	468,611	1,087,398	30.12

Fig. 23.1 Budget status report

Generally, the development of water rate schedules involves the following procedures:

- A determination of the total revenue requirements for the period that the rates are to be effective (usually one year).
- A determination of all the cost components of system operations. That is, how much does it cost to treat the water? How much does it cost to distribute? How much does it cost to install a water service to a customer? How much are administrative costs?
- Distribution of the various component costs to the various customer classes in accordance with their requirements for service.
- The design of water rates that will recover from each class of customers, within practical limits, the cost to serve that class of customers.

Sales of water to customers may be metered or unmetered. In the case of metered sales, the charge to the customer is based on a rate schedule applied to the amount of water used through each water meter. If meters are not used, the charge per customer is based on a flat rate per period of time per fixture, foot of frontage, number of rooms, or other measurable unit. Although the flat rate basis still is fairly common, meter-based rates are more widely used.

See *SMALL WATER SYSTEM OPERATION AND MAINTENANCE*, Chapter 8, "Setting Water Rates for Small Water Utilities," for an explanation and examples of how to determine and set water rates. This publication is available from Ken Kerri, Office of Water Programs, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819. Price, $20.00.

23.02 Procurement of Material

Ordering repair parts and supplies usually is done when the on-hand quantity of a stocked part or chemical falls below the reorder point, a new item is added to stock, or an item has been requested that is not stocked. Most organizations require employees to submit a requisition (similar to the one shown in Figure 23.2) when they need to purchase equipment or supplies. When the requisition has been approved by the authorized person (a supervisor or purchasing agent, in most cases) the items are ordered using a form called a purchase order. A purchase order contains a number of important items. These items include: (1) the date, (2) a complete description of each item and quantity needed, (3) prices, (4) the name of the vendor, and (5) a purchase order number.

A copy of the purchase order should be retained in a suspense file or on a clipboard until the ordered items arrive. This procedure helps keep track of the items that have been ordered but have not yet been received.

All supplies should be processed through the storeroom immediately upon arrival. When an item is received it should be so recorded on an inventory card. The inventory card will keep track of the numbers of an item in stock, when last ordered, cost, and other information. Furthermore, by always logging in supplies immediately upon receipt, you are in a position to reject defective or damaged shipments and control shortages or errors in billing. Some utilities use personal computers to keep track of orders and deliveries.

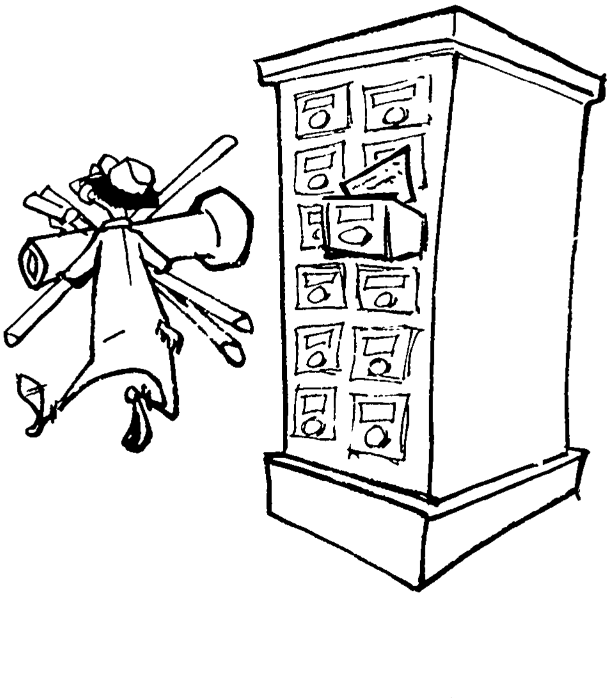
QUESTIONS

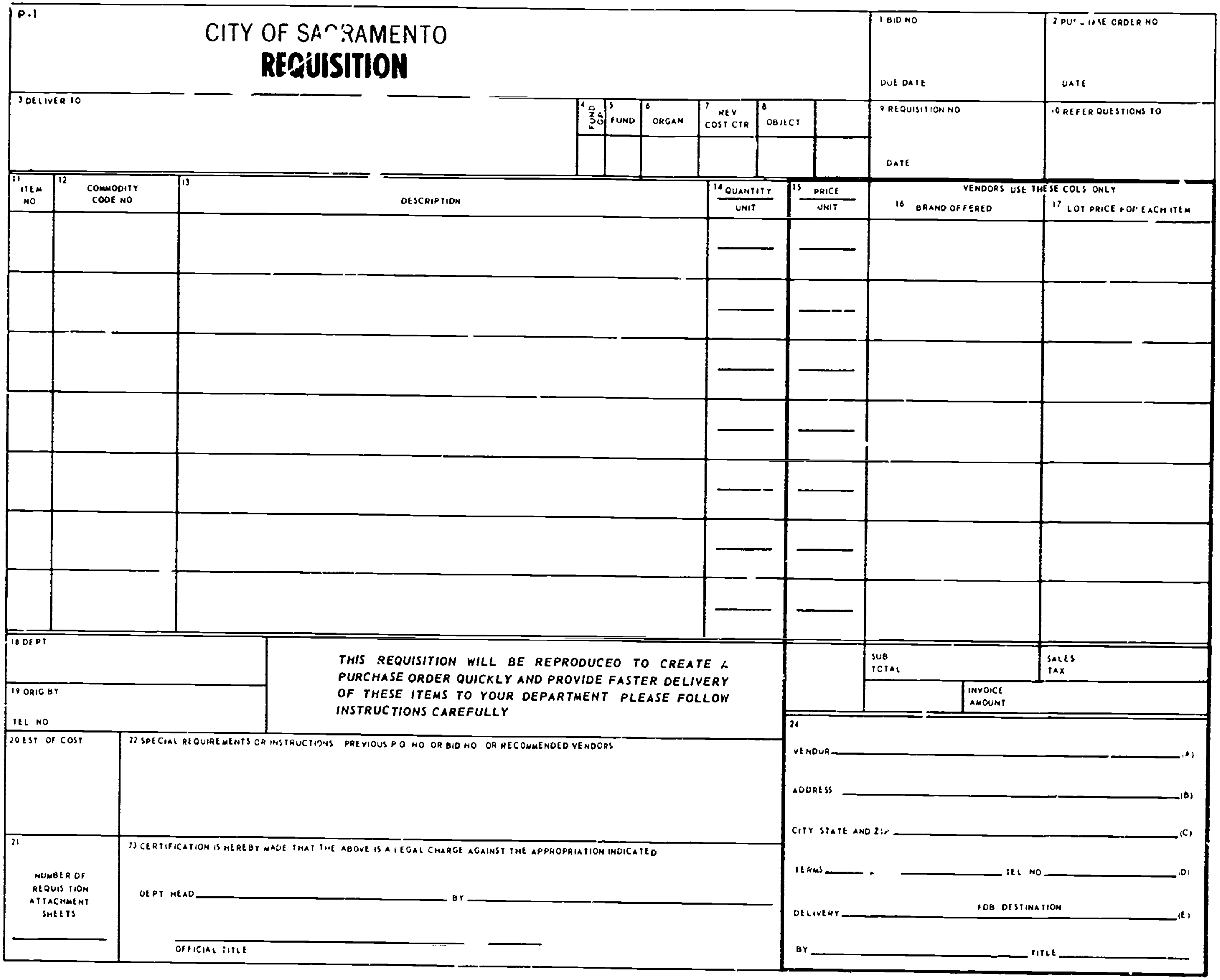
Write your answers in a notebook and then compare your answers with those on page 557.

23.0A What is budgeting?

23.0B How can waste and inefficiency be reduced or eliminated?

23.0C List the important items usually contained on a purchase order.





P-1

CITY OF SACRAMENTO

REQUISITION

1 BID NO

DUE DATE

2 PURCHASE ORDER NO

DATE

3 DELIVER TO

4 FUND GP	5 FUND	6 ORGAN	7 REV COST CTR	8 OBJECT	

9 REQUISITION NO

DATE

10 REFER QUESTIONS TO

11 ITEM NO	12 COMMODITY CODE NO	13 DESCRIPTION	14 QUANTITY UNIT	15 PRICE UNIT	16 BRAND OFFERED (VENDORS USE THESE COLS ONLY)	17 LOT PRICE FOR EACH ITEM (VENDORS USE THESE COLS ONLY)

18 DEPT

19 ORIG BY

TEL NO

THIS REQUISITION WILL BE REPRODUCED TO CREATE A PURCHASE ORDER QUICKLY AND PROVIDE FASTER DELIVERY OF THESE ITEMS TO YOUR DEPARTMENT PLEASE FOLLOW INSTRUCTIONS CAREFULLY

SUB TOTAL

SALES TAX

INVOICE AMOUNT

20 EST OF COST

22 SPECIAL REQUIREMENTS OR INSTRUCTIONS PREVIOUS P O NO OR BID NO OR RECOMMENDED VENDORS

21 NUMBER OF REQUISITION ATTACHMENT SHEETS

23 CERTIFICATION IS HEREBY MADE THAT THE ABOVE IS A LEGAL CHARGE AGAINST THE APPROPRIATION INDICATED

DEPT HEAD ______ BY ______

OFFICIAL TITLE

24

VENDOR ______ (A)

ADDRESS ______ (B)

CITY STATE AND ZIP ______ (C)

TERMS ______ TEL NO ______ (D)

DELIVERY ______ FOB DESTINATION (E)

BY ______ TITLE ______

Fig 23.2 Purchase order form

23.03 Treatment Plant Records

23.030 *Purpose of Records*

Accurate records are a very important part of effective operation of a water treatment plant and distribution system facilities. Records are a valuable source of information. They can save time when trouble develops and provide proof that problems were identified and solved. Pertinent and complete records should be used as a basis for plant operation, interpreting results of water treatment, preparing preventive maintenance programs and preparation of budget requests. When accurately kept, records provide an essential basis for design of future changes or expansions of the treatment plant, and also can be used to aid in the design of other water treatment plants where similar water may be treated and similar problems may develop.

If legal questions or problems occur in connection with the treatment of the water or the operation of the plant accurate and complete records will provide evidence of what actually occurred and what procedures were followed.

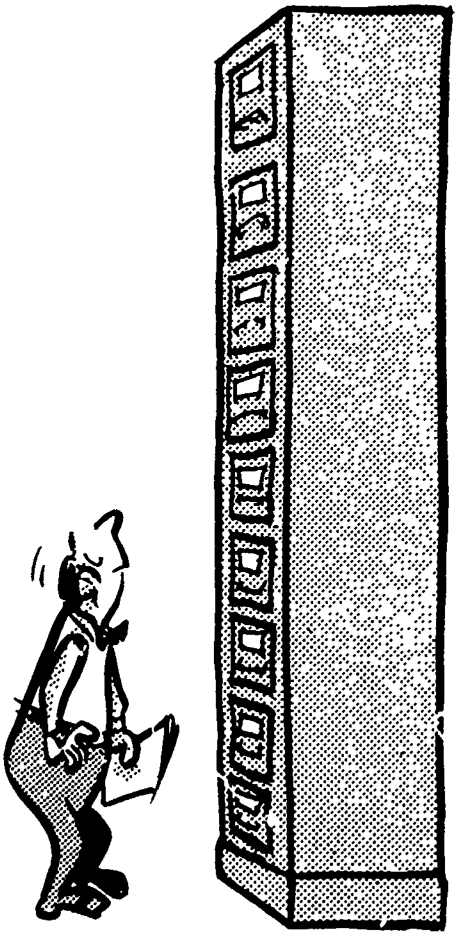
Records are essential for effective management of water treatment facilities and to satisfy legal requirements. Some of the important uses of records include:

1. Aiding operators in solving treatment and water quality problems
2. Providing a method of alerting operators to changes in source-water quality,
3. Showing that the treated water is acceptable to the consumer,
4. Documenting that the final product meets plant performance standards, as well as the standards of the regulatory agencies,
5. Determing performance of treatment processes, equipment, and the plant,
6. Satisfying legal requirements,
7. [illegible]ng in answering complaints,
8. Anticipating routine maintenance,
9. Providing data for cost analysis and preparation of budgets,
10. Providing data for future engineering designs, and
11. Providing information for monthly and annual reports.

23.031 *Types of Records*

There are many different types of records that are required for effective management and operation of water supply, treatment and distribution system facilities. Below is a listing of some essential records:

1. Source of supply,
2. Operation,
3. Laboratory,
4. Maintenance,
5. Chemical inventory and usage,
6. Purchases,
7. Chlorination station,
8. Main disinfection,
9. Cross-connection control,
10. Personnel,
11. Accidents, and
12. Customer complaints.



23.032 Types of Plant Operations Data[1]

Plant operations logs can be as different as the plants and water systems whose information they record. The differences in amount, nature, and format of data are so significant that any attempt to prepare a "typical" log would be very difficult. This section will outline the kinds of data that are usually required to help you develop a useful log for your facilities.

Treatment plant data such as total flows, chemical use, chemical doses, filter performance, reservoir levels, quality control tests, and rainfall and runoff information represent the bulk of the data required for proper plant operation. Frequently, however, source and distribution system data such as reservoir storage and water quality data are included because of the impact of this information on plant operation and operator responsibilities. Typical plant operations data include:

1. Plant title, agency and location;
2. Date,
3. Names of operators and supervisors on duty;
4. Source of supply,
   a. Reservoir elevation and volume of storage,
   b. Reservoir inflow and outflow,
   c. Evaporation and precipitation,
   d. Apparent runoff, seepage loss, or infiltration gain, and
   e. Production figures from wells;
5. Water treatment plant,
   a. Plant inflow,
   b. Treated water flow,
   c. Plant operating water (backwash), and
   d. Clear well level;
6. Distribution system,
   a. Flows to system (system demand),
   b. Distribution system reservoir levels and changes, and
   c. Comparison of production with deliveries (unaccounted for water),
7. Chemical inventory and usage,
   a. Chemical inventory/storage (measured use and deliveries),
   b. Metered or estimated plant usages, and
   c. Calculated usage of chemicals (compare with actual use);
8. Quality control tests,
   a. Turbidity,
   b. Chlorine residual,
   c. Coliforms,
   d. Odor,
   e. Color, and
   f Other;
9. Filter performance,
   a. Operation,
      (1) Total hours, all units,
      (2) Filtered water turbidities,
      (3) Head losses,
      (4) Levels, and
      (5) Flow rates;
   b Backwash,
      (1) Total hours,
      (2) Head losses,
      (3) Total washwater used, and
      (4) Duration and rate of back/surface wash,
10. Meteorologic,
    a Rainfall, evaporation, and temperature of both water and air, and
    b. Weather (clear, cloudy, windy);
11. Remarks
    Space should be provided to describe or explain unusual data or events. Extensive notes should be entered on a daily worksheet or diary.

23.033 Maintenance Records

A good plant maintenance effort depends heavily upon good recordkeeping. There are several areas where proper records and documentation can definitely improve overall plant performance.

23.034 Inventory Records

An inventory consists of the supplies the treatment plant needs to keep on hand to operate the facility. These maintenance supplies may include repair parts, spare valves, electrical supplies, tools, and lubricants. The purpose of maintaining an inventory is to provide needed parts and supplies quickly, thereby reducing equipment downtime and work delays.

In deciding what supplies to stock, keep in mind the economics involved in buying and stocking an item as opposed to depending upon outside availability to provide needed supplies. Is the item critical to continued plant or process operation? Should certain frequently used repair parts be kept on-hand? Does the item have a shelf-life?

Inventory costs can be held to a minimum by keeping on hand only those parts and supplies for which a definite need exists or which would take too long to obtain from an outside vendor. A "definite need" for an item is usually demonstrated by a history of regular use. Some items may be infrequently used but may be vital in the event of an emergency; these items should also be stocked. Take care to exclude any parts and supplies that may become obsolete, and do not stock parts for equipment scheduled for replacement.

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[1] *Also see Chapter 10, Plant Operation, Section 10.6, "Operating Records and Reports," for additional details and recordkeeping forms.*

Tools should be inventoried. Tools that are used by operators on a daily basis should be permanently signed out to them. More expensive tools and tools that are only occasionally used, however, should be kept in a storeroom. These tools should be signed out only when needed and signed back in immediately after use.

23.035 Equipment Records

You will need to keep accurate records to monitor the operation and maintenance of plant equipment. Equipment control cards and work orders can be used to:

- Record important equipment data such as make, model, serial number, and date purchased,
- Record maintenance and repair work performed to date,
- Anticipate preventive maintenance needs, and
- Schedule future maintenance work.

23.036 Disposition of Plant Records

Good recordkeeping is very important because records indicate potential problems, adequate operation, and are a good waterworks practice. Usually the only records required by the health agency is the summary of the daily turbidity of the treated surface water as it enters the distribution system. Chlorine residual and bacterial counts are often required. Other records that may also be required include:

1. Total trihalomethane (TTHM) data (frequency of this report is based on the number of people served),
2. The daily log and records of the analyses to control the treatment process may be required when there are chronic treatment problems,
3. Chlorination, constituent removal, and sequestering records may be required from small systems (especially those demonstrating little understanding of the processes), and
4. Records showing the quantity of water from each source in use may be required from systems with sources producing water not meeting state and/or local health department water quality standards.

An important question is how long records should be kept. Records should be kept as long as they may be useful. Some information will become useless after a short time, while other data may be valuable for many years. Data that might be used for future design or expansion should be kept indefinitely. Laboratory data will always be useful and should be kept indefinitely. Regulatory agencies may require you to keep certain water quality analyses (bacteriological test results) and customer complaint records on file for specified time periods (10 years for chemical analyses and bacteriological tests).

Even if old records are not consulted every day, this does not lessen their potential value. For orderly records handling and storage, set up a schedule to periodically review old reviews and to dispose of those records that are no longer needed. A decision can be made when a record is established regarding the time period for which it must be retained.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 557.

23.0D List some of the important uses of records.

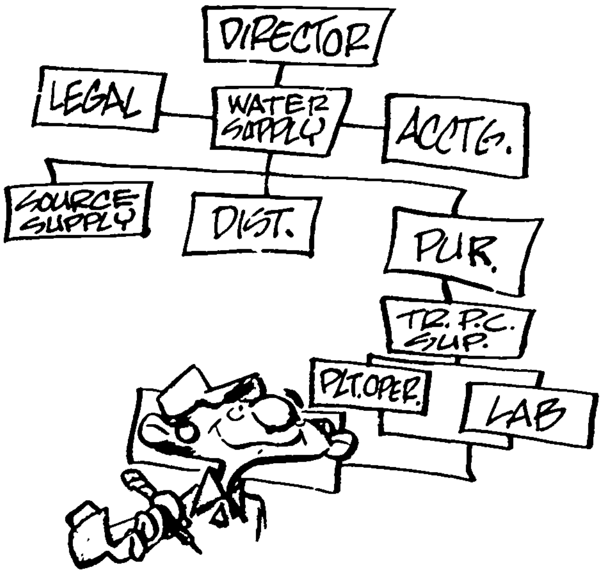
23.0E What is "unaccounted for water?"

23.0F What chemical inventory and usage records should be kept?

23.04 Organizational Planning

A definite plan of organization is essential to effectively operate a water treatment plant. Operators and other personnel need to understand their respective positions and duties in the whole picture of management. Only then can they devote their full time and energy to the effective discharge of their proper functions while avoiding duplication of effort and the confusion, interpersonal friction and working at cross purposes which could result from the lack of a clearcut plan.

The need for a plan applies to both small and large organizations. In fact, a clearly defined organizational structure may be even more important in a small utility since each operator represents a greater percentage of the staff and may perform a wider variety of functions.



There are definite guidelines which are useful in development of such an organizational plan:

1. Organization should be based specifically upon the objectives to be achieved and the activities to be performed,
2. Each person should have only one boss and all direction and guidance should come from that supervisor,
3. The number of supervisory levels above the working level should be kept to a minimum,
4. Each supervisor should have a limited number of people to directly supervise (fewer than 6),
5. Delegation of authority should be as complete as possible with the lowest levels of the work force allowed to make as many decisions as appropriate to that level,
6. The responsibility for performance of each individual should be pre-determined and then made perfectly clear to the individual and the staff, and
7. Lines of management authority must be maintained and not weakened by staff or functional authority.

To establish an organizational plan, you will need a clear understanding of the purposes and relationships of line and staff organizations. Both must be maintained to promote harmony and maximum effectiveness.

The line organization is the chain of command that extends from the manager down to the lowest level of personnel engaged in the actual operation of the utility. This line organization is the framework for directly accomplishing the objectives of the water utility agency or company. The personnel in these positions (Table 23.2) are responsible for meeting the utility's objectives. Without clearly defined objectives, the line organization will find it difficult to function effectively.

The staff organization, on the other hand, is not in the line of command. Staff consists of those positions that exist to provide advice and service to the line personnel to assist them in carrying out their objectives. Secretaries, receptionists, clerks, lawyers, accountants, and purchasing agents are usually considered staff personnel.

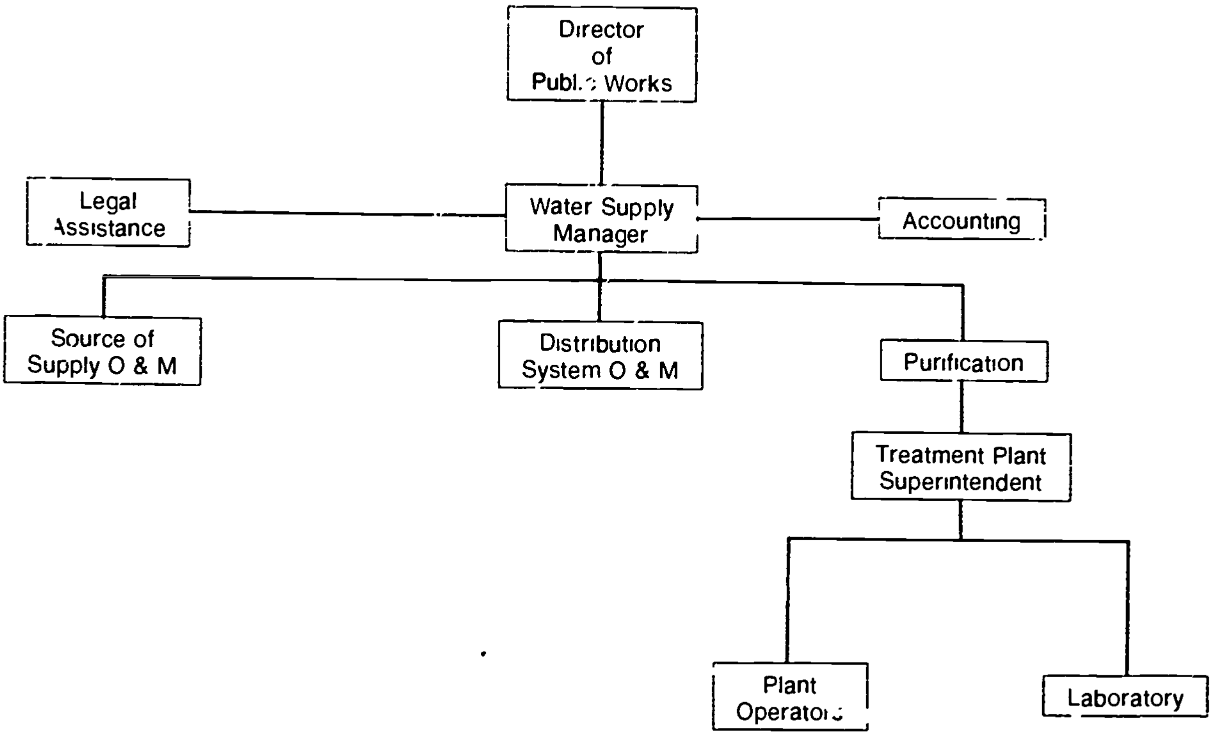
Organizational planning should be reviewed periodically to eliminate weaknesses, strengthen the structure and increase the effectiveness of management. Remember the following points when considering an organizational plan.

1. Organizations may gradually change to meet changing objectives, and must have regular attention if a logical pattern is to be maintained;
2. A good organizational plan is only a tool for helping people work together. The plan cannot provide for successful performance beyond the capabilities of the group;
3. Organizational planning should actively include all levels of the organization;
4. The organizational plan should be published in charts and manuals so that it is known to all personnel;
5. Plans must be tailored to a specific organization and its personnel and rarely can be copied from another utility without some revisions;
6. Good organizational planning can be measured in good operator morale and effectiveness, and also in dollars and cents when unnecessary jobs are eliminated and good performance is encouraged; and
7. A good organizational plan is dynamic and should be capable of changing to meet the abilities of the operators and the objectives of the utility.

The organization should strive to locate weak points and to meet changing requirements. There are several signs which may indicate difficulties, so they should be watched for. The following are some of these signs.

1. Physical, mental and emotional overloading which causes undue fatigue,
2. Indecisiveness in management which delays decision making,
3. Poor teamwork resulting from poor supervisory practices or personal inadequacies of a supervisor, and
4. Failure to train subordinates which causes problems when supervisors are promoted or move on to another job.

TABLE 23.2 EXAMPLE OF AN ORGANIZATION CHART FOR A PUBLICLY OWNED WATER UTILITY



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 557.

23.0G List the guidelines which are useful in development of an organizational plan.

23.0H What is the primary purpose of the staff organization?

23.0I How does management benefit from organizational planning?

23.0J List the signs that may indicate to a water utility potential weak points or approaching organizational problems.

23.1 PERSONNEL ADMINISTRATION

Personnel administration is the "people side" of the administrative process. Effective personnel administration begins with reasonable policies and effective supervisory skills.

23.10 Supervision

If you are responsible for the supervision of other operators, you are responsible for their safety and also their professional development. Your responsibilities may include assigning tasks to specific operators, being sure they understand the assignment and know how to do the job safely, and eventually making sure that the job was done properly. Also as a supervisor you must be able to communicate effectively with your superiors, the operators you supervise and the consumer you serve To be a successful supervisor you should:

1. Know how to do your job and the jobs you expect the operators to do who work for you.
2. Know the abilities, knowledge, skills and limitations of the operators you supervise.
3. Have sufficient technical knowledge and judgment to know when you can safely make necessary technical decisions and when you need to call for the advice of an expert
4. Be able to help train the operators who work for you, both for job improvement and for preparation for advancement in the organization.
5. Be a good representative of your supervisor and your utility agency.
6. Have integrity and be fair and objective in your relations with the operators who work for you,
7. Be cooperative with other people in your organization and the public,
8. Encourage innovation and new ideas,
9. Select the right people for the organization, and
10. Provide objective recognition. Praise people for good performance and relate rewards to performance, not seniority or personal relationships.

When a person becomes a supervisor, a new factor enters the picture—people. Getting other people to do what needs to be done, organizing their work, and motivating them is as much a specialty as any other kind of work a person may have previously done. When individuals move into a supervisory position, they cross an important line. They are no longer judged by what they can do themselves but rather their value depends upon what they get done through others.

Every new supervisor must learn to assign to other people work he can probably do better himself. And as anyone in a supervisory position knows, delegating to others is no simple task; it is easier said than done. Four mistakes that new supervisors often make are:

- They get their fingers into employees' work too often.
- They do a lot of work themselves that employees should be doing.
- They fail to train and coach people so they can do the job as well as the supervisor can.
- They expect too much of those who work for them, especially at first.

23.11 Staffing

Obviously, the most important factors which will influence the size and qualifications of staff required are the number of services and also the size and complexity of the treatment processes and facilities that must be operated and maintained Other important factors might include age and condition of facilities and expected population growth rates.

Several avenues could be taken to determine staffing requirements. There are formulas based on the size and complexity of facilities. Another possibility is to determine staff size based on population served. Perhaps the best approach is to prepare a list of tasks that must be performed, how long it will take to do each task, and the knowledge and skills required to perform the tasks. Analysis of this information will provide an indication of the qualifications and size of staff needed to operate and maintain your facilities

Items that must be considered when developing staffing requirements include the work load, objectives and funds available. The size, condition and complexity of facilities will have a great influence on the work load. Other items that should be considered include how constant is the work load, are there seasonal variations, is your recordkeeping system adequate and up-to date, and are all maintenance activities scheduled as efficiently as possible. Today in many areas population growth is a fact of life. Plans must be made for staff and facilities to be capable of providing sufficient potable water and distribution system pressures as growth occurs Records that substantiate efficient use of existing staff, productivity of staff, and a positive need for future staff are most helpful.

Important questions to be answered in relation to staffing are "What are your objectives?" and "What level of maintenance do you plan for your facilities?" A typical objective might be to deliver potable water at adequate pressures to consumers at the lowest possible cost year after year. Once you have identified your objectives and determined how well they are being met now, you can decide how to do a better job and the staffing needed to accomplish your objectives. During budget hearings you can present graphs or charts showing how you are doing and what you could accomplish with a better trained and/or larger staff.

Available funding is another important factor that must be faced when acquiring the staff you need to operate and maintain your facilities. Whatever objectives you may develop, or however extensive an operation and maintenance program you devise, you will probably be restricted, to some degree, by the amount of funds available.

Fortunately, the amount of funds available does not have to be the sole determining factor in the implementation of your desired operation and maintenance programs. Hopefully, in this course, you have learned the value of good records. As an indicator of the existing condition of your facilities, and as proof of cost-effective improvement, records can justify additional funding when it is warranted.

23.12 Training

A prime responsibility of every supervisor is to see that all operators are properly trained to recognize all hazards and to effectively accomplish the tasks they are assigned. Supervisors must motivate operators to use safe procedures. This section lists and describes possible sources and types of training available for operators.

1. On the job. Much of the training offered or given in the past has been some type of "on-the-job training" usually given by available and experienced operators. This type of training is important and has been very effective. Proof of its effectiveness is indicated by the fact that many consumers have received potable water as a result of the efforts of such training.

   One possible limitation of this type of training is that it could be too narrow in scope. "In-house" training tends to be limited to local conditions, philosophies, and experience unless the instructor makes special efforts to broaden the scope. Initial safety training should be completed BEFORE on-the-job training.

2. Professional magazines and papers. Another valuable source of training has been available through articles printed in local or national professional magazines. Local or area waterworks associations periodically present workshops where experienced operators offer papers that are of value in training less experienced people in the operation and maintenance of waterworks facilities. Such workshops make information available to smaller organizations in remote areas who would otherwise not have the benefit of such broad experience.

3. Formal training. Recently, through the efforts of local and state waterworks associations, the American Water Works Association, and the U.S. Environmental Protection Agency, attempts are being made to make formal training available to all operators. Such training also is being made available to others not now in the waterworks field, but who would like to prepare for jobs within the field. This particular training course is a result of such efforts.

4. Informal training. Effective training techniques include informal meetings using drawings from available materials, suppliers, knowledge of experienced crews members, and invited guests to talk over how to do specific jobs. Suppliers are often available to train new operators and retrain existing operators on use of equipment.

5. Training for supervisors. Every manager and supervisor must develop a personal continuing education program. Managers must keep up to date with technical advances in their field and also develop management skills.

A supervisor should participate in whatever training is available NOW. As suggested in this section, it is possible to train crews to perform effectively even without formal training aids. It is inefficient supervision to assign crews to perform work without some form of adequate training. The lack of formal courses or training material does not make adequate training impossible, it only makes it more difficult.

23.13 People

How does the manager or administrator deal with people? Every day we have to work with our supervisors, the public, the people we work with and the people who work for us. In this manual we have tried to outline how to get the job done, how to create a climate for good morale and how to provide training opportunities for operators.

A very highly specialized field has developed on how to motivate people, deal with co-workers, and how to supervise or manage people working for you. We believe these are complex topics that are beyond the scope of this manual. If you have a need for or wish to learn more on how to deal with people, we suggest enrolling in courses or reading books on supervision or personnel management.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 557.

23.1A What are the responsibilities of a supervisor?

23.1B List the important factors which will influence the size and qualifications of staff required by a water utility agency.

23.1C What should operators be trained to do?

23.14 Operator Certification

23.140 Need for Certified Operators

Virtually all states and Canadian provinces require that a certified operator be in charge of a utility agency's water supply system and water treatment plant. Water supply and treatment facilities are often classified on the basis of the number of services and/or the capacity of the treatment plant as well as on the complexity of the treatment processes in the plant. This classification and the size of the plant usually determine the numbers and grade levels of certified operators needed by the plant. To qualify for higher levels of certification, operators need greater combinations of education and experience. Education may be obtained by attending technical schools, community colleges, short courses, workshops, and successfully completing courses like this one. Once the required education and experience have been obtained for a higher level of certification, the operator must successfully pass a certification examination. This examination is based on what the operator needs to know to work at a plant with a specific plant classification. That is to say, the higher the certification you seek, the more extensive the test will be.

23.141 Why Should Water Utility Operators Be Certified?

23.1410 Safety

Certified water supply system and treatment plant operators earn their certificates by knowing how to do their jobs safely. Preparing for certification examinations is one means by which operators learn to identify safety hazards and to follow safe procedures at all times under all circumstances.

Although it is extremely important, safety is not the sole benefit to be derived from a certification program. Other benefits are described below.

23.1411 Protection of the Public's Investment

Vast sums of public funds have been invested in the construction of water supply and treatment facilities. Certification of operators assures utilities that these facilities will be operated and maintained by qualified operators who possess a certain level of competence. These operators should have the knowledge and skills not only to prevent unnecessary deterioration and failure of the facilities, but also to improve operation and maintenance techniques.

23.1412 Employee Pride and Recognition

Achievement of a level of certification is a public acknowledgment of a water supply system or treatment plant operator's skills and knowledge. Presentation of certificates at an official meeting of the governing body will place the operators in a position to receive recognition for their efforts and may even get press coverage and public opinion that is favorable. An improved public image will give the certified operator more credibility in discussions with property owners.

Recognition for their personal efforts will raise the self-esteem of all certified operators. Certification will also give water supply system and treatment plant operators an upgraded image that has been too long denied them. If properly publicized, certification ceremonies will give the public a more accurate image of the many dedicated, well qualified operators working for them. Certification provides a measurable goal that operators can strive for by preparing themselves to do a better job. Passing a certification exam should be recognized by an increase in salary and other employee benefits.

23.142 ABC

ABC stands for the Association of Boards of Certification for Operating Personnel in Water Utilities and Pollution Control Systems. If you wish to find out how to become certified in your state or province, contact:

Executive Director, ABC
Post Office Box 786
Ames, Iowa 50010-0786
Phone: (515) 232-3778

ABC will provide you with the name and address of the appropriate contact person

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 558.

23.1D Name several ways water supply and treatment facilities are generally classified.

23.1E How can an operator achieve higher levels of certification?

23.1F How can an operator find out how to become certified?

23.2 PUBLIC RELATIONS

23.20 Establish Objectives

The first step in organizing an effective public relations campaign is to establish objectives. The only way to know whether your program is a success is to have a clear idea of what you expect to achieve—for example, better customer relations, greater water conservation, and enhanced organizational credibility. Each objective must be specific, achievable, and measurable. It is also important to know your audience and tailor various elements of your public relations effort to specific groups you wish to reach, such as community leaders, school children, or the average customer. Your objective may be the same in each case, but what you say and how you say it will depend upon your target audience.

23.21 Utility Operations

Good public relations begin at home. Dedicated, service-oriented employees provide for better public relations than paid advertising or complicated public relations campaigns. For most people, contact with an agency employee establishes their first impression of the competence of the organization, and those initial opinions are difficult to change.

In addition to ensuring that employees are adequately trained to do their jobs and knowledgeable about the utility's operations, management has the responsibility to keep employees informed about the organization's plans, practices, and goals. Newsletters, bulletin boards, and regular, open communication between supervisors and subordinates will help build understanding and contribute to a team spirit.

Despite the old adage to the contrary, the customer is not always right. Management should try to instill among its employees the attitude that while the customer may be confused or unclear about the situation, everyone is entitled to courteous treatment and a factual explanation. Whenever possible, employees should phrase responses as positively, or neutrally as possible, avoiding negative language. For example, "Your complaint" is better stated as "Your question". "You should have . . . " is likely to make the customer defensive, while "Will you please . . . " is courteous and respectful. "You made a mistake" emphasizes the negative, "What we'll do . . . " is a positive, problem-solving approach.

23.22 The Mass Media

We live in the age of communications, and one of the most effective and least expensive ways to reach people is through the mass media—radio, television, and newspapers. Each medium has different needs and deadlines, and obtaining coverage for your issue or event is easier if you are aware of these constraints. Television must have strong visuals, for example. When scheduling a press conference, provide an interesting setting and be prepared to suggest good shots to the reporter. Radio's main advantage over television and newspapers is immediacy, so have a spokesperson available and prepared to give the interview over the telephone if necessary. Newspapers give more thorough, in-depth coverage to stories than do the broadcast media, so be prepared to spend extra time with print reporters and provide written backup information and additional contacts.

It is not difficult to get press coverage for your event or press conference if a few simple guidelines are followed:

1. Demonstrate that your story is newsworthy, that it involves something unusual or interesting.
2. Make sure your story will fit the targeted format (television, radio, or newspaper).
3. Provide a spokesperson who is interesting, articulate, and well prepared.

23.23 Being Interviewed

Whether you are preparing for a scheduled interview or are simply contacted by the press on a breaking news story, here are some key hints to keep in mind when being interviewed.

1. Speak in personal terms, free of institutional jargon.
2. Do not argue or show anger if the reporter appears to be rude or overly aggressive.
3. If you don't know an answer, say so and offer to find out. Don't bluff.
4. If you say you will call back by a certain time, do so. Reporters face tight deadlines.
5. State your key points early in the interview, concisely and clearly. If the reporter wants more information, he or she will ask for it.
6. If a question contains language or concepts with which you disagree, don't repeat them, even to deny them.
7. Know your facts.
8. Never ask to see a story before it is printed or broadcast. Doing so indicates that you doubt the reporter's ability and professionalism.

23.24 Public Speaking

Direct contact with people in your community is another effective tool in promoting your utility. Though the audiences tend to be small, a personal, face-to-face presentation generally leaves a strong and long-lasting impact on the listener.

Depending upon the size of the organization, your utility may wish to establish a speaker's bureau and send a list of topics to service clubs in the area. Visits to high schools and college campuses can also be beneficial, and educators are often looking for new and interesting topics to supplement their curriculum.

Public speaking takes practice. It is important to be well prepared while retaining a personal, informal style. Find out how long your talk is expected to be, and don't exceed that time frame. Have a definite beginning, middle, and end to your presentation. Visual aids such as charts, slides, or models can assist in conveying your message. The use of humor and anecdotes can help to warm up the audience and build rapport between the speaker and the listener. Just be sure the humor is natural, not forced, and that the point of your story is accessible to the particular audience. Try to keep in mind that audiences only expect you to do your best. They are interested in learning about their water supply and will appreciate that you are making a sincere effort to inform them about an important subject.

23.25 Telephone Contacts

First impressions are extremely important, and frequently a person's first contact with your water utility is over the telephone. A person who answers the phone in a courteous, pleasant, and helpful manner goes along way toward establishing a friendly, cooperative atmosphere.

Following a few simple guidelines will help to start your utility off on the right note with your customers:

1. ANSWER CALLS PROMPTLY. Your conversation will get off to a better start if the phone is answered by the third or fourth ring.
2. IDENTIFY YOURSELF. This adds a personal note and lets the caller know who he or she is talking to.
3. PAY ATTENTION. Don't conduct side conversations. Minimize distractions so you can give the caller your full attention, avoiding repetitions of names, addresses, and other pertinent facts.
4. MINIMIZE TRANSFERS. Nobody likes to get the run-around. Few things are more frustrating to a caller than being transferred from office to office, repeating the situation, problem or concern over and over again. Transfer only those calls that must be transferred, and make certain you are referring the caller to the right person. Then, explain why you are transferring the call. This lets the caller know you are referring him or her to a co-worker for a reason and reassures the customer that the problem or question will be dealt with. In some cases, it may be better to take a message and have someone return the call than to keep transferring the customer's call.

23.26 Consumer Inquiries

No single set of rules can possibly apply to all types of consumer questions or complaints about water quality and service. There are, however, basic principles to follow in responding to inquires and concerns.

1. BE PREPARED. Your employees should be familiar enough with your utility's organization, services and policies to either respond to the question or complaint or locate the person who can.
2. LISTEN. Ask the customer to describe the problem and listen carefully to the explanation. Take written notes of the facts and addresses.
3. DON'T ARGUE. Callers often express a great deal of pent-up frustration in their contacts with a utility. Give the caller your full attention. Once you've heard them out, most people will calm down and state their problems in more reasonable terms.
4. AVOID JARGON. The average consumer lacks the technical knowledge to understand the complexities of water quality. Use plain, non-technical language and avoid telling the consumer more than he or she needs to know.
5. SUMMARIZE THE PROBLEM. Repeat your understanding of the situation back to the caller. This will assure the customer that you understand the problem and offer the opportunity to clear up any confusion or missed communication.
6. PROMISE SPECIFIC ACTION. Make an effort to give the customer an immediate, clear, and accurate answer to the problem. Be as specific as possible, without overstepping your authority or promising something you can't deliver.

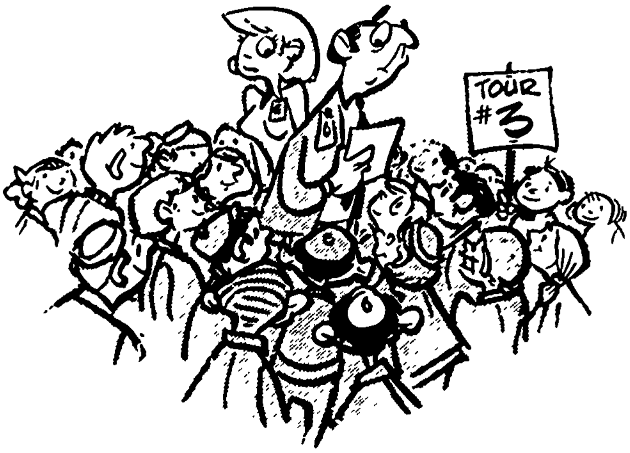
In some cases, you may wish to have a representative of the utility visit the customer and observe the problem first hand. If the complaint involves water quality, take samples if necessary and report back to the customer to be sure the problem has been resolved.

Complaints can be a valuable asset in determining consumer acceptance and pinpointing water quality problems. Customer calls are frequently your first indication that something may be wrong. Responding to complaints and inquiries promptly can save the utility money and staff resources, and minimize the number of customers who are inconvenienced. Still, education can greatly reduce complaints about water quality. Information brochures, utility bill inserts, and other educational tools help to inform customers and avoid future complaints.

23.27 Plant Tours

Tours of water treatment plants can be an excellent way to inform the public about your utility's efforts to provide a safe, high quality water supply. Political leaders, such as the City Council and members of the Board of Supervisors, should be invited and encouraged to tour the facilities, as should school groups and service clubs.

A brochure describing your utility's goals, accomplishments, operations, and processes can be a good supplement to the tour and should be handed out at the end of the visit. The more visually interesting the brochure is, the more likely that it will be read, and the use of color, photographs, graphics or other design features is encouraged. If you have access to the necessary equipment, production of a video tape program about the utility can also add interest to the facility tour.



The tour itself should be conducted by an employee who is very familiar with plant operations and can answer the types of questions that are likely to arise. Consider including:

1. A description of the sources of water supply,

2. History of the plant, the years of operation, modifications and innovations over the years,
3. Major plant design features, including plant capacity and safety features,
4. Observation of the treatment processes, including filtration, sedimentation, flocculation and disinfection,
5. A visit to the laboratory, including information on the quality of water distributed to consumers, and
6. Anticipated improvements, expansions, and long-range plans for meeting future service needs.

Plant tours can contribute to a water utility's overall program to gain financing for capital improvements. If the City Council or other governing board has seen the treatment process first hand, it is more likely to understand the need for enhancement and support future funding.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 558.

23.2A What is probably the single most important aspect of a successful public relations effort?

23.2B What attitude should management try to develop among its employees regarding the consumer?

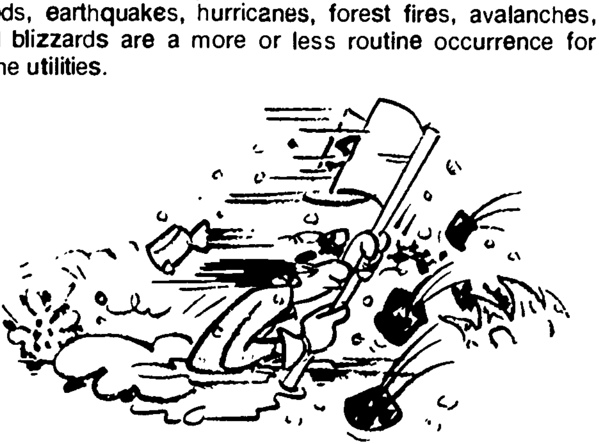
23.2C How can you prepare yourself for an interview with the news media?

23.2D How can plant tours be most beneficial for a water utility?

23.3 EMERGENCY PLANNING

Contingency planning is an essential facet of water utility management and one that is often overlooked. Although utilities in various locations will be vulnerable to somewhat different kinds of natural disasters, the effects of these disasters in many cases will be quite similar. As a first step towards an effective contingency plan, each utility should make an assessment of its own vulnerability and then develop and implement a comprehensive plan of action.

All water utilities suffer from common problems, such as equipment breakdown, leaking pipes and variations in water quality and quantity. During the past few years there has also been an increasing amount of vandalism, civil disorder, toxic spills, and employee strikes which have threatened to disrupt water utility operations. Natural disasters such as floods, earthquakes, hurricanes, forest fires, avalanches, and blizzards are a more or less routine occurrence for some utilities.



Further, in observing today's international tension and the potential for nuclear war, the effect such action would have on the operation of water utilities must be seriously considered. When such catastrophic emergencies occur, the utility must be prepared to minimize the effects of the event and have a plan for rapid recovery to avoid serving contaminated water to the consumers. Such preparation should be a specific obligation of every utility manager.

Once it is recognized that all water treatment plants are subject to a variety of emergency situations, the vulnerability of that treatment unit to the effects of a disaster must be assessed If the extent of damage can be estimated for a series of most probable events, the weak elements can be studied, and protection and recovery operations can center on these elements.

Although all elements are important for the utility to function, experience with disasters points out elements that are most subject to disruption These elements are:

1 The absence of trained personnel to make critical decisions and carry out orders,
2 The loss of power to the treatment facilities,
3. An inadequate amount of supplies and materials, and
4. Inadequate communication equipment.

The following steps should be taken in assessing the vulnerability of a system:

1 Identify and describe the treatment components,
2 Assign assumed disaster characteristics,
3. Estimate disaster effects on system components,
4 Estimate water demand, quality and quantity during and following a potential disaster, and
5 Identify key system components that would be primarily responsible for system failure.

If the assessment shows a system is unable to meet estimated requirements because of the failure of one or more critical treatment components, the vulnerable elements have been identified. Repeating this procedure using several "typical" disasters will usually point out treatment plant weaknesses. Frequently the same vulnerable element appears for a variety of assumed disaster events.

You might consider, for example, the case of the addition of toxic pollutants to water supplies. The list of toxic agents that may have a harmful effect on humans is almost endless. However, it is recognized that there is a relationship between the quantity of toxic agents added and the treatment provided for the supply. Adequate chlorination is effective against most biological agents. Other considerations are the amount of dilution water and the solubility of the chemical agents. There is the possibility that during normal detention times many of the biological agents will die off with adequate chlorination.

Although the drafting of an emergency plan for a water system may be a difficult job, the existence of such a plan can be of critical importance during an emergency situation.

An emergency operations plan need not be too detailed, since all types of emergencies cannot be anticipated and a complex response program can be more confusing than helpful. Supervisory personnel must have a detailed description of their *RESPONSIBILITIES* during emergencies. A water quality officer should be primarily responsible for the *SAFETY* of the water supply Supervisory people need information, supplies, equipment and the assistance of trained personnel All these can be provided through a properly-constructed emergency operation plan that is not extremely detailed.

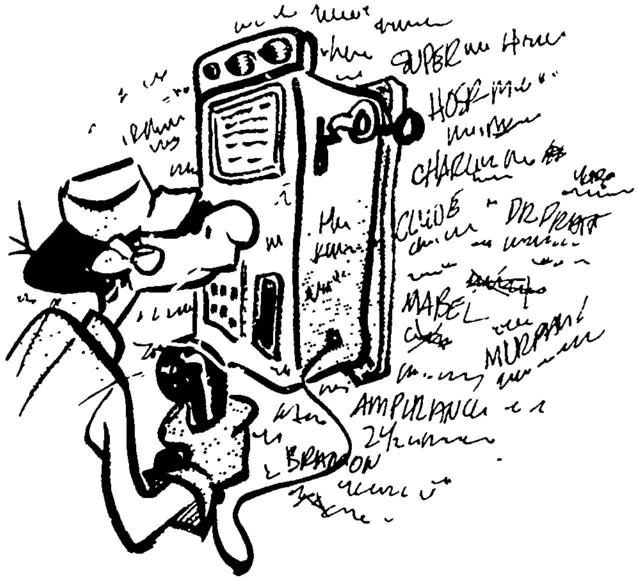
The following outline should be followed when developing an emergency operations plan:

1. Make a vulnerability assessment,
2. Inventory organizational personnel,
3. Provide for a recovery operation (plan),
4. Provide training programs for operators in carrying out the plan,
5. A plan should include local and regional coordination such as health department, police, and fire,
6. Establish a communications procedure, and
7. Provide protection for personnel, plant equipment, records and maps.

By following these steps, an emergency plan can be developed and maintained even though changes in personnel may occur. "Emergency Simulation" training sessions, including the use of standby power, equipment and field test equipment will insure that equipment and personnel are ready at times of emergency.

A list of phone numbers for operators to call in an emergency should be complete and posted by a phone for emergency use. You should prepare a list for your plant now, if you have not already done so.

1. Plant supervisor,
2. Director of public works or head of utility agency,
3. Police,
4. Fire,
5. Doctor (2 or more),
6. Ambulance (2 or more),
7. Hospital (2 or more),
8. Chlorine supplier and manufacturer,
9. CHEMTREC (800 424-9300 for hazardous chemical spills sponsored by the Manufacturing Chemists Association),
10. Pesticides (800-424-9300 for the National Agricultural Chemists Association Cleanup Crews),
11. U.S. Coast Guard's National Environmental Response Center (800-424-8802),
12. EPA Hazardous Materials Headquarters (Monday through Friday, 8:00 a.m. to 4:30 p.m., 202-245-3045; other times call 202-554-2329), and
13. FDA Poison Control Center (202-496-7691 or 202-963-7512).



For additional information on emergencies see Chapter 7, Disinfection, Section 7 52, "Chlorine Leaks," Chapter 10, Plant Operation, Section 10.9, "Emergency Conditions and Procedures," and Chapter 18, Maintenance, Section 18.02 "Emergencies."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 558.

23 3A What is the first step towards an effective contingency plan for emergencies?

23.3B How would you handle undesirable biological agents suspected in the water supply during an emergency?

23 3C Why is a too detailed emergency operation plan not needed nor desirable?

23.3D An emergency operations plan should include what specific information?

23.4 HANDLING THE THREAT OF CONTAMINATED WATER SUPPLIES[2]

23.40 Importance

More than 50 water utilities in southern Louisiana were threatened with cyanide poisoning in their water supplies in one year. Such threats can occur anywhere, and every water utility should be prepared to handle this type of emergency.

23.41 Toxicity

The term toxicity is often used when discussing contamination of a water supply with the intention of creating a serious health hazard. Toxicity is the ability of a contaminant (chemical or biological) to cause injury when introduced to the body. The degree of toxicity varies with the concentration of contaminant required to cause injury, the speed with which the injury takes place, and the severity of the injury.

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[2] *This section was reprinted from OPFLOW. Vol No. 3 March 1983, by permission. Copyright 1983, the American Water Works Association.*

The effect of a toxic contaminant, once added to a water supply, depends on several things. First the amount of contaminant added can vary, as can the size of the water supply. In general, it takes larger quantities of a contaminant to be toxic in a larger water supply. Second, the solubility of the contaminant can vary. The more soluble the substance is in water, the more likely it is to cause problems. Finally the detention time of the contaminant in the water can vary. For example, many biological agents will die before they can cause a problem in the water supply.

Generally, the terms acute and chronic are used to describe toxic agents and their effects. An acute toxic agent causes injury quickly. When the contaminant causes illness in seconds, minutes, or hours after a single exposure or a single dose, it is considered an acute toxic agent. A chronic agent causes injury to occur over an extended period of exposure. Generally, the contaminant is ingested in repeated doses over a period of days, months, or years.

23.42 Effective Dosages

When determining the effective dosage of a contaminant (the amount of that contaminant necessary to cause injury) the following facts must be considered:

1. Quantity or concentration of the contaminant,
2. Duration of exposure to the contaminant,
3. Physical form of the contaminant (size of particle; physical state — solid, liquid, gas),
4. Attraction of the contaminant to the organism being contaminated,
5. Solubility of the contaminant in the organism, and
6. Sensitivity of the organism to the contaminant.

Concentration of a contaminant can be expressed in two ways. The maximum allowable concentration (MAC) is the maximum concentration of the contaminant allowed in drinking water. Table 23.3 lists several contaminants and their MACs, specifically for short-term emergencies ranging up to three days. The MACs should not be confused with concentration required to have an acute effect on the population. Lethal dos 50 (LD 50), is used to express the concentration of a contaminant that will produce 50 percent fatalities from an average exposure.

23.43 Protective Measures

A utility can take three approaches to protect its water supply from contamination. First, the utility can isolate those reservoirs that offer easy access to the general public. These reservoirs can be fenced off and patrolled, or they can be covered. If access to on-line reservoirs is limited, persons attempting to contaminate the water supply will generally be forced to look to larger bodies of water. Contamination of these large water bodies requires larger quantities of contaminant, increases the detention time of the contaminant, and increases the likelihood of its detection.

As a second means of protection, the water utility can develop an extensive detection and monitoring program. Detecting any contaminant that might be added to a water supply is difficult and expensive. However, because most contaminants cause secondary effects in a water supply, such as taste, color, odor, or chlorine demand, detection is easier.

TABLE 23.3
EMERGENCY LIMITS OF SOME CHEMICAL POLLUTANTS IN DRINKING WATER[a]

Chemical	Concentration Limits, mg/*L* Emergency Short Term (Three days)	Long Term
Cyanide (CN)	5.0	0.01
Aldrin	0.05	0.032
Chlordane	0.06	0.003
DDT	1.4	0.042
Dieldrin	0.05	0.017
Endrin	0.01	0.001
Heptachlor	0.1	0.018
Heptachlor epoxide	0.05	0.018
Lindane	2.0	0.056
Methoxychlor	2.8	0.035
Toxaphene	1.4	0.005
Beryllium	0.1	0.000
Boron	25.0	1.000
2,4-D	2.0	0.1
Ethylene chlorohydrin	2.0	
Organiphosphorus and carbamate pesticides	2.0	0.100
Trinitrotoluene $(NO_2)(C_6H_2CH_3)$	0.75	0.005

[a] These limits, based on current knowledge and informed judgment, have been recommended by knowledgeable persons in the field of toxicology. They are subject to change should new information indicate the need. Additional information on some of the chemicals listed can be found in "Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health," Parts I and II, USDHEW, Washington, D.C., Dec. 1969.

Because utility operators "know" their water supply (they know its characteristics), any subtle changes in taste, odor, color and chlorine demand are instantly recognized. Once it has been determined that the water supply may be contaminated water samples can be tested. Tests can either be done at the utility's laboratory, if it is a large utility, or the samples can be sent to the state health department.

Finally, the utility can maintain a high chlorine residual. Generally, chlorine residuals of one mg/*L* or higher effectively oxidize or destroy most contaminants. For example, infectious hepatitis virus will not survive a free residual chlorine level of 0.7 mg/*L*

23.44 Emergency Countermeasures

Following is a list of emergency countermeasures that, when used over a short time period, can increase protection of a water supply:

1. Maintaining a high chlorine residual in the system,
2. Having engineers, chemists, and medical personnel on 24-hour alert,
3. Continuously monitoring key points in the distribution system (monitoring chlorine residual is mandatory),
4. Increasing security around exposed on-line reservoirs,
5. Sealing off access to manholes within a three- to six-block radius of highly populated areas,

6 Setting up emergency crews that can isolate sections of the distribution system, and

7 Staffing the treatment facility on a 24-hour basis

23.45 In Case of Contamination

If contamination of the water supply is discovered, the immediate concern must be the safety of the public If the contaminated water has entered the distribution system, immediate public notification is the highest priority The local police chief, sheriff or other responsible governmental authority will help to spread the word Alternate sources of water may need to be provided

If the contaminated water has not entered the distribution system it may be possible to isolate the contaminated source and continue to supply water from other, unaffected sources If the contaminated water is the only source for the community, treatment measures may be available that will remove the contaminant or reduce its toxicity

Table 23.4 lists a series of emergency treatment steps that can be taken when identified chemicals are added to the system. These emergency treatment methods are effective only if the contaminant has been identified.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 558.

23.4A What does the word toxicity mean?

23 4B The degree of toxicity varies with what factors?

23 4C List possible secondary effects in a water supply which may allow detection of a contaminant without specific testing

TABLE 23.4
EMERGENCY TREATMENT FOR REDUCING CONCENTRATION OF SPECIFIC CHEMICALS IN COMMUNITY WATER SUPPLIES[a]

Concentration	Treatment
Arsenicals	
Unknown organic and inorganic arsenicals in groundwater at concentrations of 100 mg/*L*	Precipitation with ferric sulfate and liming to pH 6 8, followed by sedimentation and filtration.
Cyanides	
Hydrogen cyanide	Prechlorination to free residual with pH 7, followed by coagulation, sedimentation, and filtration *Caution* housed facilities must be adequately ventilated. Precipitation with ferrous or ferric salts to form Prussian blue (iron ferric cyanide) followed by coagulation, sedimentation, and clarification As long as an excess of iron coagulant is applied, the filtered water should be nontoxic even though it is blue.
Acetone cyanohydrin	Same as for hydrogen cyanide
Cyanogen chloride	Same as for hydrogen cyanide
Hydrocarbons	
Kerosene peak concentrations of 140 mg/*L*	Preapplications of bleaching clay and activated carbon, plus some increase in normal dosages of alum, chlorine dioxide, lime, and carbon, to provide treatment enabling continued production of water
Miscellaneous Organic Chemicals	
LSD (lysergic acid derivative)	Chlorination in alkaline water, or water made alkaline by addition of lime or soda ash, to provide a free chlorine residual. Two parts free chlorine are required to react with each part LSD.
Nerve Agents	
(Organophosphorus compounds)	Superchlorination at pH 7 to provide at least 40 mg/*L* residual after 30-min chlorine contact time, followed by dechlorination and conventional clarification processes
Pesticides	
2,4-DCP (2,4-Dichlorophenol) and impurity in commercial 2,4-D herbicides)	Adsorption on activated carbon followed by coagulation, sedimentation, and filtration
DDT (dichloro-diphenyltrichloroethane), concentrations of 10 g/*L*	Chemical coagulation, sedimentation and filtration.
Dieldrin, concentrations of 10 g/*L*	Chemical coagulation, sedimentation, and filtration. Supplemental treatment with activated carbon may be necessary.
Endrin, concentrations of 10 g/*L*	Chemical coagulation, sedimentation, and filtration. Supplemental treatment with activated carbon may be necessary.
Lindane, concentrations of 10 g/*L*	Application of activated carbon followed by chemical coagulation, sedimentation, and filtration.
Parathion, concentrations of 10 g/*L*	Chemical coagulation, sedimentation, and filtration. Supplemental treatment with activated carbon may be necessary. Omit prechlorination as chlorine reacts with parathion to form paraoxon, which is more toxic than parathion.

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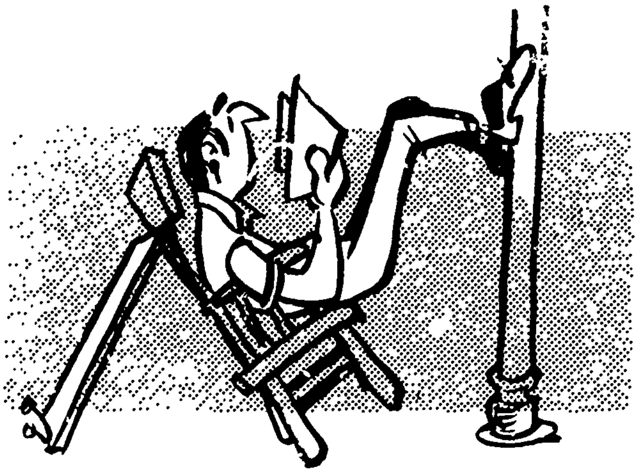
[a] Source Graham Walton, Chief, Technical Services, National Water Supply Research Laboratory, USSR Program, Oct. 24, 1968

23.5 ADDITIONAL READING

1. *TEXAS MANUAL,* Chapter 18 "Effective Public Relations in Water Works Operations," and Chapter 19, "Planning and Financing."
2. *WATER RATES* (M1). Obtain from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 30001. Price to members, $13.50, nonmembers, $17.00.
3. *WATER UTILITY MANAGEMENT PRACTICES* (M5). Obtain from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 30005. Price to members, $16.50; nonmembers, $20.50.
4. *EMERGENCY PLANNING FOR WATER UTILITY MANAGEMENT* (M19). Obtain from Computer Services, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 30019. Price to members, $13.50, nonmembers, $17.00.



DISCUSSION AND REVIEW QUESTIONS

Chapter 23. ADMINISTRATION

Please answer these discussion and review questions before continuing with the Objective Test on page 559. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. Why must a utility have clearly defined objectives?
2. How can the success of good organizational planning be measured?
3. How can the numbers and grade levels of certified operators required at a water treatment plant be determined?
4. What is the first step in organizing an effective public relations effort?
5. How can management keep employees well informed?
6. What is the value of consumer complaints?
7. What telephone procedures can be used to help your utility favorably impress people who contact the agency by phone?
8. How would you assess the vulnerability of a water supply system?
9. How can a utility protect its water supply from contamination?
10. What would you do if you discovered that contaminated water has entered your distribution system?
11. Why are records important?
12. Why should public water systems be operated by trained and certified personnel?
13. What is the difference between planning and budgeting?
14. What factors should be considered when determining a water rate schedule for a utility?
15. List the possible sources or types of training available for operators.

SUGGESTED ANSWERS

Chapter 23. Administration

Answers to questions on page 541.

23.0A Budgeting is the art of predicting the amount of money necessary to achieve an organization's goals.

23.0B Waste and inefficiency can be reduced or eliminated by carefully examining all phases of operation and maintenance when preparing accurate and realistic budgets.

23.0C Important items usually contained on a purchase order include: (1) the date, (2) a complete description of each item and quantity needed, (3) prices, (4) the name of the vendor, and (5) a purchase order number.

Answers to questions on page 545.

23.0D Some of the important uses of records include:

1. Aiding operators in solving treatment and water quality problems,
2. Providing a method of alerting operators to changes in source-water quality,
3. Showing that the treated water is acceptable to the consumer,
4. Documenting that the final product meets plant performance standards, as well as the standards of the regulatory agencies,
5. Determining performance of treatment processes, equipment, and the plant,
6. Satisfying legal requirements,
7. Aiding in answering complaints,
8. Anticipating routine maintenance,
9. Providing data for cost analysis and preparation of budgets,
10. Providing data for future engineering designs, and
11. Providing information for monthly and annual reports.

23.0E "Unaccounted for water" is the difference between the amount of treated water that enters the distribution system and water that is delivered to consumers.

23.0F Chemical inventory and usage records that should be kept include:

1. Chemical inventory/storage (measured use and deliveries),
2. Metered or estimated plant usages, and
3. Calculated usage of chemicals (compare with actual use).

Answers to questions on page 547.

23.0G Guidelines which are useful in development of an organizational plan include:

1. Organization should be based specifically upon the objectives to be achieved and the activities to be performed,
2. Each person should have only one boss and all direction and guidance should come from that supervisor,
3. The number of supervisory levels above the working level should be kept to a minimum,
4. Each supervisor should have a limited number of people to directly supervise (fewer than 6),
5. Delegation of authority should be as complete as possible with the lowest levels of the work force allowed to make as many decisions as are appropriate to that level,
6. The responsibility for performance of each individual should be pre-determined and then made perfectly clear to the individual and the staff, and
7. Lines of management authority must be maintained and not weakened by staff or functional authority.

23.0H The staff organization provides advice and service to the line personnel to assist them in meeting their objectives.

23.0I Organizational planning can benefit management by correcting weaknesses in the organization of a utility. It can also strengthen the structure and increase the effectiveness of management, thereby reducing costs and increasing efficiency.

23.0J Signs that may indicate to a utility potential weak points or approaching organizational problems include:

1. Physical, mental and emotional overloading which causes undue fatigue,
2. Indecisiveness in management which delays decision making,
3. Poor teamwork resulting from poor supervisory practices or personal inadequacies of a supervisor, and
4. Failure to train subordinates which causes problems when supervisors are promoted or move on to another job.

Answers to questions on page 548.

23.1A A supervisor is responsible for the safety and professional development of operators. Other responsibilities may include assigning tasks to specific operators, being sure they understand the assignment and know how to do the job safely, and eventually making sure that the job was done properly.

23.1B The most important factors which will influence the size and qualifications of staff required include the number of services and also the size and complexity of the treatment processes and facilities that must be operated and maintained. Other important factors might include age and condition of facilities and expected population growth rates.

23.1C Operators should be properly trained to recognize all hazards and to effectively accomplish the tasks they are assigned. Supervisors must motivate operators to use safe procedures.

Answers to questions on page 549.

23.1D Water supply and treatment facilities are often classified on the basis of the number of services and/or the capacity of the treatment plant as well as on the complexity of the treatment processes in the plant.

23.1E An operator can achieve higher levels of certification by gaining the necessary education and experience for the next level of certification. The operator then must successfully pass the next level certification examination.

23.1F To find out how to become certified, contact your state certification board or the Association of Boards of Certification (ABC) in Ames, Iowa.

Answers to questions on page 552.

23.2A Probably the single most important aspect of a public relations effort is employee job satisfaction and performance.

23.2B Management should try to develop among its employees the attitude that even though the consumer is not always right, every consumer is always entitled to courteous treatment and a proper explanation of anything the consumer does not understand.

23.2C Proper preparation for an interview with the news media includes:

1. Speak in personal terms, free of institutional jargon.
2. Do not argue or show anger if the reporter appears to be rude or overly aggressive.
3. If you don't know an answer, say so and offer to find out. Don't bluff.
4. If you say you will call back by a certain time, do so. Reporters face tight deadlines.
5. State your key points early in the interview, concisely and clearly. If the reporter wants more information, he or she will ask for it.
6. If a question contains language or concepts with which you disagree, don't repeat them, even to deny them.
7. Know your facts.
8. Never ask to see a story before it is printed or broadcast. Doing so indicates that you doubt the reporter's ability and professionalism.

23.2D Plant tours are an excellent method of informing the public of the water utility's efforts to provide a safe, wholesome water supply.

Answers to questions on page 553.

23.3A The first step towards an effective contingency plan for emergencies is to make an assessment of vulnerability. Then a comprehensive plan of action can be developed and implemented.

23.3B Adequate chlorination is effective against most biological agents during an emergency. Other considerations include the amount of dilution water and the possibility that the biological agents will die off during normal detention times with adequate chlorination.

23.3C A detailed emergency operation plan is not needed since all types of emergencies cannot be anticipated and a complex response program can be more confusing than helpful.

23.3D An emergency operations plan should include:

1. Vulnerability assessment,
2. Inventory of personnel,
3. Provisions for recovery operation,
4. Provisions for training programs for operators in carrying out the plan,
5. Inclusion of coordination plans with health, police and fire departments,
6. Establishment of a communications procedure, and
7. Provisions for protection of personnel, plant equipment, records and maps.

Answers to questions on page 555.

23.4A Toxicity is the ability of a contaminant (chemical or biological) to cause injury when introduced into the body.

23.4B The degree of toxicity varies with the concentration of contaminant required to cause injury, the speed with which the injury takes place, and the severity of the injury.

23.4C Possible secondary effects in a water supply which may allow detection of a contaminant without specific testing include taste, odor, color and chlorine demand.

OBJECTIVE TEST

Chapter 23. ADMINISTRATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1 There may be more than one correct answer to the multiple choice questions

TRUE-FALSE

1 A definite plan of organization is essential to effectively operate a water treatment plant

1 True
2 False

2 The staff organization is in the line of command

1 True
2 False

3 Organizational plans can be copied from one major utility to another

1 True
2 False

4 Radio and television give more thorough coverage of stories than newspapers

1 True
2 False

5 Usually the same vulnerable plant element appears as a problem for a variety of disaster events

1 True
2 False

6 Operators must be available during nights, weekends, and holidays to respond to emergencies

1 True
2 False

7 In a water treatment plant continuity of supply is of prime importance

1 True
2 False

8 A set of rules can be established that will apply to all types of people with consumer complaints

1 True
2 False

9. Try to be friendly and courteous at all times to people with complaints.

1 True
2 False

10 Complaints should be welcomed and accurately recorded

1 True
2 False

MULTIPLE CHOICE

11 A clear-cut organizational plan reduces or avoids

1. Confusion.
2 Duplication of effort.
3 Effective communication.
4 Friction
5 Working at cross purposes

12 Each supervisor should supervise no more than ___ people.

1 6
2. 12
3. 18
4. 24
5. 30

13 Staff personnel shown on a water utility organization chart include

1 Accountants.
2 Lawyers.
3 Operators.
4. Secretaries.
5. Superintendent.

14 Water utility operators should become certified to

1 Be able to do a better job of operating the facilities.
2. Improve the utility's safety record.
3. Increase employee pride and recognition.
4. Learn how to identify safety hazards.
5 Protect the public's investment in the utility.

15 Management has a responsibility to keep employees well informed about the organization's

1 Personnel actions (firings and demotions).
2. Plans.
3. Practices.
4 Purposes.
5. Union dues.

16 Management can keep employees well informed by using

1. Bulletin board announcements
2. Local newspapers
3. Memos.
4. Straight talk from supervisors to subordinates.
5 The office gossip.

17 Information provided during a plant our should include

1 Description of the sources of water supply.
2 Information on quality of water distributed to consumers
3 Plans for improvement.
4 Plant design features.
5 Theory of hydraulic turbulence in sedimentation basins.

18. Emergencies that confront water utilities include
    1. Budget cuts.
    2. Employee strikes.
    3 Fires
    4. Floods.
    5. Vandalism.

19 Elements of a water utility which are most likely to be weak points during a disaster include
    1. Absence of trained personnel to make critical decisions.
    2. Inadequate amount of supplies and materials.
    3. Inadequate communication equipment
    4. Loss of power to the treatment facilities.
    5. Shortage of funds to pay contractors.

20. The first step in organizing an effective public relations campaign is to
    1. Call a press conference.
    2. Conduct plant tours.
    3. Establish objectives.
    4. Meet with community leaders.
    5. Publish brochures.

21. When responding to consumer complaints or questions, proper response phrases include
    1. Will you please.
    2. You made a mistake.
    3. You should have.
    4. Your complaint.
    5. Your question.

22 To help your utility make friends with people who contact the agency by phone, you should
    1 Answer after 3 or 4 rings so callers will know you are busy
    2. Answer by saying "Hello"
    3 Extend a pleasant greeting.
    4 Leave word when away from the phone.
    5 Route the call to someone who can take a message.

23 When determing the effective dosage of a contaminant (the amount of that contaminant necessary to cause injury), which of the following facts must be considered?
    1. Duration of exposure to the contaminant
    2 Quality or concentration of the contaminant
    3 Sensitivity of consumers to the contaminant
    4 Solubility of the contaminant
    5. Who is the suspected source of the contaminant

24. Accurate records are very important because they
    1 Are a valuable source of information.
    2 Can save time when trouble develops.
    3. Help prepare preventive maintenance programs.
    4. Provide proof that problems were identified and solved.
    5. Serve as a basis for plant operation.

End of Objective Test

APPENDIX

Final Examination

How to Solve Water Treatment Plant Arithmetic Problems

Water Abbreviations

Water Words

Subject Index

WATER TREATMENT PLANT OPERATION

VOLUME II

FINAL EXAMINATION
AND
SUGGESTED ANSWERS

FINAL EXAMINATION

This final examination was prepared *TO HELP YOU* review the material in this manual. The questions are divided into four types:

1. True-False,
2. Multiple Choice,
3. Short Answers, and
4. Problems.

To work this examination:

1. Write the answers to each question in your notebook.
2. After you have worked a group of questions (you decide how many), check your answers with the suggested answers at the end of this exam, and
3. If you missed a question and don't understand why, reread the material in the manual.

You may wish to use this examination for review purposes when preparing for civil service and certification examinations.

Since you have already completed this course, you do not have to send your answers to California State University, Sacramento.

True-False

1. Iron and manganese are essential to the growth of many plants and animals, including humans
   1. True
   2. False

2. Only one cell of iron bacteria is needed to start an infestation of iron bacteria in a well
   1. True
   2. False

3. Fumes from hydrofluosilicic acid are safe to breathe
   1. True
   2. False

4. Insoluble deposits should be removed from chemical feed lines.
   1. True
   2. False

5. In the lime softening process, magnesium is precipitated out as magnesium carbonate.
   1. True
   2. False

6. Acid softening may be used instead of soda ash softening.
   1. True
   2. False

7. Dry ice should be used to keep THM samples cool when shipping and storing.
   1. True
   2. False

8. THMs are produced faster in corrosive waters than in scale forming waters
   1. True
   2. False

9. When higher mineral concentrations occur in the feedwater the mineral concentrations will decrease in the product water
   1. True
   2. False

10. An increase in feedwater temperature will decrease the water flux
    1. True
    2. False

11. Sedimentation tanks should be inspected and repaired when the tanks are emptied and cleaned.
    1. True
    2. False

12. A precoat of filter sand is required to dewater gelatinous alum sludge when using a vacuum filter.
    1. True
    2. False

13. Before attempting to change fuses, turn off power and check both power lines for voltage.
    1. True
    2. False

14 Mechanical energy is commonly converted to electrical energy by electric motors.

1 True
2 False

15 Always replace sprockets when replacing a chain.

1 True
2 False

16 A transducer is the primary element that measures a variable.

1 True
2 False

17 Thin rubber or plastic gloves can be worn to reduce markedly your chances of electrical shock

1 True
2 False

18. If an operator is unsure of how to perform a job, then it is the operator s responsibility to ask for the training needed

1. True
2 False

19 Inhalation of hydrochloric (HCl) vapors or mists can cause damage to the nasal passages.

1 True
2 False

20 Distilled water is considered pleasant to drink.

1 True
2 False

21 Dissolved oxygen in water can contribute to corrosion of piping systems

1 True
2 False

22 If the manganese concentration in a sample cannot be determined immediately, acidify the sample with acetic acid

1 True
2 False

23 Non-community water systems serve consumers less than 60 days per year

1 True
2 False

24. The MCL compliance for trihalomethanes is determined by the running average of four monthly averages

1. True
2. False

25. An acute toxic agent causes injury to occur over an extended period of time.

1. True
2. False

Multiple Choice

1 Red water complaints in drinking water may be caused by

1. Corrosive water
2 Ferric hydroxide
3 Iron bacteria
4 Iron in the water
5 Red clay or silt

2 Chemicals used to oxidize iron and manganese include

1 Alum
2 Chlorine.
3 Hydrogen sulfide.
4 Lime.
5 Potassium permanganate

3 Important features of a fluoridation system include prevention of

1. Backsiphonage.
2 Leaks
3 Monitoring.
4 Overfeeding.
5. Underfeeding.

4 When shutting down a fluoride chemical feed system, operators should

1 Confirm that safety guards are in place.
2. Drain and clean the mix and feed tanks.
3 Examine all fittings and drains for leaks.
4. Flush out all solution lines.
5 Inspect all equipment for binding and rubbing.

5 Benefits that could result from the lime-soda ash softening process include

1. Control of corrosion.
2 Increase in sodium content of softened water
3 Increase in water hardness.
4. Reduction in sludge disposal problems.
5 Removal of iron and manganese

6 Records that should be kept by the operator of an ion exchange softening plant include

1. Blend rates.
2 Gallons of brine used each day.
3 Pounds of lime used each day.
4 Results of jar tests.
5 Total flow per day that bypasses unit

7 A minimum of __ samples per quarter (every 3 months) for THM analysis must be taken on the same day for each treatment plant in the distribution system.

1 2
2 4
3 6
4 8
5 10

8 Group 1 techniques for controlling THMs include

1 Aeration.
2 Chloramines.
3 Chlorine dioxide.
4 Ozone
5 Potassium permanganate

9 The reverse osmosis elements should be cleaned when the operator observes

1. Higher differential pressures
2. Higher operating pressures
3. Higher suspended solids in product water.
4. Lower product water flow rate
5. Lower salt rejection

10. Problems encountered in electrodialysis operation include

1. Alkaline scales in the concentrating compartments.
2. Fouling of membranes
3. Sealing of membranes by inorganic materials.
4. Sealing of membranes by organic materials.
5. Strengthening of membranes.

11 Sludge may be dewatered by the use of

1. Belt filter presses.
2. Centrifuges
3. Flocculators.
4. Solar lagoons.
5. Solids-contact units.

12 Problems created by discharging sludge to sewers include

1. Fees charged could be very high.
2. Increasing flow capacity of sewers.
3. Monitoring requirements increase.
4. Operational problems may develop at wastewater treatment plant.
5. Possibility of causing a sewer blockage.

13. A good maintenance record system tells

1. How to handle consumer complaints.
2. Performance of equipment
3. Quality of raw water.
4. Quality of treated water.
5. When maintenance is due.

14 A voltage tester can be used to test for

1. Blown fuses
2. Grounds.
3. Open circuits.
4. Single phasing of motors.
5. Voltage.

15 Before a prolonged shutdown, pumps should be drained to prevent damage from

1. Cavitation.
2. Corrosion.
3. Freezing.
4. Sedimentation
5. Water hammer.

16 Velocity sensing devices measure flows by sensing

1. Inches of water (head).
2. Loss of hydraulic energy
3. Pressure differential.
4. Pressure within a restriction.
5. Rate of rotation.

17. Reliable operation of pneumatic instrumentation pressure systems requires

1. Clean air.
2. Dry air.
3. Moisturized air.
4. Pressurized air.
5. Uninterrupted power.

18. An operator must accept responsibility for

1. Being sure that safety equipment will work when needed
2. Fellow operators.
3. Operator's own welfare
4. Seeing that the supervisor complies with safety regulations.
5. Utility's equipment.

19 Ammonia cylinders should be stored

1. Away from heat
2. In cool. dry locations
3. In the same room with chlorine.
4. With caps in place when not in use
5. With protection from direct sunlight.

20. True color is normally removed or at least decreased by

1. Chlorination
2. Coagulation.
3. Filtration.
4. Ozonation
5. Sedimentation.

21 High levels of nitrate in a domestic water supply are undesirable because of

1. Hardness.
2. Health threat due to infant methemoglobinema.
3. Laundry stains
4. Nitrate tastes.
5. Potential for stimulating excessive algae growth.

22. Primary contaminants which are considered to have public health importance include

1. Lead.
2. Mercury.
3. Nitrate.
4. Odor.
5. Sulfate.

23 Turbidity is undesirable in drinking water because high turbidity

1. Increases corrosivity.
2. Interferes with disinfection.
3. Interferes with micribiological determinations.
4. Prevents maintenance of an effective disinfectant.
5. Produces aesthetic problems

24 Possible approaches for a utility to take to protect its water supply from contamination include

1. Developing an extensive detection and monitoring program.
2. Fencing off and patrolling reservoirs.
3. Having police lock up potential sources of contamination
4. Isolating reservoirs that offer easy access to the general public
5. Maintaining a low chlorine residual in the water.

25 Important uses of records include

1. Aiding operators in solving treatment and water quality problems.
2. Anticipating routine maintenance.
3. Providing data for future engineering designs
4. Satisfying legal requirements.
5. Showing that the treated water is acceptable to the consumer

Short Answers

1. How can the growth of iron bacteria in water systems be controlled?
2. Why should water being treated for iron and manganese by ion exchange not contain any dissolved oxygen?
3. Why should both underfeeding and overfeeding of fluoride compounds be avoided?
4. How would you dispose of empty fluoride chemical containers?
5. Why must water be stabilized after softening?
6. Why should the same chemical hopper or feeder not be used to feed both lime and alum at different times?
7. Why are trihalomethanes in drinking water of concern to water treatment plant operators?
8. Where are samples collected for THM analyses?
9. What are the common membrane demineralizing processes?
10. What causes "flux decline?"
11. How can sludge be removed from sedimentation tanks?
12. Why are source water stabilizing reservoirs helpful for water treatment plants?
13. Why should a qualified electrician perform most of the necessary maintenance and repair of electrical equipment?
14. Why are battery-powered lighting units considered better than engine-driven power sources?
15. Why must a suitable screen be installed on the intake end of pump suction piping?
16. What is an analog instrument?
17. How are liquid levels in chemically-active liquids measured?
18. How can pumps in a pump station be operated for similar lengths of time?
19. What items should be included in a utility's policy statement on safety?
20. Why do safety regulations prohibit the use of common drains and sumps from chemical storage areas?
21. What problems may be caused by iron in a domestic water supply?
22. What is the main source of trihalomethanes in drinking water?
23. Why are nitrate concentrations above the national standard considered an immediate health threat?
24. Why are high levels of sulfate undesirable in drinking water?
25. How can operators improve their technical knowledge and skills?

Problems

1. Determine the setting on a potassium permanganate chemical feeder in pounds per day if the chemical dose is 2.1 mg/L and the flow is 0.53 MGD.
2. Determine the setting on a potassium permanganate chemical feeder in pounds per million gallons if the chemical dose is 2.1 mg/L
3. A reaction basin 17 feet in diameter and 4.5 feet deep treats a flow of 400,000 gallons per day. What is the average detention time in minutes?
4. A flow of 0.8 MGD is to be treated with an 18 percent solution of hydrofluosilicic acid (H_2SiF_6). The water to be treated contains no fluoride and the desired fluoride concentration is 1.1 mg/L. Assume the hydrofluosilicic acid weighs 9.6 pounds per gallon. Calculate the hydrofluosilicic acid feed rate in gallons per day.
5. A flow of 400 GPM is to be treated with a 2.4 percent (0.2 pounds per gallon) solution of sodium fluoride (NaF). The water to be treated contains 0.5 mg/L of fluoride ion and the desired fluoride ion concentration is 0.9 mg/L. Calculate the sodium fluoride feed rate in gallons per day. Assume the sodium fluoride has a fluoride purity of 43.4 percent.
6. How many gallons of water with a hardness of 15 grains per gallon may be treated with an ion exchange softener with an exchange capacity of 24,000 kilograins?
7. How many hours will an ion exchange softening unit operate when treating an average flow of 350 GPM? The unit is capable of softening 700,000 gallons of water before requiring regeneration.
8. A water utility collected and analyzed eight samples from a water distribution system on the same day for TTHMs. The results are shown below.

Sample No.	1	2	3	4	5	6	7	8
TTHM, μg/L	90	100	120	90	80	110	120	80

What was the average for the day?

9. The results of the quarterly average TTHM measurements for two years are given below. Calculate the running annual average of the four quarterly measurements in micrograms per liter

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, μg/L	73	98	118	92	84	112	121	79

10. Estimate the ability of a reverse osmosis plant to reject minerals by calculating the mineral rejection as a percent. The feedwater contains 1600 mg/L TDS and the product water is 145 mg/L.
11. Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 2.4 MGD and the product flow is 2.0 MGD.
12. Calculate the pumping capacity of a pump in gallons per minute if 14 minutes are required for the water level in a tank to drop 4.5 feet. The tank is 11 feet in diameter.
13. Calculate the feed rate of a dry chemical feeder in pounds per day if 2.8 pounds of chemical are caught in a weighing tin during eight minutes
14. Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 35 mL sample was diluted to 200 mL (165 mL of odor-free water was added to the 35 mL sample).

15 Determine the taste rating for a water by calculating the arithmetic mean for the panel ratings given below

Tester No.	1	2	3	4	5	6	7
Rating	4	2	7	3	6	5	8

16 A small water system collected 12 samples during one month After each sample was collected, 10 m*L* of sample was placed in each of 5 fermentation tubes At the end of the month, the results indicated that 3 out of a total of 60 fermentation tubes were positive. What percent of the portions tested during the month were positive?

SUGGESTED ANSWERS FOR FINAL EXAMINATION

1. True Iron and manganese are essential to the growth of many plants and animals, including humans.

2 True Only one cell of iron bacteria is needed to start an infestation of iron bacteria in a well

3 False Hydrofluosilicic acid produces poisonous fumes

4 True Insoluble deposits should be removed from chemical feed lines.

5 False In the lime softening process, magnesium is precipitated out as magnesium hydroxide.

6 False Caustic soda softening may be used instead of soda ash.

7. False Do not use dry ice when shipping and storing THM samples because the sample water can freeze and break the bottle.

8 False THMs are produced faster in scale forming waters (high pH) than in corrosive waters.

9 False When higher mineral concentrations occur in the feedwater, the mineral concentrations will increase in the product water.

10. False An increase in feedwater temperature will increase the water flux.

11. True Sedimentation tanks should be inspected and repaired when the tanks are emptied and cleaned.

12. False A precoat of diatomaceous earth is required to dewater gelatinous alum sludge when using a vacuum filter.

13. True Turn off power and check both power lines for voltage before changing fuses.

14 False Electrical energy is commonly converted into mechanical energy by electric motors.

15. True Always replace sprockets when replacing a chain.

16. False A sensor is the primary element that measures a variable.

17. True Thin rubber or plastic gloves can be worn to reduce markedly your chances of electrical shock.

18 True If an operator is unsure of how to perform a job, then it is the operator's responsibility to ask for the training needed.

19 True Inhalation of hydrochloric (HCl) vapors or mists can cause damage to the nasal passage.

20. False Distilled water is not considered pleasant to drink.

21 True Dissolved oxygen in water can contribute to corrosion in piping systems

22 False If the manganese concentration in a sample cannot be determined immediately, acidify the sample with nitric acid, not acetic acid.

23. False Non-community water systems serve consumers at least 60 days a year.

24 False The MCL compliance for trihalomethanes is determined by the running average of four quarterly averages.

25. False A chronic toxic agent causes injury to occur over an extended period of time.

Multiple Choice

1. 1, 2, 3, 4 Red water complaints in drinking water may be caused by corrosive water, ferric hydroxide, iron bacteria and iron in the water

2 2, 5 Chemicals used to oxidize iron and manganese include chlorine and potassium permanganate.

3 1, 2, 4, 5 Important features of a fluoridation system include prevention of backsiphonage, leaks, overfeeding and underfeeding

4. 2, 4 When shutting down a fluoride chemical feed system, operators should drain and clean the mix and feed tanks and flush out all solution lines.

5. 1, 5 Benefits that could result from the lime-soda ash softening process include control of corrosion and removal of iron and manganese. Other items listed are limitations

6 1, 2, 5 Records that should be kept by the operator of an ion exchange softening plant include blend rates, gallons of brine used each day and total flow per day that bypasses unit.

7 2 A minimum of *4* samples per quarter (every 3 months) for THM analysis must be taken on the same day for each treatment plant in the distribution system.

8. 2, 3, 5 Chloramines, chlorine dioxide and potassium permanganate are Group 1 techniques for controlling THMs.

9 1, 2, 4, 5 The reverse osmosis elements should be cleaned when the operator observes higher differential pressures, higher operating pressures, lower product water flow rate, and lower salt rejection.

10 1, 2, 3, 4 Problems encountered in electrodialysis operation include alkaline scales in the concentrating compartments, fouling of membranes, and sealing of membranes by both organic and inorganic materials.

11 1, 2, 4 Sludge may be dewatered by the use of belt filter presses, centrifuges and solar lagoons

12 1, 3, 4, 5 Problems created by discharging sludge to sewers include: fees charged could be very high, monitoring requirements increase, operational problems may develop at wastewater treatment plant, and possibility of causing a sewer blockage.

13 2, 5 A good maintenance record system tells performance of equipment and when maintenance is due.

14 1, 2, 3, 4, 5 A voltage tester can be used to test for blown fuses, grounds, open circuits, single phasing of motors and voltage.

15 2, 3, 4 Before a prolonged shutdown, pumps should be drained to prevent damage from corrosion, freezing and sedimentation.

16 5 Velocity-sensing devices measure flows by sensing rate of rotation.

17 1, 2, 4 Reliable operation of pneumatic instrumentation pressure systems requires clean air, dry air and pressurized air.

18 1, 2, 3, 4, 5 An operator must accept responsibility for being sure that safety equipment will work when needed (your life may depend on it), fellow operators, operator's own welfare, seeing that the supervisor complies with safety regulations and the utility's equipment

19 1, 2, 4, 5 Ammonia cylinders should be stored in cool, dry locations with caps in place when not in use and away from heat, direct sunlight and chlorine

20 1, 2, 4 True color is normally removed or at least decreased by chlorination, coagulation, or ozonation.

21. 2, 5 High levels of nitrate in a domestic water supply are undesirable because of the health threat due to infant methemoglobinema and the potential for stimulating excessive algal growth

22 1, 2, 3 Lead, mercury and nitrate are primary contaminants which are considered to have public health importance.

23. 2, 3, 4, 5 Turbidity is undesirable in drinking water because high turbidity interferes with disinfection, interferes with microbiological determinations, prevents maintenance of an effective disinfectant, and produces aesthetic problems.

24 1, 2, 4 Possible approaches for a utility to take to protect its water supply from contamination include developing an extensive detection and monitoring program, fencing off and patrolling reservoirs, isolating reservoirs that offer easy access to the general public, and maintaining a *HIGH* chlorine residual in the water

25. 1, 2, 3, 4, 5 Important uses of records include aiding operators in solving treatment and water quality problems, anticipating routine maintenance, providing data for future engineering designs, satisfying legal requirements, and showing that the treated water is acceptable to the consumer.

Short Answers

1 The growth of iron bacteria can be controlled by maintaining a free chlorine residual at all times throughout the system.

2 Water being treated for iron and manganese by ion exchange should not contain any dissolved oxygen because the resin will become fouled with iron rust or insoluble manganese dioxide.

3 Underfeeding should be avoided because of the loss of benefits expected from fluoridation. Overfeeding should be avoiding due to the potential harm to consumers and the waste of chemicals and money.

4. Empty fluoride chemical containers can be disposed of by thoroughly rinsing all containers with water to remove all traces of chemicals before allowing the containers to leave the plant Containers may be burned if a nuisance will not be created Remember that fluoride fumes can kill vegetation.

5. Water must be stabilized after softening to prevent corrosion or the formation of scale in pipes

6 The same chemical hopper or feeder should not be used to feed both lime and alum because the resulting chemical reactions could generate enough heat to cause a fire.

7 Trihalomethanes in drinking water are of concern to water treatment plant operators because of the possible heatlh effects.

8 Twenty-five percent of the samples collected for THM analyses are collected from the extremities of the distribution system (the farthest points from the plant) and 75 percent must be representative of the population served

9. The common membrane demineralizing processes are reverse osmosis and electrodialysis.

10 "Flux decline" is the loss of water flow through the membrane due to compaction plus fouling.

11. Sludge can be removed from sedimentation tanks by mechanical rakes or scrapers or a vacuum-type sludge removal device may be used.

12 Source water stabilizing reservoirs are helpful because they reduce the turbidity in the water being treated and thus reduce the volume of sludge.

13. A qualified electrician should perform most of the necessary maintenance and repair of electrical equipment to avoid endangering lives and to avoid damage to equipment

14. Battery-powered lighting units are considered better than engine-driven power sources because they are more economical Also if you have a momentary power outage, the system responds without an engine generator startup.

15 A suitable screen must be installed on the intake end of pump suction piping to prevent foreign matter (sticks, refuse) from being sucked into the pump and clogging or wearing the impeller.

16. An analog instrument has a pointer (or other indicating means) for reducing a dial or scale.

17 Liquid levels in chemically-active liquids are measured with probes.

18 Pumps in a pump station can be operated for similar lengths of time by the use of manual or automatic "sequencers" which switch different pumps to the "lead" pump position and the others to the "lag" position periodically.

19 A utility's policy statement on safety should give its objective concerning the operator's welfare The statement should give the utility's recognition of the need for safety to stimulate efficiency, improve service, improve moral and to maintain good public relations. The policy should recognize the human factor (the unsafe act), and emphasize the operator's responsibility The operators should be provided with proper equipment and safe working conditions Finally, the policy must reinforce the supervisory responsibility to maintain safe work practices

20 Safety regulations prohibit the use of common drains and sumps from chemical storage areas to avoid the possibility of chemicals reacting and producing toxic gases, explosions and fires

21 Problems that may be caused by iron in a domestic water supply include staining of laundry, concrete, and porcelain A bitter astringent taste can be detected by some people at levels above 0 3 mg/*L*

22 The main source of trihalomethanes in drinking water is the chemical interaction of chlorine added for disinfection and other purposes with the commonly present natural humic substances and other THM precursors, produced either by normal organic decomposition or by the metabolism of aquatic organisms

23 Nitrate concentrations in drinking water above the national standard are considered an immediate threat to children under three months of age. In some infants, excessive levels of nitrate have been known to react with intestinal bacteria which change nitrate to nitrite which react with hemoglobin in the blood to produce an anemic condition commonly known as "blue baby."

24 High levels of sulfate are undesirable in drinking water because they tend to form hard scales in boilers and heat exchangers, cause taste effects, and cause a laxative effect.

25. Operators can improve their technical knowledge and skills by training. Sources or types of training include on the job, trade magazines and papers, workshops, formal training in classrooms, and home-study courses.

Problems

1. Determine the setting on a potassium permanganate chemical feeder in pounds per day if the chemical dose is 2.1 mg/*L* and the flow is 0 53 MGD.

Known	Unknown
Flow, MGD = 0.53 MGD Dose, mg/*L* = 2.1 mg/*L*	Chemical Feeder, lbs/day

Determine the chemical feeder setting in pounds per day

$$\text{Chemical Feeder, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8\ 34\ \text{lbs/gal})$$

$$= (0\ 53\ \text{MGD})(2\ 1\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 9\ 3\ \text{lbs/day}$$

2 Determine the setting on a potassium permanganate chemical feeder in pounds per million gallons if the chemical dose is 2 1 mg/*L*

Known	Unknown
Dose, mg/*L* = 2.1 mg/*L*	Dose, lbs/MG

Convert the dose from milligrams per liter to pounds per million gallons

$$\text{Dose, lbs/M} = \frac{(\text{Dose, mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(1000\ \text{mg/gm})(454\ \text{gm/lb})(1\ \text{Million})}$$

$$= \frac{(2\ 1\ \text{mg}/L)(3\ 785\ L/\text{gal})(1{,}000{,}000)}{(1000\ \text{mg/gm})(454\ \text{gm/lb})(1\ \text{Million})}$$

$$= 17\ 5\ \text{lbs/MG}$$

3 A reaction basin 17 feet in diameter and 4 5 feet deep treats a flow of 400.000 gallons per day. What is the average detention time in minutes?

Known		Unknown
Diameter. ft	= 17 ft	Detention Time. min
Depth. ft	= 4 5 ft	
Flow. GPD	= 400,000 GPD	

1. Calculate the basin volume in cubic feet

$$\text{Basin Vol, cu ft} = (0.785)(\text{Diameter, ft})^2(\text{Depth. ft})$$

$$= (0\ 785)(17\text{ ft})^2(4.5)$$

$$= 1021\text{ cu ft}$$

2 Convert the basin volume from cubic feet to gallons.

$$\text{Basin Vol, gal} = (\text{Basin Vol, cu ft})(7.48\text{ gal/cu ft})$$

$$= (1021\text{ cu ft})(7\ 48\text{ gal/cu ft})$$

$$= 7637\text{ gal}$$

3 Determine the average detention time in minutes in the reaction basin.

$$\text{Detention Time, min} = \frac{(\text{Basin Vol, gal})(24\text{ hr/day})(60\text{ min/hr})}{\text{Flow. gal/day}}$$

$$= \frac{(7637\text{ gal})(24\text{ hr/day})(60\text{ min/hr})}{400.000\text{ gal/day}}$$

$$= 27\ 5\text{ minutes}$$

4 A flow of 0 8 MGD is to be treated with an 18 percent solution of hydrofluosilicic acid (H_2SiF_6). The water to be treated contains no fluoride and the desired fluoride concentration is 1.1 mg/*L*. Assume the hydrofluosilicic acid weighs 9.6 pounds per gallon. Calculate the hydrofluosilicic acid feed rate in gallons per day

Known		Unknown
Flow, MGD	= 0 8 MGD	Feed Rate, gal/day
Acid Solution, %	= 18%	
Acid, lbs/gal	= 9 6 lbs/gal	
Desired F, mg/*L*	= 1 1 mg/*L*	

1 Calculate the hydrofluosilicic acid feed rate in pounds per day

$$\text{Feed Rate, lbs/day} = \frac{(\text{Flow MGD})(\text{Desired F. mg/}L)(8\ 34\text{ lbs/gal})(100\%)}{\text{Acid Solution. \%}}$$

$$= \frac{(0\ 8\text{ MGD})(1\ 1\text{ mg/}L)(8\ 34\text{ lbs/gal})(100\%)}{18\%}$$

$$= 41\text{ lbs acid/day}$$

2 Determine the feed rate of the acid in gallons per day.

$$\text{Feed Rate, gal/day} = \frac{\text{Feed Rate, lbs/day}}{9.6\text{ lbs/gal}}$$

$$= \frac{41\text{ lbs/day}}{9\ 6\text{ lbs acid/gal acid}}$$

$$= 4.3\text{ gal acid/day}$$

5. A flow of 400 GPM is to be treated with a 2.4 percent (0.2 pounds per gallon) solution of sodium fluoride (NaF). The water to be treated contains 0.5 mg/*L* of fluoride ion and the desired fluoride ion concentration is 0 9 mg/*L* Calculate the sodium fluoride feed rate in gallons per day. Assume the sodium fluoride has a fluoride purity of 43.4 percent.

Known		Unknown
Flow, MGD	400 GPM	Feed Rate. gal/day
NaF Solution. %	= 2 4%	
NaF Solution, lbs/gal	= 0 2 lbs/gal	
Desired F. mg/*L*	= 0 9 mg/*L*	
Actual F, mg/*L*	= 0.5 mg/*L*	
Purity. %	= 43.4%	

1 Convert the flow from gallons per minute to million gallons per day

$$\text{Flow, MGD} = \frac{(\text{Flow. gal/min})(60\text{ min/hr})(24\text{ hr/day})(1\text{ Million})}{1.000,000}$$

$$= \frac{(400\text{ gal/min})(60\text{ min/hr})(24\text{ hr/day})(1\text{ Million})}{1.000.000}$$

$$= 0\ 576\text{ MGD}$$

2 Determine the fluoride dose in milligrams per liter.

$$\text{Feed Dose, mg/}L = \text{Desired Dose, mg/}L - \text{Actual F, mg/}L$$

$$= 0\ 9\text{ mg/}L - 0.5\text{ mg/}L$$

$$= 0\ 4\text{ mg/}L$$

3. Calculate the feed rate in pounds of fluoride ion per day.

$$\text{Feed Rate, lbs F/day} = (\text{Flow. MGD})(\text{Feed Dose. mg/}L)(8\ 34\text{ lbs/gal})$$

$$= (0.576\text{ MGD})(0\ 4\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 1.9\text{ lbs/day}$$

4 Convert the feed rate from pounds of fluoride per day to gallons of sodium fluoride solution per day.

$$\text{Feed Rate, gal/day} = \frac{(\text{Feed Rate, lbs F/day})(100\%)}{(\text{NaF Solution, lbs F/gal})(\text{Purity, \%})}$$

$$= \frac{(1\ 9\text{ lbs F/day})(100\%)}{(0.2\text{ lbs/gal})(43.4\%)}$$

$$= 22\text{ gal/day}$$

6 How many gallons of water with a hardness of 15 grains per gallon may be treated by an ion exchange softener with an exchange capacity of 24,000 kilograins?

Known		Unknown
Hardness, grains/gal	= 15 grains/gal	Water Treated, gallons
Exchange Capacity, grains	= 24,000.000 grains	

Calculate the gallons of water that may be treated.

$$\text{Water Treated. gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gal}}$$

$$= \frac{24,000,000\text{ grains}}{15\text{ grains/gal}}$$

$$= 1,600,000\text{ gallons}$$

$$= 1\ 6\text{ M gallons}$$

7. How many hours will an ion exchange softening unit operate when treating an average flow of 350 GPM? The unit is capable of softening 700.000 gallons of water before requiring regeneration.

Known		Unknown
Ave Daily Flow, GPM	= 350 GPM	Operating Time, hr
Water Treated, gal	= 700,000 gal	

Estimate how many hours the softening unit can operate before requiring regeneration

$$\text{Operating Time, hr} = \frac{\text{Water Treated, gal}}{(\text{Ave Daily Flow, gal/min})(60\text{ min/hr})}$$

$$= \frac{700{,}000\text{ gal}}{(350\text{ gal/min})(60\text{ min/hr})}$$

$$= 33.3\text{ hours}$$

8. A water utility collected and analyzed eight samples from a water distribution system on the same day for TTHMs. The results are shown below

Sample No.	1	2	3	4	5	6	7	8
TTHM, µg/L	90	100	120	90	80	110	120	80

What was the average for the day?

Known	Unknown
Results from analysis of 8 TTHM samples	Average TTHM level for the day

Calculate the average TTHM level in micrograms per liter

$$\text{Ave TTHM, }\mu g/L = \frac{\text{Sum of Measurements, }\mu g/L}{\text{Number of Measurements}}$$

$$= \frac{90\ \mu g/L + 100\ \mu g/L + 120\ \mu g/L + 90\ \mu g/L + 80\ \mu g/L + 110\ \mu g/L + 120\ \mu g/L + 80\ \mu g/L}{8}$$

$$= \frac{790\ \mu g/L}{8}$$

$$= 99\ \mu g/L$$

9. The results of the quarterly average TTHM measurements for two years are given below. Calculate the running annual average of the four quarterly measurements in micrograms per liter

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, µg/L	73	98	118	92	84	112	121	79

Known	Unknown
Results from analysis of 2 years of TTHM sampling	Running annual average of quarterly TTHM measurements

Calculate the running annual average of the quarterly TTHM measurements

$$\text{Annual Running TTHM Average, }\mu g/L = \frac{\text{Sum of Ave TTHM for Four Quarters}}{\text{Number of Quarters}}$$

QUARTERS 1, 2, 3 AND 4

$$\text{Annual Running TTHM Average, }\mu g/L = \frac{73\ \mu g/L + 98\ \mu g/L + 118\ \mu g/L + 92\ \mu g/L}{4}$$

$$= \frac{381\ \mu g/L}{4}$$

$$= 95\ \mu g/L$$

QUARTERS 2, 3, 4 AND 1

$$\text{Annual Running TTHM Average, }\mu g/L = \frac{98\ \mu g/L + 118\ \mu g/L + 92\ \mu g/L + 84\ \mu g/L}{4}$$

$$= \frac{392\ \mu g/L}{4}$$

$$= 98\ \mu g/L$$

QUARTERS 3, 4, 1 AND 2

$$\text{Annual Running TTHM Average, }\mu g/L = \frac{118\ \mu g/L + 92\ \mu g/L + 84\ \mu g/L + 112\ \mu g/L}{4}$$

$$= \frac{406\ \mu g/L}{4}$$

$$= 102\ \mu g/L$$

QUARTERS 3, 4, 1 AND 2

$$\text{Annual Running TTHM Average, }\mu g/L = \frac{92\ \mu g/L + 84\ \mu g/L + 112\ \mu g/L + 121\ \mu g/L}{4}$$

$$= \frac{409\ \mu g/L}{4}$$

$$= 102\ \mu g/L$$

QUARTERS 1, 2, 3 AND 4

$$\text{Annual Running TTHM Average, }\mu g/L = \frac{84\ \mu g/L + 112\ \mu g/L + 121\ \mu g/L + 79\ \mu g/L}{4}$$

$$= \frac{396\ \mu g/L}{4}$$

$$= 99\ \mu g/L$$

SUMMARY OF RESULTS

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, µg/L	73	98	118	92	84	112	121	79
Annual Running TTHM, µg/L				95	98	102	102	99

10. Estimate the ability of a reverse osmosis plant to reject minerals by calculating the mineral rejection as a percent. The feedwater contains 1600 mg/L TDS and the product water is 145 mg/L

Known		Unknown
Feedwater TDS, mg/L	= 1600 mg/L	Mineral Rejection, %
Product Water TDS, mg/L	= 145 mg/L	

Calculate the mineral rejection as a percent

$$\text{Mineral Rejection, \%} = \left(1 - \frac{\text{Product TDS, mg/L}}{\text{Feed TDS, mg/L}}\right)(100\%)$$

$$= \left(1 - \frac{145\text{ mg/L}}{1600\text{ mg/L}}\right)(100\%)$$

$$= (1 - 0.09)(100\%)$$

$$= 91\%$$

11 Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 2.4 MGD and the product flow is 2.0 MGD

Known		Unknown
Product Flow, MGD	= 2.0 MGD	Recovery, %
Feed Flow, MGD	= 2.4 MGD	

Calculate the recovery as a percent.

$$\text{Recovery, \%} = \frac{(\text{Product Flow, MGD})(100\%)}{\text{Feed Flow, MGD}}$$

$$= \frac{(2.0\text{ MGD})(100\%)}{2.4\text{ MGD}}$$

$$= 83\%$$

12 Calculate the pumping capacity of a pump in gallons per minute if 14 minutes are required for the water level in a tank to drop 4.5 feet. The tank is 11 feet in diameter

Known		Unknown
Drop, ft	= 4.5 ft	Pump Capacity, GPM
Diameter, ft	= 11 ft	
Pumping Time, min	= 14 min	

1 Calculate the volume pumped in gallons

$$\text{Volume, gal} = (0.785)(\text{Diameter, ft})^2(\text{Drop, ft})(7.48\text{ gal/cu ft})$$

$$= (0.785)(11\text{ ft})^2(4.5\text{ ft})(7.48\text{ gal/cu ft})$$

$$= 3197\text{ gallons}$$

2 Estimate the pumping capacity in gallons per minute

$$\text{Pumping Capacity, GPM} = \frac{\text{Volume Pumped, gallons}}{\text{Pumping Time, min}}$$

$$= \frac{3197\text{ gallons}}{14\text{ min}}$$

$$= 228\text{ GPM}$$

13 Calculate the feed rate of a dry chemical feeder in pounds per day if 2.8 pounds of chemical are caught in a weighing tin during eight minutes

Known		Unknown
Chemical, lbs	= 2.8 lbs	Chemical Feed, lbs/day
Time, min	= 8 min	

Calculate the chemical feed rate in pounds of chemical per day.

$$\text{Chemical Feed, lbs/day} = \frac{(\text{Chemical, lbs})(60\text{ min/hr})(24\text{ hr/day})}{\text{Time, min}}$$

$$= \frac{(2.8\text{ lbs})(60\text{ min/hr})(24\text{ hr/day})}{8\text{ min}}$$

$$= 504\text{ lbs/day}$$

14. Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 35 mL sample was diluted to 200 mL (165 mL of odor-free water was added to the 35 mL sample).

Known		Unknown
Size of Sample, mL	= 35 mL	T.O.N.
Odor-Free Water, mL	= 165 mL	

Calculate the threshold odor number, T.O.N.

$$\text{T.O.N.} = \frac{\text{Size of Sample, mL} + \text{Odor-Free Water, mL}}{\text{Size of Sample, mL}}$$

$$= \frac{35\text{ mL} + 165\text{ mL}}{35\text{ mL}}$$

$$= 6$$

15 Determine the taste rating for a water by calculating the arithmetic mean for the panel ratings give below

Tester No	1	2	3	4	5	6	7
Rating	4	2	7	3	6	5	8

Known	Unknown
Taste Ratings	Arithmetic Mean, $\bar{X}$

Calculate the arithmetic mean $\bar{X}$, taste rating

$$\text{Arithmetic Mean } \bar{X} \text{ Taste Rating} = \frac{X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7}{n}$$

$$= \frac{4 + 2 + 7 + 3 + 6 + 5 + 8}{7}$$

$$= \frac{35}{7}$$

$$= 5$$

16 A small water system collected 12 samples during one month. After each sample was collected, 10 mL of sample was placed in each of 5 fermentation tubes. At the end of the month, the results indicated that 3 out of a total of 60 fermentation tubes were positive. What percent of the portions tested during the month were positive?

Known		Unknown
Number Positive/mo	= 3 positive/mo	Positive Portions, %/mo
Total Portions Tested	= 60 portions	

Calculate the percent of portions tested during the month which were positive

$$\text{Portions Positive, \%/mo} = \frac{(\text{Number Positive/mo})(100\%)}{\text{Total Portions Tested}}$$

$$= \frac{(3\text{ positive/mo})(100\%)}{60\text{ portions}}$$

$$= 5\%/\text{mo}$$

APPENDIX

HOW TO SOLVE WATER TREATMENT PLANT ARITHMETIC PROBLEMS

(VOLUME II)

by

Ken Kerri

TABLE OF CONTENTS

HOW TO SOLVE WATER TREATMENT PLANT ARITHMETIC PROBLEMS

SOLVING WATER TREATMENT PLANT OPERATION PROBLEMS (VOLUME II)

A.1 BASIC CONVERSION FACTORS (ENGLISH SYSTEM)

UNITS

1,000,000 = 1 Million	1,000,000/1 Million

LENGTH

12 in = 1 ft	12 in/ft
3 ft = 1 yd	3 ft/yd
5280 ft = 1 mi	5280 ft/mi

AREA

144 sq in = 1 sq ft	144 sq in/sq ft
43,560 sq ft = 1 acre	43,560 sq ft/ac

VOLUME

7.48 gal = 1 cu ft	7.48 gal/cu ft
1000 m*L* = 1 liter	1000 m*L*/*L*
3.785 *L* = 1 gal	3.785 *L*/gal
231 cu in = 1 gal	231 cu in/gal

WEIGHT

1000 mg = 1 gm	1000 mg/gm
1000 gm = 1 kg	1000 gm/kg
454 gm = 1 lb	454 gm/lb
2.2 lbs = 1 kg	2.2 lbs/kg

POWER

0.746 kw = 1 HP	0.746 kw/HP

DENSITY

8.34 lbs = 1 gal	8.34 lbs/gal
62.4 lbs = 1 cu ft	62.4 lbs/cu ft

DOSAGE

17.1 mg/*L* = 1 grain/gal	17.1 mg/*L*/gpg
64.7 grains = 1 mg	64.7 grains/mg

PRESSURE

2.31 ft water = 1 psi	2.31 ft/psi
0.433 psi = 1 ft water	0.433 psi/ft
1.133 ft water = 1 in Mercury	1.133 ft water/in Mercury

FLOW

694 GPM = 1 MGD	694 GPM/MGD
1.55 CFS = 1 MGD	1.55 CFS/MGD

TIME

60 sec = 1 min	60 sec/min
60 min = 1 hr	60 min/hr
24 hr = 1 day	24 hr/day

NOTE In our conversion factors the values in the right hand column may be written either as 24 hr/day or 1 day/24 hours depending on which units we wish to convert to our desired results.

A.2 BASIC FORMULAS

IRON AND MANGANESE CONTROL

1a. Stock Solution, mg/m*L* $= \dfrac{\text{(Polyphosphate, grams)(1000 mg/gm)}}{\text{(Solution, liter)(1000 m}L/L\text{)}}$

1b. Dose, mg/*L* $= \dfrac{\text{(Stock Solution, mg/m}L\text{)(Volume Added, m}L\text{)}}{\text{Sample Volume, }L}$

1c Dose, lbs/MG $= \dfrac{\text{(Dose, mg/}L\text{)(3.785 }L\text{/gal)(1,000,000)}}{\text{(1000 mg/gm)(454 gm/lb)(1 Million)}}$

2. Chemical Feeder, lbs/day = (Flow, MGD)(Dose, mg/*L*)(8.34 lbs/gal)

3. Detention Time, min $= \dfrac{\text{(Basin Vol, gal)(24 hr/day)(60 min/hr)}}{\text{Flow, gal/day}}$

4 $KMnO_4$ Dose, mg/*L* = 0.6(Iron, mg/*L*) + 2.0(Manganese, mg/*L*)

FLUORIDATION

5. Feed Rate, gal/day $= \dfrac{\text{(Feed Rate, lbs F/day)(100\%)}}{\text{(NaF Solution, lbs F/gal)(Purity, \%)}}$

6\. $$\text{Feed Solution, gal/day} = \frac{(\text{Flow, gal/day})(\text{Feed Dose, mg}/L)}{\text{Feed Solution, mg}/L}$$

7\. $$\text{Fluoride Ion Purity, \%} = \frac{(\text{Molecular Weight of Fluoride})(100\%)}{\text{Molecular Weight of Chemical}}$$

8a. $$\text{Feed Dose, mg}/L = \text{Desired Dose, mg}/L - \text{Actual Conc, mg}/L$$

8b. $$\text{Feed Rate, lbs/day} = \frac{\text{Feed Rate, lbs F/day}}{\text{lbs F/lb Commercial } Na_2SiF_6}$$

9\. $$\text{Feed Solution, gal} = \frac{(\text{Flow Vol, gal})(\text{Feed Dose, mg}/L)}{\text{Feed Solution, mg}/L}$$

10\. $$\text{Mixture Strength, \%} = \frac{(\text{Tank, gal})(\text{Tank \%}) + (\text{Vendor, gal})(\text{Vendor, \%})}{\text{Tank, gal} + \text{Vendor, gal}}$$

SOFTENING

11\. $$\text{Total Hardness, mg}/L \text{ as } CaCO_3 = \text{Calcium Hardness, mg}/L \text{ as } CaCO_3 + \text{Magnesium Hardness, mg}/L \text{ as } CaCO_3$$

12\. If alkalinity is greater than total hardness,

$$\text{Carbonate Hardness, mg}/L \text{ as } CaCO_3 = \text{Total Hardness, mg}/L \text{ as } CaCO_3$$

and

$$\text{Noncarbonate Hardness, mg}/L \text{ as } CaCO_3 = 0$$

13\. If alkalinity is less than total hardness,

$$\text{Carbonate Hardness, mg}/L \text{ as } CaCO_3 = \text{Alkalinity, mg}/L \text{ as } CaCO_3$$

and

$$\text{Noncarbonate Hardness, mg}/L \text{ as } CaCO_3 = \text{Total Hardness, mg}/L \text{ as } CaCO_3 - \text{Alkalinity, mg}/L \text{ as } CaCO_3$$

14a. $$\text{Phenolphthalein Alkalinity, mg}/L \text{ as } CaCO_3 = \frac{A \times N \times 50{,}000}{mL \text{ of sample}}$$

14b. $$\text{Total Alkalinity, mg}/L \text{ as } CaCO_3 = \frac{B \times N \times 50{,}000}{mL \text{ of sample}}$$

15a. $$\text{Hydrated Lime } (Ca(OH)_2) \text{ Feed, mg}/L = \frac{(A + B + C + D)1.15}{\text{Purity of Lime, as a decimal}}$$

15b. $$\text{Soda Ash } (Na_2CO_3) \text{ Feed, mg}/L = (\text{Noncarbonate Hardness, mg}/L \text{ as } CaCO_3)(106/100)$$

15c. $$\text{Total } CO_2 \text{ Feed, lbs/day} = (Ca(OH)_2 \text{ excess, mg}/L)(44/74) + (Mg^{2+} \text{ residual, mg}/L)(44/24.3)$$

16\. $$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Conc, mg}/L)(8.34 \text{ lbs/gal})$$

17\. $$\text{Feed Rate, lbs/min} = \frac{\text{Feeder Setting, lbs/day}}{(60 \text{ min/hr})(24 \text{ hr/day})}$$

18\. $$\text{Hardness, mg}/L = \frac{(\text{Hardness, grains/gal})(17.1 \text{ mg}/L)}{1 \text{ grain/gal}}$$

19\. $$\text{Exchange Capacity, grains} = (\text{Resin Vol, cu ft})(\text{Removal Capacity, grains/cu ft})$$

20\. $$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gal}}$$

21. Operating Time, hr $= \dfrac{\text{Water Treated, gal}}{\text{(Ave Daily Flow, gal/min)(60 min/hr)}}$

22. Salt Needed, lbs $= \left(\dfrac{\text{Salt Required,}}{\text{lbs/1000 gr}}\right)\left(\text{Hardness Removed, gr}\right)$

23 Bypass Flow, GPD $= \dfrac{\text{(Total Flow, GPD)(Plant Effl Hardness, gpg)}}{\text{Raw Water Hardness, gpg}}$

TRIHALOMETHANES

24. Ave TTHM, μg/*L* $= \dfrac{\text{Sum of Measurements, } \mu\text{g}/L}{\text{Number of Measurements}}$

25. Annual Running TTHM Average, μg/*L* $= \dfrac{\text{Sum of Ave TTHM for Four Quarters}}{\text{Number of Quarters}}$

DEMINERALIZATION

26. Flow, GPD/sq ft $= \dfrac{\text{(Flux, gm/sq cm-sec)(1 Liter)(1 Gal)(100 cm)}^2}{\text{(1000 gm)(3.785 } L\text{)(3.28 ft)}^2} \; \dfrac{\text{(3600 sec)(24 hr)}}{\text{(1 hr)(1 day)}}$

27. Mineral Rejection, % $= \left(1 - \dfrac{\text{Product TDS, mg/}L}{\text{Feed TDS, mg/}L}\right)(100\%)$

28. Recovery, % $= \dfrac{\text{(Product Flow, MGD)(100\%)}}{\text{Feed Flow, MGD}}$

29. Pump Capacity, GPM $= \dfrac{\text{Tank Volume, gal}}{\text{Pumping Time min}}$

30. Flow, GPD $= \dfrac{\text{(Volume Pumped, gal)(24 hr/day)}}{\text{Time, hr}}$

31. Polymer Feed, lbs/day $= \dfrac{\text{(Poly Conc, mg/}L\text{)(Vol Pumped, m}L\text{)(60 min/hr)(24 hr/day)}}{\text{(Time Pumped, min)(1000 m}L/L\text{)(1000 mg/gm)(454 gm/lb)}}$

32. Chemical Feed, lbs/day $= \dfrac{\text{(Chemical, gm)(60 min/hr)(24 hr/day)}}{\text{(454 gm/lb)(Time, min)}}$

SAFETY

33. Injury Freq Rate $= \dfrac{\text{(Injuries, number/yr)(1,000,000)}}{\text{Hours Worked, number/yr}}$

34. Injury Severity Rate $= \dfrac{\text{(Number of Hours Lost/yr) (1,000,000)}}{\text{Number of Hours Worked/yr}}$

ADVANCED LABORATORY PROCEDURES

35. Threshold Odor Number (T.O.N.) $= \dfrac{\text{Size of Sample, m}L + \text{Odor-Free Water, m}L}{\text{Size of Sample, m}L}$

36. Geometric Mean $= (X_1 \times X_2 \times X_3 \times \ldots X_n)^{1/n}$

37. Threshold Taste Number $= \dfrac{\text{Size of Sample, m}L + \text{Taste-Free Water, m}L}{\text{Size of Sample, m}L}$

38a. Arithmetic Mean, $\bar{X}$ Taste Rating $= \dfrac{X_1 + X_2 + X_3 + \ldots X_n}{n}$

38b. Standard Deviation, S Taste Rating $= \left[\dfrac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \ldots (X_n - \bar{X})^2}{n - 1}\right]^{0.5}$

or $= \left[\dfrac{(X_1^2 + X_2^2 + \ldots X_n^2) - (X_1 + X_2 + \ldots X_n)^2/n}{n - 1}\right]^{0.5}$

39. Portions Positive, % $= \dfrac{\text{(Number Positive/mo)(100\%)}}{\text{Total Portions Tested}}$

A.3 TYPICAL WATER TREATMENT PLANT PROBLEMS

A.30 Iron and Manganese Control

EXAMPLE 1

A standard polyphosphate solution is prepared by mixing and dissolving 1.0 grams of polyphosphate in a container and adding distilled water to the one-liter mark. Determine the concentration of the stock solution in milligrams per milliliter. If 6.0 milliliters of the stock solution are added to a one-liter sample, what is the polyphosphate dose in milligrams per liter and pounds per million gallons?

Known		Unknown
Polyphosphate, gm	= 1.0 gm	1. Stock Solution, mg/m*L*
Solution, *L*	= 1.0 *L*	2. Dose, mg/*L*
Stock Solution, m*L*	= 6 m*L*	3. Dose, lbs/MG
Sample, *L*	= 1 *L*	

1. Calculate the concentration of the stock solution in milligrams per milliliter.

$$\text{Stock Solution, mg/m}L = \frac{(\text{Polyphosphate, gm})(1000\text{ mg/gm})}{(\text{Solution, }L)(1000\text{ m}L/L)}$$

$$= \frac{(1.0\text{ gm})(1000\text{ mg/gm})}{(1\ L)(1000\text{ m}L/L)}$$

$$= 1.0\text{ mg/m}L$$

2. Determine the polyphosphate dose in the sample in milligrams per liter.

$$\text{Dose, mg/}L = \frac{(\text{Stock Solution, mg/m}L)(\text{Vol Added, m}L)}{\text{Sample Volume, }L}$$

$$= \frac{(1.0\text{ mg/m}L)(6\text{ m}L)}{1L}$$

$$= 6.0\text{ mg/}L$$

3. Determine the polyphosphate dose in the sample in pounds of phosphate per million gallons.

$$\text{Dose, lbs/MG} = \frac{(\text{Dose, mg/}L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(1000\text{ mg/gm})(454\text{ gm/lb})(1\text{ Million})}$$

$$= \frac{(6.0\text{ mg/}L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(1000\text{ mg/gm})(454\text{ gm/lb})(1\text{ Million})}$$

$$= 50\text{ lbs/MG}$$

EXAMPLE 2

Determine the chemical feeder setting in pounds of polyphosphate per day if 0.62 MGD is treated with a dose of 6 mg/*L*.

Known		Unknown
Flow, MGD	= 0.62 MGD	Chemical Feeder, lbs/day
Dose, mg/*L*	= 6 mg/*L*	

Determine the chemical feeder setting in pounds per day.

$$\text{Chemical Feeder, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (0.62\text{ MGD})(6\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 31\text{ lbs/day}$$

EXAMPLE 3

A reaction basin 14 feet in diameter and 4 feet deep treats a flow of 240,000 gallons per day. What is the average detention time in minutes?

Known		Unknown
Diameter, ft	= 14 ft	Detention Time, min
Depth, ft	= 4 ft	
Flow, GPD	= 240,000 GPD	

1. Calculate the basin volume in cubic feet.

$$\text{Basin Vol, cu ft} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})$$

$$= (0.785)(14\text{ ft})^2(4\text{ ft})$$

$$= 615\text{ cu ft}$$

2. Convert the basin volume from cubic feet to gallons.

$$\text{Basin Vol, gal} = (\text{Basin Vol, cu ft})(7.48\text{ gal/cu ft})$$

$$= (615\text{ cu ft})(7.48\text{ gal/cu ft})$$

$$= 4600\text{ gal}$$

3. Determine the average detention time in minutes for the reaction basin.

$$\text{Detention Time, min} = \frac{(\text{Basin Vol, gal})(24\text{ hr/day})(60\text{ min/hr})}{\text{Flow, gal/day}}$$

$$= \frac{(4600\text{ gal})(24\text{ hr/day})(60\text{ min/hr})}{240{,}000\text{ gal/day}}$$

$$= 28\text{ minutes}$$

EXAMPLE 4

Calculate the potassium permanganate dose in milligrams per liter for a well water with 2.4 mg/*L* iron before aeration and 0.3 mg/*L* after aeration. The manganese concentration is 0.8 mg/*L* both before and after aeration.

Known		Unknown
Iron, mg/*L*	= 0.3 mg/*L*	$KMnO_4$ Dose, mg/*L*
Manganese, mg/*L*	= 0.8 mg/*L*	

Calculate the potassium permanganate dose in milligrams per liter

$$KMnO_4\text{ Dose, mg/}L = 0.6(\text{Iron, mg/}L) + 2.0(\text{Manganese, mg/}L)$$

$$= 0.6(0.3\text{ mg/}L) + 2.0(0.8\text{ mg/}L)$$

$$= 1.78\text{ mg/}L$$

NOTE: If there are any oxidizable compounds (organic color, bacteria, or hydrogen sulfide) in the water, the dose will have to be increased.

A.31 Fluoridation

EXAMPLE 5

Determine the setting for a chemical feed pump in gallons per day when the desired fluoride dose is 1.8 pounds of fluoride per day. The sodium fluoride solution contains 0.2 pounds of fluoride per gallon and the fluoride purity is 43.4 percent.

Known		Unknown
Feed Rate, lbs F/day	= 1.8 lbs F/day	Feed Rate, gal/day
NaF Solution, lbs F/gal	= 0.2 lbs F/gal	
Purity, %	= 43.4%	

Determine the setting on the chemical feed pump in gallons per day.

$$\text{Feed Rate, gal/day} = \frac{(\text{Feed Rate, lbs F/day})(100\%)}{(\text{NaF Solution, lbs F/gal})(\text{Purity, \%})}$$

$$= \frac{(1.8 \text{ lbs F/day})(100\%)}{(0.2 \text{ lbs F/gal})(43.4\%)}$$

$$= 20.7 \text{ gal/day}$$

$$\text{or} = 21 \text{ gal/day}$$

EXAMPLE 6

Determine the setting on a chemical feed pump in gallons per day if 500,000 gallons per day of water must be treated with 0.9 mg/*L* of fluoride. The fluoride feed solution contains 18,000 mg/*L* of fluoride.

Known		Unknown
Flow, gal/day	= 500,000 gal/day	Feed Pump, gal/day
Fluoride, mg/*L*	= 0.9 mg/*L*	
Feed Solution, mg/*L*	= 18,000 mg/*L*	

Determine the setting on the chemical feed pump in gallons per day.

$$\text{Feed Solution, gal/day} = \frac{(\text{Flow, gal/day})(\text{Feed Dose, mg/}L)}{\text{Feed Solution, mg/}L}$$

$$= \frac{(500{,}000 \text{ gal/day})(0.9 \text{ mg/}L)}{18{,}000 \text{ mg/}L}$$

$$= 25 \text{ gal/day}$$

EXAMPLE 7

Determine the fluoride ion purity of Na_2SiF_6 as a percent.

Known	Unknown
Fluoride Chemical, Na_2SiF_6	Fluoride Purity, %

Determine the molecular weight of fluoride and Na_2SiF_6.

Symbol	(No. Atoms)	(Atomic Wt)	=	Molecular Wt
Na_2	(2)	(22.99)	=	45.98
Si	(1)	(28.09)	=	28.09
F_6	(6)	(19.00)	=	114.00
Molecular Weight of Chemical			=	188.07

Calculate the fluoride ion purity as a percent.

$$\text{Fluoride Ion Purity, \%} = \frac{(\text{Molecular Weight of Fluoride})(100\%)}{(\text{Molecular Weight of Chemical})}$$

$$= \frac{(114.00)(100\%)}{188.07}$$

$$= 60.62\%$$

EXAMPLE 8

A flow of 1.7 MGD is treated with sodium silicofluoride. The raw water contains 0.2 mg/*L* of fluoride ion and the desired fluoride concentration is 1.1 mg/*L*. What should be the chemical feed rate in pounds per day? Assume each pound of commercial sodium silicofluoride (Na_2SiF_6) contains 0.6 pounds of fluoride ion.

Known		Unknown
Flow, MGD	= 1.7 MGD	Feed Rate, lbs/day
Raw Water F, mg/*L*	= 0.2 mg/*L*	
Desired F, mg/*L*	= 1.1 mg/*L*	
Chemical, lbs F/lb	= 0.6 lbs F/lb	

1. Determine the fluoride feed dose in milligrams per liter.

$$\text{Feed Dose, mg/}L = \text{Desired Dose, mg/}L - \text{Actual Conc, mg/}L$$

$$= 1.1 \text{ mg/}L - 0.2 \text{ mg/}L$$

$$= 0.9 \text{ mg/}L$$

2. Calculate the fluoride feed rate in pounds per day.

$$\text{Feed Rate, lbs F/day} = (\text{Flow, MGD})(\text{Feed Dose, mg/}L)(8.34 \text{ lbs/gal})$$

$$= (1.7 \text{ MGD})(0.9 \text{ mg/}L)(8.34 \text{ lbs/gal})$$

$$= 12.8 \text{ lbs F/day}$$

3. Determine the chemical feed rate in pounds of commercial sodium silicofluoride per day.

$$\text{Feed Rate, lbs/day} = \frac{\text{Feed Rate, lbs F/day}}{\text{lbs F/lb Commercial } Na_2SiF_6}$$

$$= \frac{12.8 \text{ lbs F/day}}{0.6 \text{ lbs F/lb Commercial } Na_2SiF_6}$$

$$= 21.3 \text{ lbs/day Commercial } Na_2SiF_2$$

EXAMPLE 9

The feed solution from a saturator containing 1.8 percent fluoride ion is used to treat a total flow of 250,000 gallons of water. The raw water has a fluoride ion content of 0.2 mg/*L* and the desired fluoride level in the treated water is 0.9 mg/*L*. How many gallons of feed solution are needed?

Known		Unknown
Flow Vol, gal	= 250,000 gal	Feed Solution, gallons
Raw Water F, mg/*L*	= 0.2 mg/*L*	
Desired F, mg/*L*	= 0.9 mg/*L*	
Feed Solution, %F	= 1.8% F	

1. Convert the feed solution from a percentage fluoride ion to milligrams fluoride ion per liter of water.

$$1.0\% \text{ F} = 10{,}000 \text{ mg F/}L$$

$$\text{Feed Solution, mg/}L = \frac{(\text{Feed Solution, \%})(10{,}000 \text{ mg/}L)}{1.0\%}$$

$$= \frac{(1.8\% \text{ F})(10{,}000 \text{ mg/}L)}{1.0\%}$$

$$= 18{,}000 \text{ mg/}L$$

2. Determine the fluoride feed dose in milligrams per liter.

$$\text{Feed Dose, mg/}L = \text{Desired Dose, mg/}L - \text{Raw Water F, mg/}L$$

$$= 0.9 \text{ mg/}L - 0.2 \text{ mg/}L$$

$$= 0.7 \text{ mg/}L$$

3. Calculate the gallons of feed solution needed.

$$\text{Feed Solution, gal} = \frac{(\text{Flow Vol, gal})(\text{Feed Dose, mg/}L)}{\text{Feed Solution, mg/}L}$$

$$= \frac{(250{,}000 \text{ gal})(0.7 \text{ mg/}L)}{18{,}000 \text{ mg/}L}$$

$$= 9.7 \text{ gallons}$$

EXAMPLE 10

A hydrofluosilicic acid (H_2SiF_6) tank contains 350 gallons of acid with a strength of 19.3 percent. A commercial vendor delivers 2500 gallons of acid with a strength of 18 1 percent to the tank What is the resulting strength of the mixture as a percentage?

Known		Unknown
Tank Contents, gal	= 350 gal	Mixture Strength, %
Tank Strength, %	= 19.3%	
Vendor, gal	= 2500 gal	
Vendor Strength, %	= 18 1%	

Calculate the strength of the mixture as a percentage.

$$\text{Mixture Strength, \%} = \frac{(\text{Tank, gal})(\text{Tank, \%}) + (\text{Vendor, gal})(\text{Vendor, \%})}{\text{Tank, gal} + \text{Vendor, gal}}$$

$$= \frac{(350\text{ gal})(19\ 3\%) + (2500\text{ gal})(18\ 1\%)}{350\text{ gal} + 2500\text{ gal}}$$

$$= \frac{6755 + 45.250}{2850}$$

$$= 18\ 2\%$$

A.32 Softening

EXAMPLE 11

Determine the total hardness of $CaCO_3$ for a sample of water with a calcium content of 33 mg/*L* and a magnesium content of 6 mg/*L*.

Known		Unknown
Calcium, mg/*L*	= 33 mg/*L*	Total Hardness, mg/*L* as $CaCO_3$
Magnesium, mg/*L*	= 6 mg/*L*	

Calculate the total hardness as milligrams per liter of calcium carbonate equivalent.

$$\text{Total Hardness, mg/}L\text{ as }CaCO_3 = \text{Calcium Hardness, mg/}L\text{ as }CaCO_3 + \text{Magnesium Hardness, mg/}L\text{ as }CaCO_3$$

$$= 2.5(\text{Ca, mg/}L) + 4.12(\text{Mg, mg/}L)$$

$$= 2.5(33\text{ mg/}L) + 4\ 12(6\text{ mg/}L)$$

$$= 82\text{ mg/}L + 25\text{ mg/}L$$

$$= 107\text{ mg/}L\text{ as }CaCO_3$$

EXAMPLE 12

The alkalinity of a water is 120 mg/*L* as $CaCO_3$ and the total hardness is 105 mg/*L* as $CaCO_3$. What is the carbonate and noncarbonate hardness in mg/*L* as $CaCO_3$?

Known		Unknown
Alkalinity, mg/*L*	= 120 mg/*L* as $CaCO_3$	1. Carbonate Hardness, mg/*L* as $CaCO_3$
Total Hardness, mg/*L*	= 105 mg/*L* as $CaCO_3$	2. Noncarbonate Hardness, mg/*L* as $CaCO_3$

1. Determine the carbonate hardness in mg/*L* as $CaCO_3$.

   Since the alkalinity is greater than the total hardness, ($120\text{ mg/}L > 105\text{ mg/}L$),

   $$\text{Carbonate Hardness, mg/}L\text{ as }CaCO_3 = \text{Total Hardness, mg/}L\text{ as }CaCO_3$$

   $$= 105\text{ mg/}L\text{ as }CaCO_3$$

2. Determine the noncarbonate hardness in mg/*L* as $CaCO_3$

   Since the alkalinity is greater than the total hardness,

   $$\text{Noncarbonate Hardness, mg/}L\text{ as }CaCO_3 = 0$$

   In other words, all of the hardness is in the carbonate form.

EXAMPLE 13

The alkalinity of a water is 92 mg/*L* as $CaCO_3$ and the total hardness is 105 mg/*L*. What is the carbonate and noncarbonate hardness in mg/*L* as $CaCO_3$?

Known		Unknown
Alkalinity, mg/*L*	= 92 mg/*L* as $CaCO_3$	1. Carbonate Hardness, mg/*L* as $CaCO_3$
Total Hardness, mg/*L*	= 105 mg/*L* as $CaCO_3$	2. Noncarbonate Hardness, mg/*L* as $CaCO_3$

1 Determine the carbonate hardness in mg/*L* as $CaCO_3$.

Since the alkalinity is less than the total hardness ($92\text{ mg/}L < 105\text{ mg/}L$)

$$\text{Carbonate Hardness, mg/}L\text{ as }CaCO_3 = \text{Alkalinity, mg/}L\text{ as }CaCO_3$$

$$= 92\text{ mg/}L\text{ as }CaCO_3$$

2 Determine the noncarbonate hardness in mg/*L* as $CaCO_3$.

Since the alkalinity is less than the total hardness ($92\text{ mg/}L < 105\text{ mg/}L$)

$$\text{Noncarbonate Hardness, mg/}L\text{ as }CaCO_3 = \text{Total Hardness, mg/}L\text{ as }CaCO_3 - \text{Alkalinity, mg/}L\text{ as }CaCO_3$$

$$= 105\text{ mg/}L - 92\text{ mg/}L$$

$$= 13\text{ mg/}L\text{ as }CaCO_3$$

EXAMPLE 14

Results from alkalinity titrations on a water sample were as follows.

Known

Sample size, m*L*	= 100 m*L*
m*L* titrant used to pH 8.3, A	= 1.1 m*L*
Total m*L* of titrant used, B	= 12.4 m*L*
Acid normality, *N*	= 0.02 *N* H_2SO_4

Unknown

1. Total Alkalinity, mg/*L* as $CaCO_3$
2. Bicarbonate Alkalinity, mg/*L* as $CaCO_3$
3. Carbonate Alkalinity, mg/*L* as $CaCO_3$
4. Hydroxide Alkalinity, mg/*L* as $CaCO_3$

See Table 14.4, page 74 for alkalinity relationships among constituents

1. Calculate the phenolphthalein alkalinity in mg/*L* as $CaCO_3$.

$$\text{Phenolphthalein Alkalinity, mg/}L\text{ as CaCO}_3 = \frac{A \times N \times 50{,}000}{mL\text{ of sample}}$$

$$= \frac{(1.1\ mL)(0.02\ N)(50{,}000)}{100\ mL}$$

$$= 11\ mg/L\text{ as CaCO}_3$$

2. Calculate the total alkalinity in mg/L as $CaCO_3$.

$$\text{Total Alkalinity, mg/}L\text{ as CaCO}_3 = \frac{B \times N \times 50{,}000}{mL\text{ of sample}}$$

$$= \frac{(12.4\ mL)(0.02\ N)(50{,}000)}{100\ mL}$$

$$= 124\ mg/L\text{ as CaCO}_3$$

3. Refer to Table 14.4 for alkalinity constituents. The second row indicates that since P is less than ½T (11 mg/L < ½(124 mg/L)), bicarbonate alkalinity is T-2P and carbonate alkalinity is 2P.

$$\text{Bicarbonate Alkalinity, mg/}L\text{ as CaCO}_3 = T - 2P$$

$$= 124\ mg/L - 2(11\ mg/L)$$

$$= 102\ mg/L\text{ as CaCO}_3$$

$$\text{Carbonate Alkalinity, mg/}L\text{ as CaCO}_3 = 2P$$

$$= 2(11\ mg/L)$$

$$= 22\ mg/L\text{ as CaCO}_3$$

$$\text{Hydroxide Alkalinity, mg/}L\text{ as CaCO}_3 = 0\ mg/L\text{ as CaCO}_3$$

EXAMPLE 15

Calculate the hydrated lime ($Ca(OH)_2$) with 90 percent purity, soda ash, and carbon dioxide requirements in milligrams per liter for the water shown below.

Known

Constituent	Source Water	Softened Water After Recarbonation and Filtration
CO_2, mg/L	= 7 mg/L	= 0 mg/L
Total Alkalinity, mg/L	= 125 mg/L as $CaCO_3$	= 22 mg/L as $CaCO_3$
Total Hardness, mg/L	= 240 mg/L as $CaCO_3$	= 35 mg/L as $CaCO_3$
Mg^{2+}, mg/L	= 38 mg/L as $CaCO_3$	= 8 mg/L as $CaCO_3$
pH	= 7 6	= 8 8
Lime Purity, %	= 90%	

Unknown

1. Hydrated Lime, mg/L
2. Soda Ash, mg/L
3. Carbon Dioxide, mg/L

1. Calculate the hydrated lime ($Ca(OH)_2$) required in milligrams per liter.

$$A = (CO_2,\ mg/L)(74/44)$$

$$= (7\ mg/L)(74/44)$$

$$= 12\ mg/L$$

$$B = (\text{Alkalinity, mg/}L)(74/100)$$

$$= (125\ mg/L)(74/100)$$

$$= 93\ mg/L$$

$$C = (\text{Hydroxide, mg/}L)(74/100)$$

$$= 0$$

$$D = (Mg^{2+},\ mg/L)(74/24.3)$$

$$= (38\ mg/L)(74/24.3)$$

$$= 116\ mg/L$$

$$\text{Hydrated Lime } (Ca(OH)_2)\text{ Feed, mg/}L = \frac{(A + B + C + D)1.15}{\text{Purity of Lime, as a decimal}}$$

$$= \frac{(12\ mg/L + 93\ mg/L + 0 + 116 mg/L)1.15}{0.90}$$

$$= \frac{(221\ mg/L)(1.15)}{0.90}$$

$$= 282\ mg/L$$

2. Calculate the soda ash required in milligrams per liter.

$$\text{Noncarbonate Hardness, mg/}L\text{ as CaCO}_3 = \text{Total Hardness, mg/}L\text{ as CaCO}_3 - \text{Carbonate Hardness, mg/}L\text{ as CaCO}_3$$

$$= 240\ mg/L - 125\ mg/L$$

$$= 115\ mg/L\text{ as CaCO}_3$$

$$\text{Soda Ash } (Na_2CO_3)\text{ Feed, mg/}L = (\text{Noncarbonate Hardness, mg/}L\text{ as CaCO}_3)(106/100)$$

$$= (115\ mg/L)(106/100)$$

$$= 122\ mg/L$$

3. Calculate the dosage of carbon dioxide required for recarbonation.

$$\text{Excess Lime, mg/}L = (A + B + C + D)(0.15)$$

$$= (12\ mg/L + 93\ mg/L + 0 + 116\ mg/L)(0.15)$$

$$= (221\ mg/L)(0.15)$$

$$= 33\ mg/L$$

$$\text{Total } CO_2\text{ Feed, mg/}L = (Ca(OH)_2\text{ excess, mg/}L)(44/74) + (Mg^{2+}\text{ residual, mg/}L)(44/24.3)$$

$$= (33\ mg/L)(44/74) + 8\ mg/L)(44/24.3)$$

$$= 20\ mg/L + 15\ mg/L$$

$$= 35\ mg/L$$

EXAMPLE 16

The optimum lime dosage from the jar tests is 180 mg/L. If the flow to be treated is 1.7 MGD, what is the feeder setting in pounds per day and the feed rate in pounds per minute?

Known	Unknown
Lime Dose, mg/L = 180 mg/L	1. Feeder Setting, lbs/day
Flow, MGD = 1.7 MGD	2. Feed Rate, lbs/min

1. Calculate the feeder setting in pounds per day.

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Lime, mg/}L)(8.34\text{ lbs/gal})$$

$$= (1.7\ MGD)(180\ mg/L)(8.34\text{ lbs/gal})$$

$$= 2{,}550\text{ lbs/day}$$

2. Calculate the feed rate in pounds per minute

$$\text{Feed Rate, lbs/min} = \frac{\text{Feeder Setting, lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$

$$= \frac{2{,}550\ \text{lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$

$$= 1.8\ \text{lbs/min}$$

EXAMPLE 17

How much soda ash is required (pounds per day and pounds per minute) to remove 40 mg/*L* noncarbonate hardness as $CaCO_3$ from a flow of 1.7 MGD?

Known		Unknown
Noncarbonate Hardness Removed, mg/*L* as $CaCO_3$	= 40 mg/*L*	1. Feeder Setting, lbs/day
Flow, MGD	= 1.7 MGD	2. Feed Rate, lbs/min

1. Calculate the soda ash dose in milligrams per liter. See Section 14.316, "Calculation of Chemical Dosages," page 77, for the following formula.

$$\text{Soda Ash mg/}L = \left(\frac{\text{Noncarbonate Hardness,}}{\text{mg/}L\ \text{as}\ CaCO_3}\right)(106/100)$$

$$= (40\ \text{mg/}L)(106/100)$$

$$= 43\ \text{mg/}L$$

2. Determine the feeder setting in pounds per day.

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})(\text{Soda Ash, mg/}L)(8.34\ \text{lbs/gal})$$

$$= (1.7\ \text{MGD})(43\ \text{mg/}L)(8.34\ \text{lbs/gal})$$

$$= 610\ \text{lbs/day}$$

3. Calculate the soda ash feed rate in pounds per minute.

$$\text{Feed Rate, lbs/min} = \frac{\text{Feeder Setting, lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$

$$= \frac{610\ \text{lbs/day}}{(60\ \text{min/hr})(24\ \text{hr/day})}$$

$$= 0.43\ \text{lbs/min}$$

EXAMPLE 18

What is the hardness in milligrams per liter for a water with a hardness of 12 grains per gallon?

Known	Unknown
Hardness, gpg = 12 grains/gallon	Hardness, mg/*L*

Calculate the hardness in milligrams per liter.

$$\text{Hardness, mg/}L = \frac{(\text{Hardness, grains/gal})(17.1\ \text{mg/}L)}{1\ \text{grain/gal}}$$

$$= \frac{(12\ \text{grains/gal})(17.1\ \text{mg/}L)}{1\ \text{grain/gal}}$$

$$= 205\ \text{mg/}L$$

EXAMPLE 19

Estimate the exchange capacity in grains of hardness for an ion exchange unit which contains 600 cubic feet of resin with a removal capacity of 25,000 grains per cubic foot.

Known		Unknown
Resin Vol, cu ft	= 600 cu ft	Exchange Capacity, grains
Removal Cap, gr/cu ft	= 25,000 gr/cu ft	

Estimate the exchange capacity in grains of hardness.

$$\text{Exchange Capacity, grains} = (\text{Resin Vol, cu ft})(\text{Removal Capacity, gr/cu ft})$$

$$= (600\ \text{cu ft})(25{,}000\ \text{gr/cu ft})$$

$$= 15{,}000{,}000\ \text{grains of hardness}$$

EXAMPLE 20

How many gallons of water with a hardness of 12 grains per gallon may be treated by an ion exchange softener with an exchange capacity of 15,000,000 grains?

Known		Unknown
Hardness, grains/gal	= 12 grains/gal	Water Treated, gallons
Exchange Capacity, grains	= 15,000,000 grains	

Calculate the gallons of water that may be treated.

$$\text{Water Treated, gal} = \frac{\text{Exchange Capacity, grains}}{\text{Hardness, grains/gal}}$$

$$= \frac{15{,}000{,}000\ \text{grains}}{12\ \text{grains/gal}}$$

$$= 1{,}250{,}000\ \text{gallons}$$

EXAMPLE 21

How many hours will an ion exchange softening unit operate when treating an average daily flow of 750 GPM? The unit is capable of softening 1,250,000 gallons of water before requiring regeneration.

Known		Unknown
Ave Daily Flow, GPM	= 750 GPM	Operating Time, hr
Water Treated, gal	= 1,250,000 gal	

Estimate how many hours the softening unit can operate before requiring regeneration.

$$\text{Operating Time, hr} = \frac{\text{Water Treated, gal}}{(\text{Ave Daily Flow, gal/min})(60\ \text{min/hr})}$$

$$= \frac{1{,}250{,}000\ \text{gal}}{(750\ \text{gal/min})(60\ \text{min/hr})}$$

$$= 27.8\ \text{hours}$$

EXAMPLE 22

Determine the pounds of salt needed to regenerate an ion exchange softening unit capable of removing 15,000,000 grains of hardness if 0.25 pounds of salt are required for every 1000 grains of hardness removed.

Known	Unknown
Hardness Removed, gr = 15,000,000 grains	Salt Needed, lbs
Salt Required, lbs/1000 gr = 0.25 lbs salt/1000 gr	

$$\text{Salt Needed, lbs} = (\text{Salt Required, lbs/1000 gr})(\text{Hardness Removed, gr})$$

$$= \left(\frac{0.25 \text{ lbs salt}}{1000 \text{ grains}}\right)(15{,}000{,}000 \text{ grains})$$

$$= 3750 \text{ lbs of salt}$$

EXAMPLE 23

Estimate the bypass flow around an ion exchange softener if the plant treats 250,000 gallons per day with a source water hardness of 20 grains per gallon if the desired product water hardness is 5 grains per gallon.

Known	Unknown
Total Flow, GPD = 250,000 GPD	Bypass Flow, GPD
Source Water Hardness, gpg = 20 grains/gallon	
Plant Effl Hardness, gpg = 5 grains/gallon	

Estimate the bypass flow in gallons per day.

$$\text{Bypass Flow, GPD} = \frac{(\text{Total Flow, GPD})(\text{Plant Effl Hardness, gpg})}{\text{Source Water Hardness, gpg}}$$

$$= \frac{(250{,}000 \text{ GPD})(5 \text{ gpg})}{20 \text{ gpg}}$$

$$= 62{,}500 \text{ GPD}$$

A.33 Trihalomethanes

EXAMPLE 24

A water utility collected and analyzed eight samples from a water distribution system on the same day for TTHMs. The results are shown below.

Sample No.	1	2	3	4	5	6	7	8
TTHM, µg/L	80	90	100	90	110	100	100	90

What was the average TTHM for the day?

Known	Unknown
Results from analysis of 8 TTHM samples	Average TTHM level for the day

Calculate the average TTHM level in micrograms per liter

$$\text{Ave TTHM, } \mu g/L = \frac{\text{Sum of Measurement, } \mu g/L}{\text{Number of Measurements}}$$

$$= \frac{80\ \mu g/L + 90\ \mu g/L + 100\ \mu g/L + 90\ \mu g/L + 110\ \mu g/L + 100\ \mu g/L + 100\ \mu g/L + 90\ \mu g/L}{8}$$

$$= \frac{760\ \mu g/L}{8}$$

$$= 95\ \mu g/L$$

EXAMPLE 25

The results of the quarterly average TTHM measurement for two years are given below. Calculate the running annual average of the four quarterly measurements in micrograms per liter.

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, µg/L	77	88	112	95	83	87	109	89

Known	Unknown
Results from analysis of two years of TTHM sampling	Running Annual Average of quarterly TTHM measurements

Calculate the running annual average of the quarterly TTHM measurements.

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{\text{Sum of Ave TTHM for Four Quarters}}{\text{Number of Quarters}}$$

QUARTERS 1, 2, 3 AND 4

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{77\ \mu g/L + 88\ \mu g/L + 112\ \mu g/L + 95\ \mu g/L}{4}$$

$$= \frac{372\ \mu g/L}{4}$$

$$= 93\ \mu g/L$$

QUARTERS 2, 3, 4 AND 1

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{88\ \mu g/L + 112\ \mu g/L + 95\ \mu g/L + 83\ \mu g/L}{4}$$

$$= \frac{378\ \mu g/L}{4}$$

$$= 95\ \mu g/L$$

QUARTERS 3, 4, 1 AND 2

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{112\ \mu g/L + 95\ \mu g/L + 83\ \mu g/L + 87\ \mu g/L}{4}$$

$$= \frac{377\ \mu g/L}{4}$$

$$= 94\ \mu g/L$$

QUARTERS 4, 1, 2 AND 3

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{95\ \mu g/L + 83\ \mu g/L + 87\ \mu g/L + 109\ \mu g/L}{4}$$

$$= \frac{374\ \mu g/L}{4}$$

$$= 94\ \mu g/L$$

QUARTERS 1, 2, 3 AND 4

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{83\ \mu g/L + 87\ \mu g/L + 109\ \mu g/L + 89\ \mu g/L}{4}$$

$$= \frac{368\ \mu g/L}{4}$$

$$= 92\ \mu g/L$$

SUMMARY OF RESULTS

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, µg/L	77	88	112	95	83	87	109	89
Annual Running TTHM Ave, µg/L				93	95	94	94	92

A.34 Demineralization

EXAMPLE 26

Convert a water flux of 12×10^{-4} gm/sq cm-sec to gallons per day per square foot.

Known		Unknown
Water Flux, gm/sq cm-sec	$= 12 \times 10^{-4}$ gm/sq cm-sec	Flow, GPD/sq ft

Convert the water flux from gm/sq cm-sec to flow in GPD/sq ft.

$$\text{Flow, GPD/sq ft} = \frac{(\text{Flux, gm/sq cm-sec})(1\ \text{Liter})(1\ \text{Gal})(100\ \text{cm})^2(3600\ \text{sec})(24\ \text{hr})}{(1000\ \text{gm})(3.785\ L)(3.28\ \text{ft})^2(1\ \text{hr})(1\ \text{day})}$$

$$= \frac{(0.0012\ \text{gm/sq cm-sec})(1\ \text{Liter})(1\ \text{Gal})(100\ \text{cm})^2(3600\ \text{sec})(24\ \text{hr})}{(1000\ \text{gm})(3.785\ L)(3.28\ \text{ft})^2(1\ \text{hr})(1\ \text{day})}$$

$$= 25.5\ \text{GPD/sq ft}$$

EXAMPLE 27

Estimate the ability of a reverse osmosis plant to reject minerals by calculating the mineral rejection as a percent. The feedwater contains 1800 mg/*L* TDS and the product water TDS is 120 mg/*L*.

Known		Unknown
Feedwater TDS, mg/*L*	= 1800 mg/*L*	Mineral Rejection, %
Product Water TDS, mg/*L*	= 120 mg/*L*	

Calculate the mineral rejection as a percent.

$$\text{Mineral Rejection, \%} = \left(1 - \frac{\text{Product TDS, mg}/L}{\text{Feed TDS, mg}/L}\right)(100\%)$$

$$= \left(1 - \frac{120\ \text{mg}/L}{1800\ \text{mg}/L}\right)(100\%)$$

$$= (1 - 0.067)(100\%)$$

$$= 93.3\%$$

EXAMPLE 28

Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 2.0 MGD and the product flow is 1.75 MGD.

Known		Unknown
Product Flow, MGD	= 1.75 MGD	Recovery, %
Feed Flow, MGD	= 2.0 MGD	

Calculate the recovery as a percent.

$$\text{Recovery, \%} = \frac{(\text{Product Flow, MGD})(100\%)}{\text{Feed Flow, MGD}}$$

$$= \frac{(1.75\ \text{MGD})(100\%)}{2.0\ \text{MGD}}$$

$$= 87.5\%$$

A.35 Maintenance

EXAMPLE 29

Calculate the pumping capacity of a pump in gallons per minute when 12 minutes are required for the water to rise 3 feet in an 8 foot by 6 foot rectangular tank.

Known		Unknown
Length, ft	= 8 ft	Pump Capacity, GPM
Width, ft	= 6 ft	
Depth, ft	= 3 ft	
Time, min	= 12 min	

1. Calculate the volume pumped in cubic feet.

$$\text{Volume Pumped, cu ft} = (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})$$

$$= (8\ \text{ft})(6\ \text{ft})(3\ \text{ft})$$

$$= 144\ \text{cu ft}$$

2. Convert the volume pumped from cubic feet to gallons.

$$\text{Volume Pumped, gal} = (\text{Volume Pumped, cu ft})(7.48\ \text{gal/cu ft})$$

$$= (144\ \text{cu ft})(7.48\ \text{gal/cu ft})$$

$$= 1077\ \text{gal}$$

3. Calculate the pump capacity in gallons per minute.

$$\text{Pump Capacity, GPM} = \frac{\text{Volume Pumped, gal}}{\text{Pumping Time, min}}$$

$$= \frac{1077\ \text{gal}}{12\ \text{min}}$$

$$= 90\ \text{GPM}$$

EXAMPLE 30

A small chemical feed pump lowered the chemical solution in a 2.5-foot diameter tank 2.25 feet during seven hours. Estimate the flow delivered by the pump in gallons per minute and gallons per day.

Known		Unknown
Tank Diameter, ft	= 2.5 ft	Flow, GPM
Chemical Drop, ft	= 2.25 ft	Flow, GPD
Time, hr	= 7.0 hr	

1. Determine the gallons of chemical solution pumped.

$$\text{Volume, gal} = (0.785)(\text{Diameter, ft})^2(\text{Drop, ft})(7.48\ \text{gal/cu ft})$$

$$= (0.785)(2.5\ \text{ft})^2(2.25\ \text{ft})(7.48\ \text{gal/cu ft})$$

$$= 83\ \text{gallons}$$

2. Estimate the flow delivered by the pump in gallons per minute and gallons per day.

$$\text{Flow, GPM} = \frac{\text{Volume Pumped, gal}}{(\text{Time, hr})(60\ \text{min/hr})}$$

$$= \frac{83\ \text{gallons}}{(7\ \text{hr})(60\ \text{min/hr})}$$

$$= 0.2\ \text{GPM}$$

or

$$\text{Flow, GPD} = \frac{(\text{Volume Pumped, gal})(24\ \text{hr/day})}{\text{Time, hr}}$$

$$= \frac{(83\ \text{gallons})(24\ \text{hr/day})}{7\ \text{hr}}$$

$$= 285\ \text{GPD}$$

EXAMPLE 31

Determine the chemical feed in pounds of polymer per day from a chemical feed pump The polymer solution is 1.8 percent or 18,000 mg polymer per liter Assume a specific gravity of the polymer solution of 1 0. During a test run the chemical feed pump delivered 650 m*L* of polymer solution in 4.5 minutes.

Known	Unknown
Polymer Solution, % = 1 8 %	Polymer Feed, lbs/day
Polymer Conc. mg/*L* = 18,000 mg/*L*	
Polymer Sp Gr = 1 0	
Volume Pumped, m*L* = 650 m*L*	
Time Pumped, min = 4.5 min	

Calculate the polymer fed by the chemical feed pump in pounds of polymer per day.

$$\text{Polymer Feed, lbs/day} = \frac{(\text{Poly Conc. mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= \frac{(18{,}000\text{ mg}/L)(650\text{ m}L)(60\text{ min/hr})(24\text{ hr/day})}{(4\ 5\text{ min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= 8\ 2\text{ lbs/day}$$

EXAMPLE 32

Determine the actual chemical feed in pounds per day from a dry chemical feeder. A pie tin placed under the chemical feeder caught 824 grams of chemical during five minutes

Known	Unknown
Chemical, gm = 824 gm	Chemical Feed, lbs/day
Time, min = 5 min	

Determine the chemical feed in pounds per day.

$$\text{Chemical Feed, lbs/day} = \frac{(\text{Chemical, gm})(60\text{ min/hr})(24\text{ hr/day})}{(454\text{ gm/lb})(\text{Time, min})}$$

$$= \frac{(824\text{ gm})(60\text{ min/hr})(24\text{ hr/day})}{(454\text{ gm/lb})(5\text{ min})}$$

$$= 523\text{ lbs/day}$$

A.36 Safety

EXAMPLE 33

Calculate the injury frequency rate for a water utility where there were four injuries in one year and the operators worked 97,120 hours.

Known	Unknown
Injuries, number/yr = 4 injuries/yr	Injury Frequency Rate
Hours Worked, number/yr = 97,120 hrs/yr	

Calculate the injury frequency rate.

$$\text{Injury Freq Rate} = \frac{(\text{Injuries, number/yr})(1{,}000\,000)}{\text{Hours Worked, number/yr}}$$

$$= \frac{(4\text{ injuries/yr})(1{,}000{,}000)}{97{,}120\text{ hrs/yr}}$$

$$= 41.2$$

EXAMPLE 34

Calculate the injury severity rate for a water company which experienced 57 operator-hours lost due to injuries while the operators worked 97,120 hours during the year

Known	Unknown
Number of Hours Lost = 57 hrs/yr	Injury Severity Rate
Number of Hours Worked = 97,120 hrs/yr	

Calculate the injury severity rate

$$\text{Injury Severity Rate} = \frac{(\text{Number of Hours Lost/yr})(1{,}000{,}000)}{\text{Number of Hours Worked/yr}}$$

$$= \frac{(57\text{ hrs/yr})(1{,}000{,}000)}{97{,}120\text{ hrs/yr}}$$

$$= 587$$

A.37 Advanced Laboratory Procedures

EXAMPLE 35

Calculate the threshold odor number (T O.N.) for a sample when the first detectable odor occurred when the 70 m*L* sample was diluted to 200 m*L* (130 m*L* of odor-free water was added to the 70 m*L* sample)

Known	Unknown
Size of Sample, m*L* = 70 m*L*	T.O.N.
Odor-Free Water, m*L* = 130 m*L*	

Calculate the threshold odor number, T.O.N.

$$\text{T.O.N.} = \frac{\text{Size of Sample, m}L + \text{Odor-Free Water, m}L}{\text{Size of Sample, m}L}$$

$$= \frac{(70\text{ m}L + 130\text{ m}L}{70\text{ m}L}$$

$$= 3$$

EXAMPLE 36

Determine the geometric mean threshold odor number for a panel of six testers given the results shown below.

Known	Unknown
Tester 1, $X_1 = 2$	Geometric Mean Threshold Odor Number
Tester 2, $X_2 = 4$	
Tester 3, $X_3 = 3$	
Tester 4, $X_4 = 8$	
Tester 5, $X_5 = 6$	
Tester 6, $X_6 = 2$	

Calculate the geometric mean

$$\text{Geometric Mean T.O.N.} = (X_1 \times X_2 \times X_3 \times X_4 \times X_5 \times X_6)^{1/n}$$

$$= (2 \times 4 \times 3 \times 8 \times 6 \times 2)^{1/6}$$

$$= (2304)^{0\ 167}$$

$$= 3.6$$

EXAMPLE 37

Calculate the threshold taste number for a sample when the first detectable taste occurred when the 8.3 mL sample was diluted to 200 mL (191.7 mL of taste-free water was added to the 8.3 mL sample).

Known		Unknown
Sample Size, mL	= 8.3 mL	Threshold Taste Number
Taste-Free Water, mL	= 191.7	

(See top of right column for solution →)

Calculate the threshold taste number

$$\text{Threshold Taste Number} = \frac{\text{Sample Size, mL} + \text{Taste-Free Water, mL}}{\text{Sample Size, mL}}$$

$$= \frac{8.3\text{ mL} + 191.7\text{ mL}}{8.3\text{ mL}}$$

$$= 24$$

EXAMPLE 38

Determine the taste rating for a water by calculating the arithmetic mean and standard deviation for the panel ratings given below.

Known	Unknown
Tester 1, $X_1 = 2$	1. Arithmetic Mean, $\bar{X}$
Tester 2, $X_2 = 5$	2. Standard Deviation, S
Tester 3, $X_3 = 3$	
Tester 4, $X_4 = 6$	
Tester 5, $X_5 = 2$	
Tester 6, $X_6 = 6$	

1. Calculate the arithmetic mean, $\bar{X}$, taste rating.

$$\text{Arithmetic Mean, } \bar{X} \text{ Taste Rating} = \frac{X_1 + X_2 + X_3 + X_4 + X_5 + X_6}{n}$$

$$= \frac{2 + 5 + 3 + 6 + 2 + 6}{6}$$

$$= \frac{24}{6}$$

$$= 4$$

2. Calculate the standard deviation, S, of the taste rating.

$$\text{Standard Deviation, S} = \left[\frac{(X_1-\bar{X})^2 + (X_2-\bar{X})^2 + (X_3-\bar{X})^2 + (X_4-\bar{X})^2 + (X_5-\bar{X})^2 + (X_6-\bar{X})^2}{n-1}\right]^{0.5}$$

$$= \left[\frac{(2-4)^2 + (5-4)^2 + (3-4)^2 + (6-4)^2 + (2-4)^2 + (6-4)^2}{6-1}\right]^{0.5}$$

$$= \left[\frac{(-2)^2 + (1)^2 + (-1)^2 + (2)^2 + (-2)^2 + (2)^2}{5}\right]^{0.5}$$

$$= \left[\frac{4 + 1 + 1 + 4 + 4 + 4}{5}\right]^{0.5}$$

$$= \left[\frac{18}{5}\right]^{0.5}$$

$$= (3.6)^{0.5}$$

$$= 1.9$$

or

$$\text{Standard Deviation, S} = \left[\frac{(X_1^2 + X_2^2 + X_3^2 + X_4^2 + X_5^2 + X_6^2) - (X_1 + X_2 + X_3 + X_4 + X_5 + X_6)^2/n}{n-1}\right]^{0.5}$$

$$= \left[\frac{(2^2+5^2+3^2+6^2+2^2+6^2) - (2+5+3+6+2+6)^2/6}{n-1}\right]^{0.5}$$

$$= \left[\frac{(4+25+9+36+4+36) - (24)^2/6}{5}\right]^{0.5}$$

$$= \left[\frac{114-96}{5}\right]^{0.5}$$

$$= \left[\frac{18}{5}\right]^{0.5}$$

$$= (3.6)^{0.5}$$

$$= 1.9$$

EXAMPLE 39

A small water system collected 14 samples during one month. After each sample was collected, 10 m*L* of each sample was placed in each of 5 fermentation tubes. At the end of the month, the results indicated that 2 out of a total of 70 fermentation tubes were positive. What percent of the portions tested during the month were positive?

Known		Unknown
Number Positive/mo	= 2 positive/mo	Portions Positive, %/mo
Total Portions Tested	= 70 portions	

Calculate the percent of the portions tested during the month which were positive.

$$\text{Portions Positive, \%/mo} = \frac{(\text{Number Positive/mo})(100\%)}{\text{Total Portions Tested}}$$

$$= \frac{(2\text{ positive/mo})(100\%)}{70\text{ portions}}$$

$$= 3\%/\text{mo}$$

A.4 BASIC CONVERSION FACTORS (METRIC SYSTEM)

LENGTH

100 cm = 1 m	100 cm/m
3.281 ft = 1 m	3.281 ft/m

AREA

2.4711 ac = 1 ha*	2.4711 ac/ha
10,000 sq m = 1 ha	10,000 sq m/ha

VOLUME

1000 m*L* = 1 liter	1000 m*L*/*L*
1000 *L* = 1 cu m	1000 *L*/cu m
3.785 *L* = 1 gal	3.785 *L*/gal

WEIGHT

1000 mg = 1 gm	1000 mg/gm
1000 gm = 1 kg	1000 gm/kg

DENSITY

1 kg = 1 liter	1 kg/*L*

PRESSURE

10.015 M = 1 kg/sq cm	10.015 m/kg/sq cm
1 Pascal = 1 N/sq m	1 Pa/N/sq m
1 psi = 6895 Pa	1 psi/6895 Pa

FLOW

3785 cu m/day = 1 MGD	3785 cu m/day/MGD
3.785 M*L*/day = 1 MGD	3.785 M*L*/day/MGD

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* hectare

A.5 TYPICAL WATER TREATMENT PLANT PROBLEMS

A.50 Iron and Manganese Control

EXAMPLE 1

A standard polyphosphate solution is prepared by mixing and dissolving 1.0 grams of polyphosphate in a container and adding distilled water to the one-liter mark. Determine the concentration of the stock solution in milligrams per liter. If 6 milliliters of the stock solution are added to a one-liter sample, what is the polyphosphate dose in milligrams per liter and milligrams per kilogram?

Known		Unknown
Polyphosphate, gm	= 1.0 gm	1. Stock Solution, mg/m*L*
Solution, *L*	= 1.0 *L*	2. Dose, mg/*L*
Stock Solution, m*L*	= 6 m*L*	3. Dose, mg/kg
Sample, *L*	= 1 *L*	

1. Calculate the concentration of the stock solution in milligrams per milliliter.

$$\text{Stock Solution, mg/m}L = \frac{(\text{Polyphosphate, gm})(1000 \text{ mg/gm})}{(\text{Solution, } L)(1000 \text{ m}L/L)}$$

$$= \frac{(1.0 \text{ gm})(1000 \text{ mg/gm})}{(1\ L)(1000 \text{ m}L/L)}$$

$$= 1.0 \text{ mg/m}L$$

2. Determine the polyphosphate dose in the sample in milligrams per liter.

$$\text{Dose, mg/}L = \frac{(\text{Stock Solution, mg/m}L)(\text{Vol Added, m}L)}{\text{Sample Volume, } L}$$

$$= \frac{(1.0 \text{ mg/m}L)(6 \text{ m}L)}{1 L}$$

$$= 6.0 \text{ mg/}L$$

3. Determine the polyphosphate dose in the sample in milligrams of phosphate per kilogram of water.

$$\text{Dose, mg/kg} = \frac{(\text{Stock Solution, mg/}L)(\text{Vol Added, m}L)}{(\text{Sample Volume, } L)(1 \text{ kg/}L)}$$

$$= \frac{(1.0 \text{ mg/m}L)(6 \text{ m}L)}{(1\ L)(1 \text{ kg/}L)}$$

$$= 6.0 \text{ mg/kg}$$

EXAMPLE 2

Determine the chemical feeder setting in grams per second and kilograms per day if 2.4 M*L*D (mega or million liters per day) are treated with a dose of 5 mg/*L*.

Known	Unknown
Flow, M*L*D = 2.4 M*L*D	1. Chemical Feeder, gm/sec
Dose, mg/*L* = 5 mg/*L*	2. Chemical Feeder, kg/day

1. Determine the chemical feeder setting in grams per second.

$$\text{Chemical Feeder, gm/sec} = \frac{(\text{Flow, M}L\text{D})(\text{Dose, mg/}L)(1{,}000{,}000/\text{M})}{(24 \text{ hr/day})(60 \text{ min/hr})(60 \text{ sec/min})(1000 \text{ mg/gm})}$$

$$= \frac{(2.4 \text{ M}L\text{D})(5 \text{ mg/}L)(1{,}000{,}000/\text{M})}{(24 \text{ hr/day})(60 \text{ min/hr})(60 \text{ sec/min})(1000 \text{ mg/gm})}$$

$$= 0.139 \text{ gm/sec}$$

$$\text{or} \quad = 139 \text{ mg/sec}$$

2. Determine the chemical feeder setting in kilograms per day.

$$\text{Chemical Feeder, kg/day} = \frac{(\text{Flow, M}L\text{D})(\text{Dose, mg/}L)(1{,}000{,}000/\text{M})}{(1000 \text{ mg/gm})(1000 \text{ gm/kg})}$$

$$= \frac{(2.4 \text{ M}L\text{D})(5 \text{ mg/}L)(1{,}000{,}000/\text{M})}{(1000 \text{ mg/gm})(1000 \text{ gm/kg})}$$

$$= 12 \text{ kg/day}$$

EXAMPLE 3

A reaction basin 4 meters in diameter and 1.2 meters deep treats a flow of 0.9 M*L*D. What is the average detention time in minutes?

Known	Unknown
Diameter, m = 4 m	Detention Time, min
Depth, m = 1.2 m	
Flow, M*L*D = 0.9 M*L*D	

1. Calculate the basin volume in cubic meters.

$$\text{Basin Vol, cu m} = (0.785)(\text{Diameter, m})^2(\text{Depth, m})$$

$$= (0.785)(4 \text{ m})^2(1.2 \text{ m})$$

$$= 15.1 \text{ cu m}$$

2. Determine the average detention time in minutes for the reaction basin.

$$\text{Detention Time, min} = \frac{(\text{Basin Vol, cu m})(24 \text{ hr/day})(60 \text{ min/hr})(1000\ L/\text{cu m})}{(\text{Flow, M}L\text{D})(1{,}000{,}000/\text{M})}$$

$$= \frac{(15.1 \text{ cu m})(24 \text{ hr/day})(60 \text{ min/hr})(1000\ L/\text{cu m})}{(0.9 \text{ M}L\text{D})(1{,}000{,}000/\text{M})}$$

$$= 24 \text{ minutes}$$

EXAMPLE 4

Calculate the potassium permanganate dose in milligrams per liter for a well water with 2.4 mg/*L* iron before aeration and 0.3 mg/*L* after aeration. The manganese concentration is 0.8 mg/*L* both before and after aeration.

Known	Unknown
Iron, mg/*L* = 0.3 mg/*L*	$KMnO_4$ Dose, mg/*L*
Manganese, mg/*L* = 0.8 mg/*L*	

Calculate the potassium permanganate dose in milligrams per liter.

$$KMnO_4 \text{ Dose, mg/}L = 0.6(\text{Iron, mg/}L) + 2.0(\text{Manganese, mg/}L)$$

$$= 0.6(0.3 \text{ mg/}L) + 2.0(0.8 \text{ mg/}L)$$

$$= 1.78 \text{ mg/}L$$

NOTE: If there are any oxidizable compounds (organic color, bacteria, or hydrogen sulfide) in the water, the dose will have to be increased.

A.51 Fluoridation

EXAMPLE 5

Determine the setting for a chemical feed pump in gallons per day when the desired fluoride dose is 0.9 kilograms of fluoride per day. The sodium fluoride solution contains 0.025 kilograms of fluoride per gallon and the fluoride purity is 43.4 percent.

Known	Unknown
Feed Rate, lbs F/day = 0.9 kg F/day	1. Feed Rate, liters/day
NaF Solution, kg F/*L* = 0.025 kg F/*L*	2. Feed Rate, m*L*/sec
Purity, % = 43.4%	

Determine the setting on the chemical feed pump in liters per day.

$$\text{Feed Rate, } L\text{/day} = \frac{(\text{Feed Rate, kg F/day})(100\%)}{(\text{NaF Solution, kg F/}L)(\text{Purity, \%})}$$

$$= \frac{(0.9 \text{ kg F/day})(100\%)}{(0.025 \text{ kg F/}L)(43.4\%)}$$

$$= 83 \text{ liters/day}$$

2. Convert the feed rate from kilograms per day to grams per second.

$$\text{Feed Rate, gm/sec} = \frac{(\text{Feed Rate, kg/day})(1000\ \text{gm/kg})}{(24\ \text{hr/day})(60\ \text{min/hr})(60\ \text{sec/min})}$$

$$= \frac{(0.9\ \text{kg/day})(1000\ \text{gm/kg})}{(24\ \text{hr/day})(60\ \text{min/hr})(60\ \text{sec/min})}$$

$$= 0.010\ \text{gm/sec}$$

$$\text{or} \quad = 10\ \text{mg/sec}$$

3. Determine the setting on the chemical feed pump in milliliters per second.

$$\text{Feed Rate, mL/sec} = \frac{(\text{Feed Rate, gm/sec})(100\%)(1000\ \text{mL/L})}{(\text{NaF Solution, kg F/L})(\text{Purity, \%})(1000\ \text{gm/kg})}$$

$$= \frac{(0.010\ \text{gm/sec})(100\%)(1000\ \text{mL/L})}{(0.025\ \text{kg F/L})(43.4\%)(1000\ \text{gm/kg})}$$

$$= 0.92\ \text{mL/sec}$$

EXAMPLE 6

Determine the setting on a chemical feed pump in liters per day and milliliters per second if 2 megaliters per day of water must be treated with 0.9 mg/*L* of fluoride. The fluoride feed solution contains 18,000 mg/*L* of fluoride.

Known		Unknown
Flow, M*L*D	= 2 M*L*D	1. Feed Pump, liters/day
Fluoride, mg/*L*	= 0.9 mg/*L*	2. Feed Pump, m*L*/sec
Feed Solution, mg/*L*	= 18,000 mg/*L*	

1. Determine the setting on the chemical feed pump in liters per day.

$$\text{Feed Pump, liters/day} = \frac{(\text{Flow, MLD})(\text{Feed Dose, mg/L})(1{,}000{,}000/\text{M})}{\text{Feed Solution, mg/L}}$$

$$= \frac{(2.0\ \text{MLD})(0.9\ \text{mg/L})(1{,}000{,}000/\text{M})}{18{,}000\ \text{mg/L}}$$

$$= 100\ \text{liters/day}$$

2. Determine the setting on the chemical feed pump in milliliters per second.

$$\text{Feed Pump, mL/sec} = \frac{(\text{Flow, MLD})(\text{Feed Dose, mg/L})(1{,}000{,}000/\text{M})}{(\text{Feed Solution, mg/L})(24\ \text{hr/day})(60\ \text{min/hr})(60\ \text{sec/min})}$$

$$= \frac{(2\ \text{MLD})(0.9\ \text{mg/L})(1{,}000{,}000/\text{M})}{(18{,}000\ \text{mg/L})(24\ \text{hr/day})(60\ \text{min/hr})(60\ \text{sec/min})}$$

$$= 1.16\ \text{mL/sec}$$

EXAMPLE 7

Determine the fluoride ion purity of Na_2SiF_6 as a percent.

Known	Unknown
Fluoride Chemical, Na_2SiF_6	Fluoride Purity, %

Determine the molecular weight of fluoride and Na_2SiF_6.

Symbol	(No. Atoms)	(Atomic Wt)	=	Molecular Wt
Na_2	(2)	(22.99)	=	45.98
Si	(1)	(28.09)	=	28.09
F_6	(6)	(19.00)	=	114.00
Molecular Weight of Chemical			=	188.07

Calculate the fluoride ion purity as a percent.

$$\text{Fluoride Ion Purity, \%} = \frac{(\text{Molecular Weight of Fluoride})(100\%)}{(\text{Molecular Weight of Chemical})}$$

$$= \frac{(114.00)(100\%)}{188.07}$$

$$= 60.62\%$$

EXAMPLE 8

A flow of 6.5 M*L*D is treated with sodium silicofluoride. The raw water contains 0.2 mg/*L* of fluoride ion and the desired fluoride concentration is 1.1 mg/*L*. What should be the chemical feed rate in kilograms per day and milligrams per second? Assume each gram of commercial sodium silicofluoride (Na_2SiF_6) contains 0.6 grams of fluoride ion.

Known		Unknown
Flow, M*L*D	= 6.5 M*L*D	1. Feed Rate, kg/day
Raw Water F, mg/*L*	= 0.2 mg/*L*	2. Feed Rate, mg/sec
Desired F, mg/*L*	= 1.1 mg/*L*	
Chemical, gm F/gm	= 0.6 gm F/gm	

1. Determine the fluoride feed dose in milligrams per liter.

$$\text{Feed Dose, mg/L} = \text{Desired Dose, mg/L} - \text{Actual Conc, mg/L}$$

$$= 1.1\ \text{mg/L} - 0.2\ \text{mg/L}$$

$$= 0.9\ \text{mg/L}$$

2. Calculate the chemical feed rate in kilograms per day.

$$\text{Feed Rate, kg/day} = \frac{(\text{Flow, MLD})(\text{Feed Dose, mg/L})(1{,}000{,}000/\text{M})}{(\text{Purity, gm F/gm chemical})(1000\ \text{mg/gm})(1000\ \text{gm/kg})}$$

$$= \frac{(6.5\ \text{MLD})(0.9\ \text{mg/L})(1{,}000{,}000/\text{M})}{(0.6\ \text{gm F/gm chemical})(1000\ \text{mg/gm})(1000\ \text{gm/kg})}$$

$$= 9.75\ \text{kg/day}$$

3. Calculate the chemical feed rate in milligrams per second.

$$\text{Feed Rate, mg/sec} = \frac{(\text{Flow, MLD})(\text{Dose, mg/L})(1{,}000{,}000/\text{M})}{(\text{Purity, gm F/gm chemical})(24\ \text{hr/day})(60\ \text{min/hr})(60\ \text{sec/min})}$$

$$= \frac{(6.5\ \text{MLD})(0.9\ \text{mg/L})(1{,}000{,}000/\text{M})}{(0.6\ \text{gm F/gm chemical})(24\ \text{hr/day})(60\ \text{min/hr})(60\ \text{sec/min})}$$

$$= 113\ \text{mg/sec}$$

EXAMPLE 9

The feed solution from a saturator containing 1.8 percent fluoride ion is used to treat a total flow of 0.95 megaliters (M*L*) of water. The raw water has a fluoride ion content of 0.2 mg/*L* and the desired fluoride level in the treated water is 0.9 mg/*L*. How many gallons of feed solution are needed?

Known		Unknown
Flow Vol, M*L*	= 0.95 M*L*	Feed Solution, liters
Raw Water F, mg/*L*	= 0.2 mg/*L*	
Desired F, mg/*L*	= 0.9 mg/*L*	
Feed Solution, %F	= 1.8% F	

1. Convert the feed solution from a percentage fluoride ion to milligrams fluoride ion per liter of water.

$$1.0\%\ F = 10{,}000\ mg\ F/L$$

$$\text{Feed Solution, mg/}L = \frac{(\text{Feed Solution, \%})(10{,}000\ mg/L)}{1.0\%}$$

$$= \frac{(1.8\%\ F)(10{,}000\ mg/L)}{1.0\%}$$

$$= 18{,}000\ mg/L$$

2. Determine the fluoride feed dose in milligrams per liter

$$\text{Feed Dose, mg/}L = \text{Desired Dose, mg/}L - \text{Raw Water F, mg/}L$$

$$= 0.9\ mg/L - 0.2\ mg/L$$

$$= 0.7\ mg/L$$

3. Calculate the liters of feed solution needed.

$$\text{Feed Solution, } L = \frac{(\text{Flow Vol, M}L)(\text{Feed Dose, mg/}L)(1{,}000{,}000/\text{M})}{\text{Feed Solution, mg/}L}$$

$$= \frac{(0.95\ ML)(0.7\ mg/L)(1{,}000{,}000/M)}{18{,}000\ mg/L}$$

$$= 37\ \text{liters}$$

EXAMPLE 10

A hydrofluosilicic acid (H_2SiF_6) tank contains 1300 liters of acid with a strength of 19.3 percent. A commercial vendor delivers 10,000 liters of acid with a strength of 18.1 percent to the tank. What is the resulting strength of the mixture as a percentage?

Known		Unknown
Tank Contents, liters	= 1300 *L*	Mixture Strength, %
Tank Strength, %	= 19.3%	
Vendor, *L*	= 10,000 *L*	
Vendor Strength, %	= 18.1%	

Calculate the strength of the mixture as a percentage.

$$\text{Mixture Strength, \%} = \frac{(\text{Tank, } L)(\text{Tank, \%}) + (\text{Vendor, } L)(\text{Vendor, \%})}{\text{Tank, } L + \text{Vendor, } L}$$

$$= \frac{(1300\ L)(19.3\%) + (10{,}000\ L)(18.1\%)}{1300\ L + 10{,}000\ L}$$

$$= \frac{25{,}090 + 181.000}{11{,}300}$$

$$= 18.2\%$$

A.52 Softening

EXAMPLE 11

Determine the total hardness of $CaCO_3$ for a sample of water with a calcium content of 33 mg/*L* and a magnesium content of 6 mg/*L*.

Known		Unknown
Calcium, mg/*L*	= 33 mg/*L*	Total Hardness, mg/*L* as $CaCO_3$
Magnesium, mg/*L*	= 6 mg/*L*	

Calculate the total hardness as milli grams per liter of calcium carbonate equivalent.

$$\text{Total Hardness, mg/}L \text{ as } CaCO_3 = \text{Calcium Hardness, mg/}L \text{ as } CaCO_3 + \text{Magnesium Hardness, mg/}L \text{ as } CaCO_3$$

$$= 2.5(\text{Ca, mg/}L) + 4.12(\text{Mg, mg/}L)$$

$$= 2.5(33\ mg/L) + 4.12(6\ mg/L)$$

$$= 82\ mg/L + 25\ mg/L$$

$$= 107\ mg/L \text{ as } CaCO_3$$

EXAMPLE 12

The alkalinity of a water is 120 mg/*L* as $CaCO_3$ and the total hardness is 105 mg/*L* as $CaCO_3$. What is the carbonate and noncarbonate hardness in mg/*L* as $CaCO_3$?

	Known	Unknown
Alkalinity, mg/*L*	= 120 mg/*L* as $CaCO_3$	1. Carbonate Hardness, mg/*L* as $CaCO_3$
Total Hardness, mg/*L*	= 105 mg/*L* as $CaCO_3$	2. Noncarbonate Hardness, mg/*L* as $CaCO_3$

1. Determine the carbonate hardness in mg/*L* as $CaCO_3$.

Since the alkalinity is greater than the total hardness, (120 mg/*L* > 105 mg/*L*),

$$\text{Carbonate Hardness, mg/}L \text{ as } CaCO_3 = \text{Total Hardness, mg/}L \text{ as } CaCO_3$$

$$= 105\ mg/L \text{ as } CaCO_3$$

2. Determine the noncarbonate hardness in mg/*L* as $CaCO_3$

Since the alkalinity is greater than the total hardness,

$$\text{Noncarbonate Hardness, mg/}L \text{ as } CaCO_3 = 0$$

In other words, all of the hardness is in the carbonate form.

EXAMPLE 13

The alkalinity of a water is 92 mg/*L* as $CaCO_3$ and the total hardness is 105 mg/*L* What is the carbonate and noncarbonate hardness in mg/*L* as $CaCO_3$?

	Known	Unknown
Alkalinity, mg/*L*	= 92 mg/*L* as $CaCO_3$	1. Carbonate Hardness, mg/*L* as $CaCO_3$
Total Hardness, mg/*L*	= 105 mg/*L* as $CaCO_3$	2. Noncarbonate Hardness, mg/*L* as $CaCO_3$

1. Determine the carbonate hardness in mg/*L* as $CaCO_3$.

Since the alkalinity is less than the total hardness (92 mg/*L* < 105 mg/*L*)

$$\text{Carbonate Hardness, mg/}L \text{ as } CaCO_3 = \text{Alkalinity, mg/}L \text{ as } CaCO_3$$

$$= 92\ mg/L \text{ as } CaCO_3$$

2. Determine the noncarbonate hardness in mg/*L* as $CaCO_3$.

Since the alkalinity is less than the total hardness (92 mg/*L* < 105 mg/*L*)

$$\begin{aligned}\text{Noncarbonate Hardness, mg}/L\text{ as CaCO}_3 &= \text{Total Hardness, mg}/L\text{ as CaCO}_3 - \text{Alkalinity, mg}/L\text{ as CaCO}_3\\ &= 105\text{ mg}/L - 92\text{ mg}/L\\ &= 13\text{ mg}/L\text{ as CaCO}_3\end{aligned}$$

EXAMPLE 14

Results from alkalinity titrations on a water sample were as follows:

Known

Sample size, m*L* = 100 m*L*
m*L* titrant used to pH 8.3, A = 1.1 m*L*
Total m*L* of titrant used, B = 12.4 m*L*
Acid normality, *N* = 0.02 *N* H_2SO_4

Unknown

1. Total Alkalinity, mg/*L* as $CaCO_3$
2. Bicarbonate Alkalinity, mg/*L* as $CaCO_3$
3. Carbonate Alkalinity, mg/*L* as $CaCO_3$
4. Hydroxide Alkalinity, mg/*L* as $CaCO_3$

See Table 14.4, page 74, for alkalinity relationships among constituents.

1. Calculate the phenolphthalein alkalinity in mg/*L* as $CaCO_3$.

$$\begin{aligned}\text{Phenolphthalein Alkalinity, mg}/L\text{ as CaCO}_3 &= \frac{A \times N \times 50{,}000}{\text{m}L\text{ of sample}}\\ &= \frac{(1.1\text{ m}L)(0.02\ N)(50{,}000)}{100\text{ m}L}\\ &= 11\text{ mg}/L\text{ as CaCO}_3\end{aligned}$$

2. Calculate the total alkalinity in mg/*L* as $CaCO_3$.

$$\begin{aligned}\text{Total Alkalinity, mg}/L\text{ as CaCO}_3 &= \frac{B \times N \times 50{,}000}{\text{m}L\text{ of sample}}\\ &= \frac{(12.4\text{ m}L)(0.02\ N)(50{,}000)}{100\text{ m}L}\\ &= 124\text{ mg}/L\text{ as CaCO}_3\end{aligned}$$

3. Refer to Table 14.4 for alkalinity constituents. The second row indicates that since P is less than ½T (11 mg/*L* < ½(124 mg/*L*), bicarbonate alkalinity is T-2P and carbonate alkalinity is 2P.

$$\begin{aligned}\text{Bicarbonate Alkalinity, mg}/L\text{ as CaCO}_3 &= T - 2P\\ &= 124\text{ mg}/L - 2(11\text{ mg}/L)\\ &= 102\text{ mg}/L\text{ as CaCO}_3\end{aligned}$$

$$\begin{aligned}\text{Carbonate Alkalinity, mg}/L\text{ as CaCO}_3 &= 2P\\ &= 2(11\text{ mg}/L)\\ &= 22\text{ mg}/L\text{ as CaCO}_3\end{aligned}$$

$$\text{Hydroxide Alkalinity, mg}/L\text{ as CaCO}_3 = 0\text{ mg}/L\text{ as CaCO}_3$$

EXAMPLE 15

Calculate the hydrated lime ($Ca(OH)_2$) with 90 percent purity, soda ash, and carbon dioxide requirements in milligrams per liter for the water shown below.

Known

Constituents	Source Water	Softened Water After Recarbonation and Filtration
CO_2, mg/*L*	= 7 mg/*L*	= 0 mg/*L*
Total Alkalinity, mg/*L*	= 125 mg/*L* as $CaCO_3$	= 22 mg/*L* as $CaCO_3$
Total Hardness, mg/*L*	= 240 mg/*L* as $CaCO_3$	= 35 mg/*L* as $CaCO_3$
Mg^{2+}, mg/*L*	= 38 mg/*L* as $CaCO_3$	= 8 mg/*L* as $CaCO_3$
pH	= 7.6	= 8.8
Lime Purity, %	= 90%	

Unknown

1. Hydrated Lime, mg/*L*
2. Soda Ash, mg/*L*
3. Carbon Dioxide, mg/*L*

1. Calculate the hydrated lime ($Ca(OH)_2$) required in milligrams per liter.

$$\begin{aligned}A &= (\text{CO}_2,\text{ mg}/L)(74/44)\\ &= (7\text{ mg}/L)(74/44)\\ &= 12\text{ mg}/L\end{aligned}$$

$$\begin{aligned}B &= (\text{Alkalinity, mg}/L)(74/100)\\ &= (125\text{ mg}/L)(74/100)\\ &= 93\text{ mg}/L\end{aligned}$$

$$\begin{aligned}C &= (\text{Hydroxide, mg}/L)(74/100)\\ &= 0\end{aligned}$$

$$\begin{aligned}D &= (\text{Mg}^{2+},\text{ mg}/L)(74/24.3)\\ &= (38\text{ mg}/L)(74/24.3)\\ &= 116\text{ mg}/L\end{aligned}$$

$$\begin{aligned}\text{Hydrated Lime (Ca(OH)}_2\text{) Feed, mg}/L &= \frac{(A + B + C + D)1.15}{\text{Purity of Lime, as a decimal}}\\ &= \frac{(12\text{ mg}/L + 93\text{ mg}/L + 0 + 116\text{mg}/L)1.15}{0.90}\\ &= \frac{(221\text{ mg}/L)(1.15)}{0.90}\\ &= 282\text{ mg}/L\end{aligned}$$

2. Calculate the soda ash required in milligrams per liter.

$$\begin{aligned}\text{Noncarbonate Hardness, mg}/L\text{ as CaCO}_3 &= \text{Total Hardness, mg}/L\text{ as CaCO}_3 - \text{Carbonate Hardness, mg}/L\text{ as CaCO}_3\\ &= 240\text{ mg}/L - 125\text{ mg}/L\\ &= 115\text{ mg}/L\text{ as CaCO}_3\end{aligned}$$

$$\begin{aligned}\text{Soda Ash (Na}_2\text{CO}_3\text{) Feed, mg}/L &= (\text{Noncarbonate Hardness, mg}/L\text{ as CaCO}_3)(106/100)\\ &= (115\text{ mg}/L)(106/100)\\ &= 122\text{ mg}/L\end{aligned}$$

3. Calculate the dosage of carbon dioxide required for recarbonation.

$$\begin{aligned}\text{Excess Lime, mg/}L &= (A + B + C + D)(0.15)\\ &= (12\text{ mg/}L + 93\text{ mg/}L + 0 + 116\text{ mg/}L)(0.15)\\ &= (221\text{ mg/}L)(0.15)\\ &= 33\text{ mg/}L\end{aligned}$$

$$\begin{aligned}\text{Total CO}_2\text{ Feed, mg/}L &= (\text{Ca(OH)}_2\text{ excess, mg/}L)(44/74) + (\text{Mg}^{2+}\text{ residual, mg/}L)(44/24.3)\\ &= (33\text{ mg/}L)(44/74) + (8\text{ mg/}L)(44/24.3)\\ &= 20\text{ mg/}L + 15\text{ mg/}L\\ &= 35\text{ mg/}L\end{aligned}$$

EXAMPLE 16

The optimum lime dosage from the jar tests is 180 mg/*L*. If the flow to be treated is 6.5 M*L*D, what is the feeder setting in kilograms per day and the feed rate in grams per second?

Known		Unknown
Lime Dose, mg/*L*	= 180 mg/*L*	1. Feeder Setting, kg/day
Flow, M*L*D	= 6.5 M*L*D	2. Feed Rate, gm/sec

1. Calculate the feeder setting in kilograms per day.

$$\begin{aligned}\text{Feeder Setting, kg/day} &= \frac{(\text{Flow, M}L\text{D})(\text{Lime, mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}\\ &= \frac{(6.5\text{ M}L\text{D})(180\text{ mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}\\ &= 1170\text{ kg/day}\end{aligned}$$

2. Calculate the feed rate in grams per second.

$$\begin{aligned}\text{Feed Rate, gm/sec} &= \frac{(\text{Flow, M}L\text{D})(\text{Lime, mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}\\ &= \frac{(6.5\text{ M}L\text{D})(180\text{ mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}\\ &= 13.5\text{ gm/sec}\end{aligned}$$

EXAMPLE 17

How much soda ash is required (kilograms per day and grams per second) to remove 40 mg/*L* noncarbonate hardness as $CaCO_3$ from a flow of 6.5 M*L*D?

Known		Unknown
Noncarbonate Hardness, Removed, mg/*L* as $CaCO_3$	= 40 mg/*L*	1. Feeder Setting, kg/day
Flow, M*L*D	= 6.5 M*L*D	2. Feed Rate, gm/sec

1. Calculate the soda ash dose in milligrams per liter. See Section 14.316, "Calculation of Chemical Dosages," page 77, for the following formula.

$$\begin{aligned}\text{Soda Ash, mg/}L &= \left(\begin{matrix}\text{Noncarbonate Hardness,}\\ \text{mg/}L\text{ as CaCO}_3\end{matrix}\right)(106/100)\\ &= (40\text{ mg/}L)(106/100)\\ &= 43\text{ mg/}L\end{aligned}$$

2. Determine the feeder setting in kilograms per day.

$$\begin{aligned}\text{Feeder Setting, kg/day} &= \frac{(\text{Flow, M}L\text{D})(\text{Soda Ash, mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}\\ &= \frac{(6.5\text{ M}L\text{D})(40\text{ mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(1000\text{ gm/kg})}\\ &= 260\text{ kg/day}\end{aligned}$$

3. Calculate the soda ash feed rate in grams per second.

$$\begin{aligned}\text{Feed Rate, gm/sec} &= \frac{(\text{Flow, M}L\text{D})(\text{Soda Ash, mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}\\ &= \frac{(6.5\text{ M}L\text{D})(40\text{ mg/}L)(1{,}000{,}000/\text{M})}{(1000\text{ mg/gm})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}\\ &= 3.0\text{ gm/sec}\end{aligned}$$

EXAMPLE 18

What is the hardness in grains per gallon for a water with a hardness of 200 mg/*L*?

Known	Unknown
Hardness, mg/*L* = 12 mg/*L*	Hardness, grains/gallon

Calculate the hardness in grains per gallon.

$$\begin{aligned}\text{Hardness, grains/gal} &= \frac{(\text{Hardness, mg/}L)(1\text{ grain/gal})}{17.1\text{ mg/}L}\\ &= \frac{(200\text{ mg/}L)(1\text{ grain/gal})}{17.1\text{ mg/}L}\\ &= 11.7\text{ grains/gal}\end{aligned}$$

EXAMPLE 19

Estimate the exchange capacity in milligrams of hardness for an ion exchange unit which contains 20 cubic meters of resin with a removal capacity of 14,000 milligrams per cubic meter.

Known		Unknown
Resin Vol, cu m	= 20 cu m	Exchange Capacity, milligrams
Removal Cap, mg/cu m	= 14,000 mg/cu m	

Estimate the exchange capacity in milligrams of hardness.

$$\begin{aligned}\text{Exchange Capacity, milligrams} &= (\text{Resin Vol, cu m})(\text{Removal Capacity, mg/cu m})\\ &= (20\text{ cu m})(14{,}000\text{ mg/cu m})\\ &= 280{,}000\text{ mg of hardness}\end{aligned}$$

EXAMPLE 20

How many liters of water with a hardness of 200 mg/*L* may be treated by an ion exchange softener with an exchange capacity of 280,000 milligrams?

Known		Unknown
Hardness, mg/*L*	= 200 mg/*L*	Water Treated, liters
Exchange Capacity, mg	= 280,000 milligrams	

Calculate the liters of water that may be treated

$$\text{Water Treated, liters} = \frac{\text{Exchange Capacity, mg}}{\text{Hardness, mg}/L}$$

$$= \frac{280{,}000\ \text{mg}}{200\ \text{mg}/L}$$

$$= 1400\ \text{liters}$$

EXAMPLE 21

How many hours will an ion exchange softening unit operate when treating an average daily flow of 50 liters per second. The unit is capable of softening 4,500,000 liters of water before requiring regeneration.

Known		Unknown
Ave Daily Flow, *L*/sec	= 50 *L*/sec	Operating Time, hr
Water Treated, *L*	= 4,500,000 *L*	

Estimate how many hours the softening unit can operate before requiring regeneration.

$$\text{Operating Time, hr} = \frac{\text{Water Treated, } L}{(\text{Ave Daily Flow, } L/\text{sec})(60\ \text{sec/min})(60\ \text{min/hr})}$$

$$= \frac{4{,}500{,}000\ L}{(50\ L/\text{sec})(60\ \text{sec/min})(60\ \text{min/hr})}$$

$$= 25\ \text{hours}$$

EXAMPLE 22

Determine the kilograms of salt needed to regenerate an ion exchange softening unit capable of removing 225,000 milligrams of hardness if 7 kilograms of salt are required for every 1000 milligrams of hardness removed.

Known		Unknown
Hardness Removed, mg	= 225,000 mg	Salt Needed, kg
Salt Required, kg/1000 mg	= 7 kg salt/1000 mg	

Calculate the kilograms of salt needed to regenerate the ion exchange softening unit.

$$\text{Salt Needed, kg} = (\text{Salt Required, kg/1000 mg})(\text{Hardness Removed, mg})$$

$$= \frac{(7\ \text{kg salt})(225{,}000\ \text{mg})}{1000\ \text{mg}}$$

$$= 1575\ \text{kilograms of salt}$$

EXAMPLE 23

Estimate the bypass flow in cubic meters per day and megaliters per day around an ion exchange softener in a plant that treats 1000 cubic meters per day with a source water hardness of 350 mg/*L* if the desired product water hardness is 80 mg/*L*.

Known		Unknown
Total Flow, cu m/day	= 1000 cu m/day	1. Bypass Flow, cu m/day
Source Water Hardness, mg/*L*	= 350 mg/*L*	2. Bypass Flow, M*L*D
Plant Effl Hardness, mg/*L*	= 80 mg/*L*	

1 Estimate the bypass flow in cubic meters per day.

$$\text{Bypass Flow, cu m/day} = \frac{(\text{Total Flow, cu m/day})(\text{Plant Effl Hardness, mg}/L)}{\text{Source Water Hardness, mg}/L}$$

$$= \frac{(1000\ \text{cu m/day})(80\ \text{mg}/L)}{350\ \text{mg}/L}$$

$$= 229\ \text{cu m/day}$$

2 Estimate the bypass flow in megaliters per day.

$$\text{Bypass Flow, M}L\text{D} = \frac{(\text{Total Flow cu m/day})(\text{Plant Effl Hardness, mg}/L)(1000\ L/\text{cu m})}{(\text{Source Water Hardness, mg}/L)(1\,000\,000/\text{M})}$$

$$= \frac{(1000\ \text{cu m/day})(80\ \text{mg}/L)(1000\ L/\text{cu m})}{(350\ \text{mg}/L)(1\,000\,000/\text{M})}$$

$$= 0.229\ \text{M}L\text{D}$$

A.53 Trihalomethanes

EXAMPLE 24

A water utility collected and analyzed eight samples from a water distribution system on the same day for TTHMs The results are shown below.

Sample No.	1	2	3	4	5	6	7	8
TTHM, µg/*L*	80	90	100	90	110	100	100	90

What was the average TTHM for the day?

Known	Unknown
Results from analysis of 8 TTHM samples	Average TTHM level for the day

Calculate the average TTHM level in micrograms per liter.

$$\text{Ave TTHM, } \mu g/L = \frac{\text{Sum of Measurement, } \mu g/L}{\text{Number of Measurements}}$$

$$= \frac{80\ \mu g/L + 90\ \mu g/L + 100\ \mu g/L + 90\ \mu g/L + 110\ \mu g/L + 100\ \mu g/L + 100\ \mu g/L + 90\ \mu g/L}{8}$$

$$= \frac{760\ \mu g/L}{8}$$

$$= 95\ \mu g/L$$

EXAMPLE 25

The results of the quarterly average TTHM measurement for two years are given below. Calculate the running annual average of the four quarterly measurements in micrograms per liter.

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, µg/*L*	77	88	112	95	83	87	109	89

Known	Unknown
Results from analysis of two years of TTHM sampling	Running Annual Average of quarterly TTHM measurements

Calculate the running annual average of the quarterly TTHM measurements.

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{\text{Sum of Ave TTHM for Four Quarters}}{\text{Number of Quarters}}$$

QUARTERS 1, 2, 3 AND 4

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{77\ \mu g/L + 88\ \mu g/L + 112\ \mu g/L + 95\ \mu g/L}{4}$$

$$= \frac{372\ \mu g/L}{4}$$

$$= 93\ \mu g/L$$

QUARTERS 2, 3, 4 AND 1

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{88\ \mu g/L + 112\ \mu g/L + 95\ \mu g/L + 83\ \mu g/L}{4}$$

$$= \frac{378\ \mu g/L}{4}$$

$$= 95\ \mu g/L$$

QUARTERS 3, 4, 1 AND 2

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{112\ \mu g/L + 95\ \mu g/L + 83\ \mu g/L + 87\ \mu g/L}{4}$$

$$= \frac{377\ \mu g/L}{4}$$

$$= 94\ \mu g/L$$

QUARTERS 4, 1, 2 AND 3

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{95\ \mu g/L + 83\ \mu g/L + 87\ \mu g/L + 109\ \mu g/L}{4}$$

$$= \frac{374\ \mu g/L}{4}$$

$$= 94\ \mu g/L$$

QUARTERS 1, 2, 3 AND 4

$$\text{Annual Running TTHM Average, } \mu g/L = \frac{83\ \mu g/L + 87\ \mu g/L + 109\ \mu g/L + 89\ \mu g/L}{4}$$

$$= \frac{368\ \mu g/L}{4}$$

$$= 92\ \mu g/L$$

SUMMARY OF RESULTS

Quarter	1	2	3	4	1	2	3	4
Ave Quarterly TTHM, μg/L	77	88	112	95	83	87	109	89
Annual Running TTHM Ave, μg/L				93	95	94	94	92

A.54 Demineralization

EXAMPLE 26

Convert a water flux of 12×10^{-4} gm/sq cm-sec to liters per second per square centimeter and liters per day per square centimeter.

Known		Unknown
Water Flux, gm/sq cm-sec	= 12×10^{-4} gm/sq cm-sec	1. Flow, liters per sec/sq cm 2. Flow, liters per day/sq cm

1. Convert the water flux from gm/sq cm-sec to flow in liters per second per square centimeter.

$$\text{Flow, } L/\text{sq cm-sec} = \frac{\text{Flux, gm/sq cm-sec}}{1000\ \text{gm}/L}$$

$$= \frac{12 \times 10^{-4}\ \text{gm/sq cm-sec}}{1000\ \text{gm}/L}$$

$$= 12 \times 10^{-7}\ L/\text{sq cm-sec}$$

2. Convert the water flux from gm/sq cm-sec to flow in liters per day per square centimeter.

$$\text{Flow, } L/\text{sq cm-day} = \frac{(\text{Flux, gm/sq cm-sec})(60\ \text{sec/min})(60\ \text{min/hr})(24\ \text{hr/day})}{1000\ \text{gm}/L}$$

$$= \frac{(0.0012\ \text{gm/sq cm-sec})(60\ \text{sec/min})(60\ \text{min/hr})(24\ \text{hr/day})}{1000\ \text{gm}/L}$$

$$= 0.10\ L/\text{sq cm-day}$$

EXAMPLE 27

Estimate the ability of a reverse osmosis plant to reject minerals by calculating the mineral rejection as a percent. The feedwater contains 1800 mg/*L* TDS and the product water TDS is 120 mg/*L*.

Known		Unknown
Feedwater TDS, mg/*L*	= 1800 mg/*L*	Mineral Rejection, %
Product Water TDS, mg/*L*	= 120 mg/*L*	

Calculate the mineral rejection as a percent.

$$\text{Mineral Rejection, \%} = \left(1 - \frac{\text{Product TDS, mg}/L}{\text{Feed TDS, mg}/L}\right)(100\%)$$

$$= \left(1 - \frac{120\ \text{mg}/L}{1800\ \text{mg}/L}\right)(100\%)$$

$$= (1 - 0.067)(100\%)$$

$$= 93.3\%$$

EXAMPLE 28

Estimate the percent recovery of a reverse osmosis unit with a 4-2-1 arrangement if the feed flow is 8.0 MLD and the product flow is 7.0 MLD.

Known		Unknown
Product Flow, MLD	= 8.0 MLD	Recovery, %
Feed Flow, MLD	= 7.0 MLD	

Calculate the recovery as a percent.

$$\text{Recovery, \%} = \frac{(\text{Product Flow, MLD})\ (100\%)}{\text{Feed Flow, MLD}}$$

$$= \frac{(7.0\ \text{MLD})(100\%)}{8.0\ \text{MLD}}$$

$$= 87.5\%$$

A.55 Maintenance

EXAMPLE 29

Calculate the pumping capacity of a pump in liters per second when 12 minutes are required for the water to rise 1.0 meters in a 2.5 meter by 2.0 meter rectangular tank.

Known	Unknown
Length, m = 2.5 m	Pump Capacity, *L*/sec
Width, m = 2.0 m	
Depth, m = 1.0 m	
Time, min = 12 min	

1. Calculate the volume pumped in cubic meters.

$$\begin{aligned}\text{Volume Pumped, cu m} &= (\text{Length, ft})(\text{Width, m})(\text{Depth, m})\\ &= (2.5\text{ m})(2.0\text{ m})(1.0\text{ m})\\ &= 5.0\text{ m}\end{aligned}$$

2. Calculate the pump capacity in liters per second.

$$\begin{aligned}\text{Pump Capacity, Liters/sec} &= \frac{(\text{Volume Pumped, cu m})(1000\ L/\text{cu m})}{\text{Pumping Time, min}}\\ &= \frac{(5.0\text{ cu m})(1000\ L/\text{cu m})}{12\text{ min}}\\ &= 417\ L/\text{sec}\end{aligned}$$

EXAMPLE 30

A small chemical feed pump lowered the chemical solution in a 0.8-meter diameter tank 0.7 meters during 7.0 hours Estimate the flow delivered by the pump in liters per second and milliliters per second.

Known	Unknown
Tank Diameter, m = 0.8 m	1. Flow, *L*/sec
Chemical Drop, m = 0.7 m	2. Flow, m*L*/sec
Time, hr = 7.0 hr	

1. Determine the liters of chemical solution pumped

$$\begin{aligned}\text{Volume, liters} &= (0.785)(\text{Diameter, m})^2(\text{Drop, m})(1000\ L/\text{cu m})\\ &= (0.785)(0.8\text{ m})^2(0.7\text{ m})(1000\ L/\text{cu m})\\ &= 352\text{ liters}\end{aligned}$$

2. Estimate the flow delivered by the pump in liters per second.

$$\begin{aligned}\text{Flow, } L/\text{sec} &= \frac{\text{Volume Pumped, } L}{(\text{Pumping Time, hr})(60\text{ min/hr})(60\text{ sec/min})}\\ &= \frac{352\ L}{(7.0\text{ hr})(60\text{ min/hr})(60\text{ sec/min})}\\ &= 0.014\ L/\text{sec}\end{aligned}$$

3. Estimate the flow delivered by the pump in milliliters per second.

$$\begin{aligned}\text{Flow, m}L/\text{sec} &= \frac{(\text{Volume Pumped, } L)(1000\text{ m}L/L)}{(\text{Pumping Time, hr})(60\text{ min/hr})(60\text{ sec/min})}\\ &= \frac{(352\ L)(1000\text{ m}L/L)}{(7.0\text{ hr})(60\text{ min/hr})(60\text{ sec/min})}\\ &= 14\text{ m}L/\text{sec}\end{aligned}$$

EXAMPLE 31

Determine the chemical feed in kilograms of polymer per day and grams per second from a chemical feed pump. The polymer solution is 1.8 percent or 18,000 mg polymer per liter. Assume a specific gravity of the polymer solution of 1.0. During a test run the chemical feed pump delivered 650 m*L* of polymer solution in 4.5 minutes.

Known	Unknown
Polymer Solution, % = 1.8 %	1. Polymer Feed, kg/day
Polymer Conc, mg/*L* = 18,000 mg/*L*	2. Polymer Feed, gm/sec
Polymer Sp Gr = 1.0	
Volume Pumped, m*L* = 650 m*L*	
Time Pumped, min = 4.5 min	

1. Calculate the polymer fed by the chemical feed pump in kilograms of polymer per day.

$$\begin{aligned}\text{Polymer Feed, kg/day} &= \frac{(\text{Vol Pumped, m}L)(\text{Poly Conc, mg}/L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(1000\text{ gm/kg})}\\ &= \frac{(650\text{ m}L)(18{,}000\text{ mg}/L)(60\text{ min/hr})(24\text{ hr/day})}{(4.5\text{ min})(1000\text{ m}L/L)(1000\text{ mg/gm})(1000\text{ gm/kg})}\\ &= 3.7\text{ kg/day}\end{aligned}$$

2. Calculate the polymer fed by the chemical feed pump in grams of polymer per second.

$$\begin{aligned}\text{Polymer Feed, gm/sec} &= \frac{(\text{Vol Pumped, m}L)(\text{Poly Conc, mg}/L)}{(\text{Time Pumped, min})(1000\text{ m}L/L)(60\text{ sec/min})(1000\text{ mg/gm})}\\ &= \frac{(650\text{ m}L)(18{,}000\text{ mg}/L)}{(4.5\text{ min})(1000\text{ m}L/L)(60\text{ sec/min})(1000\text{ mg/gm})}\\ &= 0.043\text{ gm/sec}\\ \text{or}\quad &= 43\text{ mg/sec}\end{aligned}$$

EXAMPLE 32

Determine the actual chemical feed in kilograms per day and grams per second from a dry chemical feeder. A pie tin placed under the chemical feeder caught 824 grams of chemical during five minutes.

Known	Unknown
Chemical, gm = 824 gm	1. Chemical Feed, kg/day
Time, min = 5 min	2. Chemical Feed, gm/sec

1. Determine the chemical feed in kilograms per day.

$$\begin{aligned}\text{Chemical Feed, kg/day} &= \frac{(\text{Chemical, gm})(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time, min})(1000\text{ gm/kg})}\\ &= \frac{(824\text{ gm})(60\text{ min/hr})(24\text{ hr/day})}{(5\text{ min})(1000\text{ gm/kg})}\\ &= 237\text{ kg/day}\end{aligned}$$

2. Determine the chemical feed in grams per second.

$$\begin{aligned}\text{Chemical Feed, gm/sec} &= \frac{\text{Chemical, gm}}{(\text{Time, min})(60\text{ sec/min})}\\ &= \frac{824\text{ gm}}{(5\text{ min})(60\text{ sec/min})}\\ &= 2.75\text{ gm/sec}\end{aligned}$$

A.56 Safety

EXAMPLE 33

Calculate the injury frequency rate for a water utility where there were four injuries in one year and the operators worked 97,120 hours.

Known		Unknown
Injuries, number/yr	= 4 injuries/yr	Injury Frequency Rate
Hours Worked number/yr	= 97,120 hrs/yr	

Calculate the injury frequency rate.

$$\text{Injury Freq Rate} = \frac{(\text{Injuries, number/yr})(1{,}000{,}000)}{\text{Hours Worked, number/yr}}$$

$$= \frac{(4\text{ injuries/yr})(1{,}000{,}000)}{97{,}120\text{ hrs/yr}}$$

$$= 41.2$$

EXAMPLE 34

Calculate the injury severity rate for a water company which experienced 57 operator-hours lost due to injuries while the operators worked 97,120 hours during the year.

Known	Unknown
Number of Hours Lost = 57 hr/yr	Injury Severity Rate
Number of Hours Worked = 97,120 hrs/yr	

Calculate the injury severity rate.

$$\text{Injury Severity Rate} = \frac{(\text{Number of Hours Lost/yr})(1{,}000{,}000)}{\text{Number of Hours Worked/yr}}$$

$$= \frac{(57\text{ hrs/yr})(1{,}000{,}000)}{97{,}120\text{ hrs/yr}}$$

$$= 587$$

A.57 Advanced Laboratory Procedures

EXAMPLE 35

Calculate the threshold odor number (T.O.N.) for a sample when the first detectable odor occurred when the 70 m*L* sample was diluted to 200 m*L* (130 m*L* of odor-free water was added to the 70 m*L* sample).

Known	Unknown
Size of Sample, m*L* = 70 m*L*	T.O.N.
Odor-Free Water, m*L* = 130 m*L*	

Calculate the threshold odor number, T.O.N.

$$\text{T.O.N.} = \frac{\text{Size of Sample, m}L + \text{Odor-Free Water, m}L}{\text{Size of Sample, m}L}$$

$$= \frac{(70\text{ m}L + 130\ \text{[illegible]}}{70\text{ m}L}$$

$$= 3$$

EXAMPLE 36

Determine the geometric mean threshold odor number for a panel of six testers given the results shown below.

Known	Unknown
Tester 1, $X_1 = 2$	Geometric Mean Threshold Odor Number
Tester 2, $X_2 = 4$	
Tester 3, $X_3 = 3$	
Tester 4, $X_4 = 8$	
Tester 5, $X_5 = 6$	
Tester 6, $X_6 = 2$	

Calculate the geometric mean.

$$\text{Geometric Mean T.O.N.} = (X_1 \times X_2 \times X_3 \times X_4 \times X_5 \times X_6)^{1/n}$$

$$= (2 \times 4 \times 3 \times 8 \times 6 \times 2)^{1/6}$$

$$= (2304)^{0.167}$$

$$= 3.6$$

EXAMPLE 37

Calculate the threshold taste number for a sample when the first detectable taste occurred when the 8.3 m*L* sample was diluted to 200 m*L* (191.7 m*L* of taste-free water was added to the 8.3 m*L* sample).

Known	Unknown
Sample Size, m*L* = 8.3 m*L*	Threshold Taste Number
Taste-Free Water, m*L* = 191.7	

Calculate the threshold taste number.

$$\text{Threshold Taste Number} = \frac{\text{Sample Size, m}L + \text{Taste-Free Water, m}L}{\text{Sample Size, m}L}$$

$$= \frac{8.3\text{ m}L + 191.7\text{ m}L}{8.3\text{ m}L}$$

$$= 24$$

EXAMPLE 38

Determine the taste rating for a water by calculating the arithmetic mean and standard deviation for the panel ratings given below.

Known	Unknown
Tester 1, $X_1 = 2$	1. Arithmetic Mean, $\bar{X}$
Tester 2, $X_2 = 5$	2. Standard Deviation, S
Tester 3, $X_3 = 3$	
Tester 4, $X_4 = 6$	
Tester 5, $X_5 = 2$	
Tester 6, $X_6 = 6$	

1. Calculate the arithmetic mean, $\bar{X}$, taste rating

$$\text{Arithmetic Mean, } \bar{X} \text{ Taste Rating} = \frac{X_1 + X_2 + X_3 + X_4 + X_5 + X_6}{n}$$

$$= \frac{2 + 5 + 3 + 6 + 2 + 6}{6}$$

$$= \frac{24}{6}$$

$$= 4$$

2. Calculate the standard deviation, S, of the taste rating.

$$\text{Standard Deviation, S} = \left[\frac{(X_1-\bar{X})^2 + (X_2-\bar{X})^2 + (X_3-\bar{X})^2 + (X_4-\bar{X})^2 + (X_5-\bar{X})^2 + (X_6-\bar{X})^2}{n-1}\right]^{0.5}$$

$$= \left[\frac{(2-4)^2 + (5-4)^2 + (3-4)^2 + (6-4)^2 + (2-4)^2 + (6-4)^2}{6-1}\right]^{0.5}$$

$$= \left[\frac{(-2)^2 + (1)^2 + (-1)^2 + (2)^2 + (-2)^2 + (2)^2}{5}\right]^{0.5}$$

$$= \left[\frac{4+1+1+4+4+4}{5}\right]^{0.5}$$

$$= \left[\frac{18}{5}\right]^{0.5}$$

$$= (3.6)^{0.5}$$

$$= 1.9$$

or

$$\text{Standard Deviation, S} = \left[\frac{(X_1^2 + X_2^2 + X_3^2 + X_4^2 + X_5^2 + X_6^2) - (X_1+X_2+X_3+X_4+X_5+X_6)^2/n}{n-1}\right]^{0.5}$$

$$= \left[\frac{(2^2+5^2+3^2+6^2+2^2+6^2) - (2+5+3+6+2+6)^2/6}{n-1}\right]^{0.5}$$

$$= \left[\frac{(4+25+9+36+4+36) - (24)^2/6}{5}\right]^{0.5}$$

$$= \left[\frac{114-96}{5}\right]^{0.5}$$

$$= \left[\frac{18}{5}\right]^{0.5}$$

$$= (3.6)^{0.5}$$

$$= 1.9$$

EXAMPLE 39

A small water system collected 14 samples during one month. After each sample was collected, 10 *mL* of each sample was placed in each of 5 fermentation tubes. At the end of the month, the results indicated that 2 out of a total of 70 fermentation tubes were positive. What percent of the portions tested during the month were positive?

	Known	Unknown
Number Positive/mo	= 2 positive/mo	Portions Positive, %/mo
Total Portions Tested	70 portions	

Calculate the percent of the portions tested during the month which were positive.

$$\text{Portions Positive, \%/mo} = \frac{(\text{Number Positive/mo})(100\%)}{\text{Total Portions Tested}}$$

$$= \frac{(2\text{ positive/mo})(100\%)}{70\text{ portions}}$$

$$= 3\%/\text{mo}$$

WATER ABBREVIATIONS

ac	acre
ac-ft	acre-feet
af	acre feet
amp	ampere
°C	degrees Celsius
cfm	cubic feet per minute
cfs	cubic feet per second
Ci	Curie
cm	centimeter
cu ft	cubic feet
cu in	cubic inch
cu m	cubic meter
cu yd	cubic yard
°F	degrees Fahrenheit
ft	feet or foot
ft-lb/min	foot-pounds per minute
g	gravity
gal	gallon
gal/day	gallons per day
gm	gram
GPD	gallons per day
GPM	gallons per minute
gpg	grains per gallon
gr	grain
ha	hectare
HP	horsepower
hr	hour
in	inch
k	kilo
kg	kilogram
km	kilometer
kN	kilonewton
kW	kilowatt
kWh	kilowatt-hour
L	liter
lb	pound
lbs/sq in	pounds per square inch
m	meter
M	mega
M	million
mg	milligram
mg/*L*	milligram per liter
MGD	million gallons per day
m*L*	milliliter
min	minute
mm	millimeter
N	Newton
ohm	ohm
Pa	Pascal
pCi	picoCurie
psf	pounds per square foot
psi	pounds per square inch
psig	pounds per square inch gage
ppb	parts per billion
ppm	parts per million
sec	second
sq ft	square feet
sq in	square inches
W	watt

WATER WORDS

A Summary of the Words Defined

in

WATER TREATMENT PLANT OPERATION

and

WATER SUPPLY SYSTEM OPERATION

PROJECT PRONUNCIATION KEY

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this Key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This Key is designed solely to aid operators in this program.

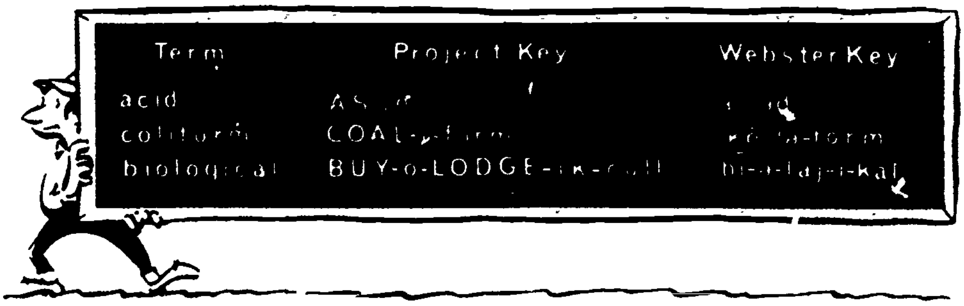
You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation Key. Each Key will be different from each other and from this Key. Examples of the differences between the Key used in this program and the *WEBSTER'S NEW WORLD DICTIONARY* "Key[1]", are shown below.

In using this Key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	SYLLABLE				
Word	1st	2nd	3rd	4th	5th
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word *ACID* has its first syllable accented. The second word, *COAGULANT*, has its second syllable accented. The third word, *BIOLOGICAL*, has its first and third syllables accented.

We hope you will find the Key useful in unlocking the pronunciation of any new word.



Term	Project Key	Webster Key
acid	AS-id	[illegible]
coliform	COAL-i-form	kō-lə-form
biological	BUY-o-LODGE-ik-cull	bi-o-laj-i-kal

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[1] The WEBSTER'S NEW WORLD DICTIONARY, *Second College Edition, 1972, was chosen rather than an unabridged dictionary because of its availability to the operator. Other editions may be slightly different.*

WATER WORDS

ABC ABC

See Association of BOARDS of Certification

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ACCURACY ACCURACY

How closely an instrument measures the true or actual value of the process variable being measured or sensed.

ACID RAIN ACID RAIN

Precipitation which has been rendered (made) acidic by airborne pollutants.

ACIDIC (uh-SID-ick) ACIDIC

The condition of water or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

ACIDIFIED (uh-SID-uh-FIE-d) ACIDIFIED

The addition of an acid (usually nitric or sulfuric) to a sample to lower the pH below 2.0. The purpose of acidification is to "fix" a sample so it won't change until it is analyzed.

ACRE-FOOT ACRE-FOOT

A volume of water that covers one acre to a depth of one foot, or 43,560 cubic feet (1233.5 cubic meters).

ACTIVATED CARBON ACTIVATED CARBON

Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water

ADSORBATE (add-SORE-bait) ADSORBATE

The material being removed by the adsorption process.

ADSORBENT (add-SORE-bent) ADSORBENT

The material (activated carbon) that is responsible for removing the undesirable substance in the adsorption process.

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AERATION (air-A-shun) AERATION

The process of adding air to water Air can be added to water by either passing air through water or passing water through air

AEROBIC (air-O-bick) AEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is present in the water.

AESTHETIC (es-THET-ick) AESTHETIC

Attractive or appealing.

AGE TANK AGE TANK

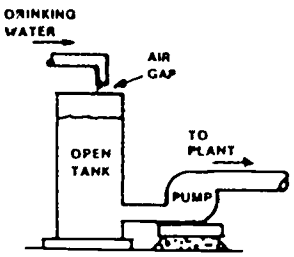
A tank used to store a chemical solution of known concentration for feed to a chemical feeder. Also called a DAY TANK.

AIR BINDING
AIR BINDING

A situation where air enters the filter media Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

AIR GAP
AIR GAP

An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water



AIR PADDING
AIR PADDING

Pumping dry air into a container to assist with the withdrawal of a liquid or to force a liquefied gas such as chlorine out of a container.

AIR STRIPPING
AIR STRIPPING

A treatment process used to remove dissolved gases and volatile substances from water Large volumes of air are bubbled through the water being treated to remove (strip out) the dissolved gases and volatile substances.

ALARM CONTACT
ALARM CONTACT

A switch that operates when some pre-set low, high or abnormal condition exists.

ALGAE (Al-gee)
ALGAE

Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.

ALGAL BLOOM (AL-gull)
ALGAL BLOOM

Sudden, massive growths of microscopic and macroscopic plant life, such as green or blue-green algae, which develop in lakes and reservoirs.

ALGICIDE (AL-gi-SIDE)
ALGICIDE

Any substance or chemical specifically formulated to kill or control algae.

ALIPHATIC HYDROXY ACIDS (AL-uh-FAT-ick)
ALIPHATIC HYDROXY ACIDS

Organic acids with carbon atoms arranged in branched or unbranched open chains rather than in rings

ALIQUOT (AL-li-kwot)
ALIQUOT

Portion of a sample

ALKALI (AL-ka-lie)
ALKALI

Various soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical water treatment processes.

ALKALINE (AL-ka-LINE)
ALKALINE

The condition of water or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

ALKALINITY (AL-ka-LIN-it-tee)
ALKALINITY

The capacity of water to neutralize acids This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

ALLUVIAL (uh-LOU-vee-ul)
ALLUVIAL

Relating to mud and/or sand deposited by flowing water. Alluvial deposits may occur after a heavy rain storm.

ALTERNATING CURRENT (A.C.)
ALTERNATING CURRENT (A.C.)

An electric current that reverses its direction (positive/negative values) at regular intervals.

ALTITUDE VALVE ALTITUDE VALVE

A valve that automatically shuts off the flow into an elevated tank when the water level in the tank reaches a predetermined level. The valve automatically opens when the pressure in the distribution system drops below the pressure in the tank.

AMBIENT TEMPERATURE (AM-bee-ent) AMBIENT TEMPERATURE

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

AMERICAN WATER WORKS ASSOCIATION AMERICAN WATER WORKS ASSOCIATION

A professional organization for all persons working in the water utility field. For information on AWWA membership and publications, contact AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235

AMPERAGE (AM-purr-age) AMPERAGE

The strength of an electric current measured in amperes. The amount of electric current flow, similar to the flow of water in gallons per minute.

AMPERE (AM-peer) AMPERE

The unit used to measure current strength. The current produced by an electromotive force of one volt acting through a resistance of one ohm.

AMPEROMETRIC (am-PURR-o-MET-rick) AMPEROMETRIC

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION AMPEROMETRIC TITRATION

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. See TITRATE

AMPLITUDE AMPLITUDE

The maximum strength of an alternating current during its cycle, as distinguished from the mean or effective strength.

ANAEROBIC (AN-air-O-bick) ANAEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is *NOT* present in water.

ANALOG ANALOG

The readout of an instrument by a pointer (or other indicating means) against a dial or scale.

ANGSTROM (ANG-strem) ANGSTROM

A unit of length equal to one tenth of a nanometer or one ten-billionth of a meter (1 Angstrom = 0.000 000 000 1 meter). One Angstrom is the approximate diameter of an atom.

ANALYZER ANALYZER

A device which conducts periodic or continuous measurement of some factor such as chlorine, fluoride or turbidity. Analyzers operate by any of several methods including photocells, conductivity or complex instrumentation.

ANION (AN-EYE-en) ANION

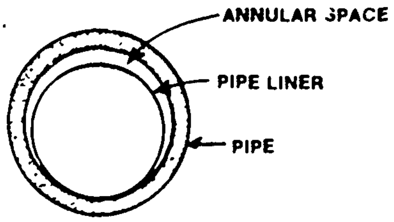
A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of a difference in electrical potential. Chloride (Cl^-) is an anion.

ANIONIC POLYMER (AN-eye-ON-ick) ANIONIC POLYMER

A polymer having negatively charged groups of ions, often used as a filter aid and for dewatering sludges

ANNULAR SPACE (AN-you-ler) ANNULAR SPACE

A ring-shaped space located between two circular objects, such as two pipes.



ANODE (an-O-d) ANODE

The positive pole or electrode of an electrolytic system, such as a battery. The anode attracts negatively charged particles or ions (anions).

APPROPRIATIVE APPROPRIATIVE

Water rights to or ownership of a water supply which is acquired for the beneficial use of water by following a specific legal procedure

APPURTENANCE (uh-PURR-ten-nans) APPURTENANCE

Machinery, appliances, structures and other parts of the main structure necessary to allow it to operate as intended, but not considered part of the main structure.

AQUEOUS (A-kwee-us) AQUEOUS

Something made up of, similar to, or containing water; watery.

AQUIFER (ACK-wi-fer) AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water

ARTESIAN (are-TEE-zhun) ARTESIAN

Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given an opportunity to do so.

ASEPTIC (a-SEP-tick) ASEPTIC

Free from the living germs of disease, fermentation or putrefaction. Sterile.

ASSOCIATION OF BOARDS OF CERTIFICATION ASSOCIATION OF BOARDS OF CERTIFICATION

An international organization representing over 110 boards which certify the operators of waterworks and wastewater facilities. For information on ABC publications regarding the preparation of and how to study for operator certification examinations, contact ABC, P.O. Box 786, Ames, Iowa 50010-0786.

ASYMMETRIC (A-see-MET-rick) ASYMMETRIC

Not similar in size, shape, form or arrangement of parts on opposite sides of a line, point or plane.

ATOM ATOM

The smallest unit of a chemical element, composed of protons, neutrons and electrons.

AVAILABLE CHLORINE AVAILABLE CHLORINE

A measure of the amount of chlorine available in chlorinated lime, hypochlorite compounds, and other materials that are used as a source of chlorine when compared with that of elemental (liquid or gaseous) chlorine.

AVAILABLE EXPANSION AVAILABLE EXPANSION

The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called FREEBOARD.

AVERAGE AVERAGE

A number obtained by adding quantities or measurements and dividing the sum or total by the number of quantities or measurements Also called the ARITHMETIC MEAN.

$$\text{Average} = \frac{\text{Sum of Measurements}}{\text{Number of Measurements}}$$

AVERAGE DEMAND AVERAGE DEMAND

The total demand for water during a period of time divided by the number of days in that time period. This is also called the AVERAGE DAILY DEMAND.

AWWA AWWA

See AMERICAN WATER WORKS ASSOCIATION

AXIAL TO IMPELLER AXIAL TO IMPELLER

The direction in which material being pumped flows around the impeller or flow parallel to the impeller shaft.

AXIS OF IMPELLER AXIS OF IMPELLER

An imaginary line running along the center of a shaft (such as an impeller shaft).

BACK PRESSURE BACK PRESSURE

A pressure that can cause water to backflow into the water supply when a user's water system is at a higher pressure than the public water system.

BACKFLOW BACKFLOW

A reverse flow condition, created by a difference in water pressures, which causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source Also see BACKSIPHONAGE.

BACKSIPHONAGE BACKSIPHONAGE

A form of backflow caused by a negative or below atmospheric pressure within a water system. Also see BACKFLOW.

BACKWASHING BACKWASHING

The process of reversing the flow of water back through the filter media to remove the entrapped solids.

BACTERIA (back-TEER-e-uh) BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BAFFLE BAFFLE

A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solutions, slurry)

BAILER (BAY-ler) BAILER

A 10- to 20-foot-long pipe equipped with a valve at the lower end. A bailer is used to remove slurry from the bottom or the side of a well as it is being drilled

BASE METAL BASE METAL

A metal (such as iron) which reacts with dilute hydrochloric acid to form hydrogen. Also see NOBLE METAL

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated or a chemical solution is prepared, and the tank is emptied The tank may then be filled and the process repeated.

BENCH SCALE TESTS BENCH SCALE TESTS

A method of studying different ways or chemical doses for treating water on a small scale in a laboratory.

BIOCHEMICAL OXYGEN DEMAND BIOCHEMICAL OXYGEN DEMAND

BOD The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BIOLOGICAL GROWTH BIOLOGICAL GROWTH

The activity and growth of any and all living organisms.

BLANK BLANK

A bottle containing only dilution water or distilled water, the sample being tested is not added. Tests are frequently run on a SAMPLE and a BLANK and the differences are compared.

BOD (pronounce as separate letters) BOD

Biochemical **O**xygen **D**emand The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation

BONNET (BON-it) BONNET

The cover on a gate valve.

BOWLS, PUMP BOWLS, PUMP

The submerged pumping unit in a well, including the shaft, impellers and housing.

BRAKE HORSEPOWER BRAKE HORSEPOWER

(1) The horsepower required at the top or end of a pump shaft (input to a pump).

(2) The energy provided by a motor or other power source.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water until the chlorine demand has been satisfied At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

BREAKTHROUGH BREAKTHROUGH

A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter effluent turbidity A breakthrough can occur (1) when a filter is first placed in service, (2) when the effluent valve suddenly opens or closes, and (3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).

BRINELLING (bruh-NEL-ing) BRINELLING

Tiny indentations (dents) high on the shoulder of the bearing race or bearing A type of bearing failure

BUFFER BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH

BUFFER CAPACITY BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

C FACTOR C FACTOR

A factor or value used to indicate the smoothness of the interior of a pipe. The higher the C Factor, the smoother the pipe, the greater the carrying capacity, and the smaller the friction or energy losses from water flowing in the pipe To calculate the C Factor, measure the flow, pipe diameter, distance between two pressure gages, and the friction or energy loss of the water between the gages.

$$\text{C Factor} = \frac{\text{Flow, GPM}}{193.75\,(\text{Diameter, ft})^{2.63}\,(\text{Slope})^{0.54}}$$

CAISSON (KAY-sawn) CAISSON

A structure or chamber which is usually sunk or lowered by digging from the inside Used to gain access to the bottom of a stream or other body of water

CALCIUM CARBONATE EQUILIBRIUM CALCIUM CARBONATE EQUILIBRIUM

A water is considered stable when it is just saturated with calcium carbonate. In this condition the water will neither dissolve nor deposit calcium carbonate Thus, in this water the calcium carbonate is in equilibrium with the hydrogen ion concentration.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalent value to calcium carbonate For example the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CALIBRATION CALIBRATION

A procedure which checks or adjusts an instrument's accuracy by comparison with a standard or reference

CAPILLARY ACTION CAPILLARY ACTION

The movement of water through very small spaces due to molecular forces.

CAPILLARY FORCES CAPILLARY FORCES

The molecular forces which cause the movement of water through very small spaces.

CAPILLARY FRINGE CAPILLARY FRINGE

The porous material just above the water table which may hold water by capillarity (a property of surface tension that draws water upwards) in the smaller void spaces

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce cancer in an organism.

CATALYST (CAT-uh-LIST) CATALYST

A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.

CATALYZE (CAT-uh-LIZE) CATALYZE

To act as a catalyst. Or, to speed up a chemical reaction.

CATALYZED (CAT-uh-LIZED) CATALYZED

To be acted upon by a catalyst

CATHODE (KA-thow-d) CATHODE

The negative pole or electrode of an electrolytic cell or system. The cathode attracts positively charged particles or ions (cations).

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic This concentrates corrosion on auxiliary anodic parts which are deliberately allowed to corrode instead of letting the structure corrode

CATION (CAT-EYE-en) CATION

A positively charged ion in an electrolyte solution, attracted to the cathode under the influence of a difference in electrical potential Sodium ion (Na^+) is a cation.

CATIONIC POLYMER CATIONIC POLYMER

A polymer having positively charged groups of ions; often used as a coagulant aid.

CAVITATION (CAV-uh-TAY-shun) CAVITATION

The formation and collapse of a gas pocket or bubble on the blade of an impeller or the gate of a valve The collapse of this gas pocket or bubble drives water into the impeller or gate with a terrific force that can cause pitting on the impeller or gate surface Cavitation is accompanied by loud noises that sound like someone is pounding on the impeller or gate with a hammer.

CENTRATE CENTRATE

The water leaving a centifuge after most of the solids have been removed

CENTRIFUGAL PUMP (sen-TRIF-uh-gull) CENTRIFUGAL PUMP

A pump consisting of an impeller fixed on a rotating shaft that is enclosed in a casing, and having an inlet and discharge connection. As the rotating impeller whirls the water around, centrifugal force builds up enough pressure to force the water through the discharge outlet

CENTRIFUGE CENTRIFUGE

A mechanical device that uses centrifugal or rotational forces to separate solids from liquids

CHECK SAMPLING CHECK SAMPLING

Whenever an initial or routine sample analysis indicates that an MCL has been exceeded, *CHECK SAMPLING* is required to confirm the routine sampling results. Check sampling is in addition to the routine sampling program.

CHECK VALVE CHECK VALVE

A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flow.

CHELATING AGENT (key-LAY-ting) CHELATING AGENT

A chemical used to prevent the precipitation of metals (such as copper).

CHELATION (key-LAY-shun) CHELATION

A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid) Chelation is used to prevent the precipitation of metals (copper). Also see SEQUESTRATION.

CHLORAMINATION (KLOR-am-i-NAY-shun) CHLORAMINATION

The application of chlorine and ammonia to water to form chloramines for the purpose of disinfection.

CHLORAMINES (KLOR-uh-means) CHLORAMINES

Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

CHLORINATION (KLOR-uh-NAY-shun) CHLORINATION

The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors)

CHLORINATOR (KLOR-uh-NAY-ter) CHLORINATOR

A metering device which is used to add chlorine to water

CHLORINE DEMAND CHLORINE DEMAND

Chlorine demand is the difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

$$\text{Chlorine Demand, mg}/L = \underset{\text{Applied, mg}/L}{\text{Chlorine}} - \underset{\text{Residual, mg}/L}{\text{Chlorine}}$$

CHLORINE REQUIREMENT CHLORINE REQUIREMENT

The amount of chlorine which is needed for a particular purpose Some reasons for adding chlorine are reducing the number of coliform bacteria (Most Probable Number), obtaining a particular chlorine residual, or oxidizing some substance in the water. In each case a definite dosage of chlorine will be necessary This dosage is the chlorine requirement.

CHLOROPHENOLIC (klor-o-FEE-NO-lick) CHLOROPHENOLIC

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

CHLOROPHENOXY (KLOR-o-fuh-KNOX-ee) CHLOROPHENOXY

A class of herbicides that may be found in domestic water supplies and cause adverse health effects. Two widely used chlorophenoxy herbicides are 2,4-D (2,4-Dichlorophenoxy acetic acid) and 2,4,5-TP (2,4,5-Trichlorophenoxy propionic acid (silvex)).

CHLORORGANIC (klor-or-GAN-nick) CHLORORGANIC

Organic compounds combined with chlorine These compounds generally originate from, or are associated with, life processes such as those of algae in water.

CIRCLE OF INFLUENCE CIRCLE OF INFLUENCE

The circular outer edge of a depression produced in the water table by the pumping of water from a well. Also see CONE OF INFLUENCE and CONE OF DEPRESSION

[SEE DRAWING ON PAGE 600]

CIRCUIT CIRCUIT

The complete path of an electric current, including the generating apparatus or other source, or, a specific segment or section of the complete path.

CIRCUIT BREAKER CIRCUIT BREAKER

A safety device in an electrical circuit that automatically shuts off the circuit when it becomes overloaded. The device can be manually reset.

CISTERN (SIS-turn) CISTERN

A small tank (usually covered) or a storage facility used to store water for a home or farm Often used to store rain water.

CLARIFIER (KLAIR-uh-fire) CLARIFIER

A large circular or rectangular tank or basin in which water is held for a period of time during which the heavier suspended solids settle to the bottom Clarifiers are also called SETTLING BASINS and SEDIMENTATION BASINS

CLEAR WELL CLEAR WELL

A reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand Also used to provide chlorine contact time for disinfection.

COAGULANT AID COAGULANT AID

Any chemical or substance used to assist or modify coagulation.

COAGULANTS (co-AGG-you-lents) COAGULANTS

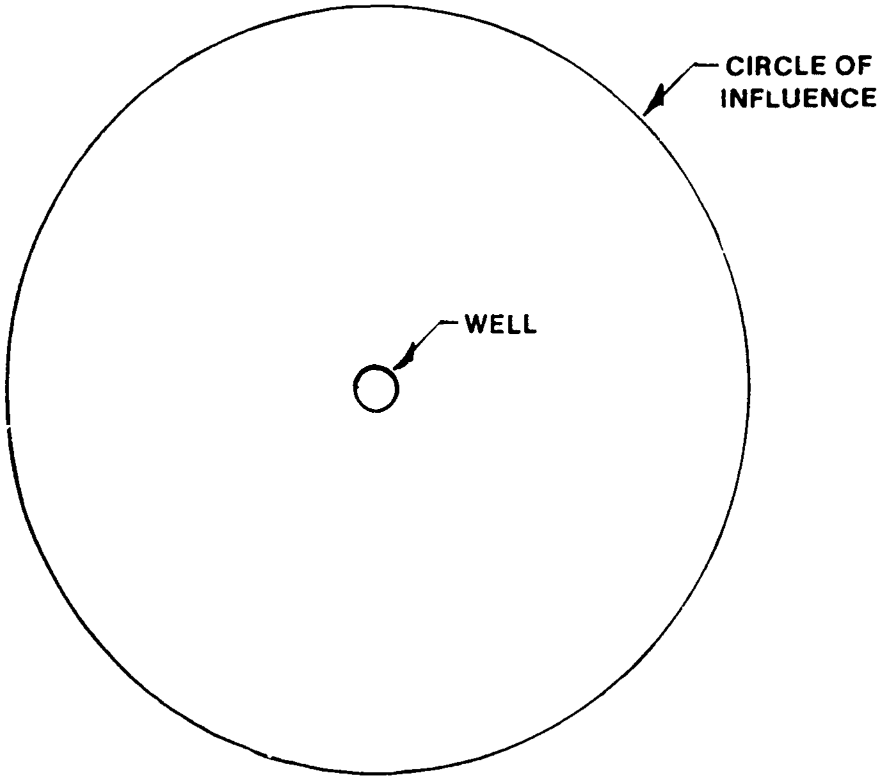
Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the water by settling, skimming, draining or filtering.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

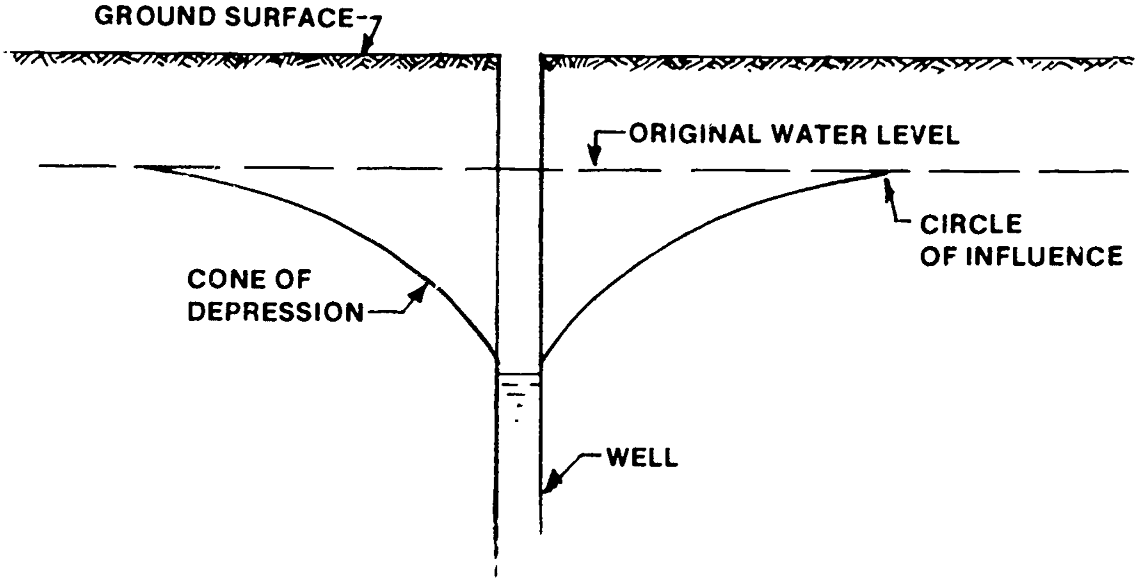
The clumping together of very fine particles into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

COLIFORM (COAL-i-form) COLIFORM

A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhibit the intestines of warm-blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.



TOP OR PLAN VIEW



SIDE OR ELEVATION VIEW

COLLOIDS (CALL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other This repulsion prevents the particles from clumping together, becoming heavier, and settling out

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

COMBINED AVAILABLE RESIDUAL CHLORINE COMBINED AVAILABLE RESIDUAL CHLORINE

The concentration of residual chlorine which is combined with ammonia (NH_3) and/or organic nitrogen in water as a chloramine (or other chloro derivative) yet is still available to oxidize organic matter and utilize its bactericidal properties

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water to produce combined available residual chlorine. This residual can be made up of monochloramines, dichloramines, and nitrogen trichloride.

COMPLETE TREATMENT COMPLETE TREATMENT

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called CONVENTIONAL FILTRATION.

COMPOSITE (come-PAH-zit) (PROPORTIONAL) SAMPLES COMPOSITE (PROPORTIONAL) SAMPLES

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period

COMPOUND COMPOUND

A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride-NaCl) is a compound.

CONCENTRATION POLARIZATION CONCENTRATION POLARIZATION

(1) The ratio of the salt concentration in the membrane boundary layer to the salt concentration in the water being treated The most common and serious problem resulting from concentration polarization is the increasing tendency for precipitation of sparingly soluble salts and the deposition of particulate matter on the membrane surface.

(2) Used in corrosion studies to indicate a depletion of ions near an electrode.

(3) The basis for chemical analysis by a polarograph.

CONDITIONING CONDITIONING

Pretreatment of sludge to facilitate removal of water in subsequent treatment processes

CONDUCTANCE CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water Also called SPECIFIC CONDUCTANCE.

CONDUCTIVITY CONDUCTIVITY

A measure of the ability of a solution (water) to carry an electric current

CONDUCTOR CONDUCTOR

A substance, body, device or wire that readily conducts or carries electrical current.

CONDUCTOR CASING CONDUCTOR CASING

The outer casing of a well. The purpose of this casing is to prevent contaminants from surface waters or shallow groundwaters from entering a well.

CONE OF DEPRESSION CONE OF DEPRESSION

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well Also see CIRCLE OF INFLUENCE and CONE OF INFLUENCE.

[SEE DRAWING ON PAGE 610]

CONE OF INFLUENCE CONE OF INFLUENCE

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF DEPRESSION

[SEE DRAWING ON PAGE 600]

CONFINED SPACE* CONFINED SPACE

A space defined by the concurrent existence of the following conditions.

A Existing ventilation is insufficient to remove dangerous air contamination and/or oxygen deficiency which may exist or develop, and

B Ready access or egress (getting out) for the removal of a suddenly disabled employee (operator) is difficult due to the location and/or size of the opening(s)

Also see definitions of *DANGEROUS AIR CONTAMINATION* and *DEFICIENCY.*

CONSOLIDATED FORMATION CONSOLIDATED FORMATION

A geologic material whose particles are stratified (layered), cemented or firmly packed together (hard rock), usually occurring at a depth below the ground surface. Also see UNCONSOLIDATED FORMATION.

CONTACTOR CONTACTOR

An electrical switch, usually magnetically operated

CONTAMINATION CONTAMINATION

The introduction into water of microorganisms, chemicals, toxic substances, wastes, or wastewater in a concentration that makes the water unfit for its next intended use

CONTINUOUS SAMPLE CONTINUOUS SAMPLE

A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples Frequently, several taps (faucets) will flow continuously in the laboratory to provide test samples from various places in a water treatment plant.

CONTROL LOOP CONTROL LOOP

The path through the control system between the sensor, which measures a process variable, and the controller, which controls or adjusts the process variable.

CONTROL SYSTEM CONTROL SYSTEM

A system which senses and controls its own operation on a close, continuous basis in what is called proportional (or modulating) control.

CONTROLLER CONTROLLER

A device which controls the starting, stopping, or operation of a device or piece of equipment

CONVENTIONAL FILTRATION CONVENTIONAL FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration Also called COMPLETE TREATMENT. Also see DIRECT FILTRATION and IN-LINE FILTRATION.

CONVENTIONAL TREATMENT CONVENTIONAL TREATMENT

See CONVENTIONAL FILTRATION. Also called COMPLETE TREATMENT.

CORPORATION STOP CORPORATION STOP

A water service shutoff valve located at a street water main This valve cannot be operated from the ground surface because it is buried and there is no valve box. Also called a CORPORATION COCK.

CORROSION CORROSION

The gradual decomposition or destruction of a material by chemical action, often due to an electrochemical reaction. Corrosion may be caused by (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, or (3) differential-concentration cells. Corrosion starts at the surface of a material and moves inward.

CORROSION INHIBITORS CORROSION INHIBITORS

Substances that slow the rate of corrosion.

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* *CONFINED SPACES, General Industry Safety Orders, Article 108, Title 8, California Administrative Code, Cal/OSHA Consultation Service, Sacramento, California, October, 1980.*

CORROSIVITY CORROSIVITY

An indication of the corrosiveness of a water. The corrosiveness of a water is described by the water's pH, alkalinity, hardness, temperature, total dissolved solids, dissolved oxygen, and the Langelier Index.

COULOMB (COO-lahm) COULOMB

A measurement of the amount of electrical charge conveyed by an electric current of one ampere in one second. One coulomb equals about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons).

COUPON COUPON

A steel specimen inserted into water to measure the corrosiveness of water. The rate of corrosion is measured as the loss of weight of the coupon (in milligrams) per surface area (in square decimeters) exposed to the water per day.

10 decimeters = 1 meter = 100 centimeters

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

CURB STOP CURB STOP

A water service shutoff valve located in a water service pipe near the curb and between the water main and the building. This valve is usually operated by a wrench or valve key and is used to start or stop flows in the water service line to a building. Also called a "curb cock."

CURIE CURIE

A measure of radioactivity. One Curie of radioactivity is equivalent to 3.7×10^{10} or 37,000,000,000 nuclear disintegrations per second.

CURRENT CURRENT

A movement or flow of electricity. Water flowing in a pipe is measured in gallons per second past a certain point, not by the number of water molecules going past a point. Electric current is measured by the number of coulombs per second flowing past a certain point in a conductor. A coulomb is equal to about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons). A flow of one coulomb per second is called one ampere, the unit of the rate of flow of current.

CYCLE CYCLE

A complete alteration of voltage and/or current in an alternating current (A.C.) circuit.

DANGEROUS AIR CONTAMINATION DANGEROUS AIR CONTAMINATION

An atmosphere presenting a threat of causing death, injury, acute illness, or disablement due to the presence of flammable and/or explosive, toxic or otherwise injurious or incapacitating substances.

A. Dangerous air contamination due to the flammability of a gas or vapor is defined as an atmosphere containing the gas or vapor at a concentration greater than 20 percent of its lower explosive (lower flammable) limit.

B. Dangerous air contamination due to a combustible particulate is defined as a concentration greater than 20 percent of the minimum explosive concentration of the particulate.

C. Dangerous air contamination due to the toxicity of a substance is defined as the atmospheric concentration immediately hazardous to life or health.

DATEOMETER (day-TOM-uh-ter) DATEOMETER

A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.

DATUM LINE DATUM LINE

A line from which heights and depths are calculated or measured. Also called a DATUM PLANE or a DATUM LEVEL.

DAY TANK DAY TANK

A tank used to store a chemical solution of known concentration for feed to a chemical feeder. A day tank usually stores sufficient chemical solution to properly treat the water being treated for at least one day. Also called an AGE TANK.

DEAD END DEAD END

The end of a water main which is not connected to other parts of the distribution system by means of a connecting loop of pipe.

DECANT DECANT

To draw off the upper layer of liquid (water) after the heavier material (a solid or another liquid) has settled.

DECHLORINATION (dee-KLOR-uh-NAY-shun) DECHLORINATION

The deliberate removal of chlorine from water The partial or complete reduction of residual chlorine by any chemical or physical process.

DECIBEL (DES-uh-bull) DECIBEL

A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average level at which sound causes pain to humans.

DECOMPOSITION DECOMPOSITION

The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) tends to produce much less objectionable tastes and odors.

DEFLUORIDATION (de-FLOOR-uh-DAY-shun) DEFLUORIDATION

The removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth.

DEGASIFICATION (DEE-GAS-if-uh-KAY-shun) DEGASIFICATION

A water treatment process which removes dissolved gases from the water The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

DEMINERALIZATION (DEE-MIN-er-al-uh-ZAY-shun) DEMINERALIZATION

A treatment process which removes dissolved minerals (salts) from water.

DENSITY (DEN-sit-tee) DENSITY

A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic feet. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DESALINIZATION (DEE-SAY-leen-uh-ZAY-shun) DESALINIZATION

The removal of dissolved salts (such as sodium chloride, NaCl) from water by natural means (leaching) or by specific water treatment processes.

DESICCANT (DESS-uh-kant) DESICCANT

A drying agent which is capable of removing or absorbing moisture from the atmosphere in a small enclosure.

DESICCATION (DESS-uh-KAY-shun) DESICCATION

A process used to thoroughly dry air; to remove virtually all moisture from air.

DESICCATOR (DESS-uh-KAY-tor) DESICCATOR

A closed container into which heated weighing or drying dishes are placed to cool in a dry environment. The dishes may be empty or they may contain a sample. Desiccators contain a substance, such as anhydrous calcium chloride, which absorbs moisture and keeps the relative humidity near zero so that the dish or sample will not gain weight from absorbed moisture.

DESTRATIFICATION (de-STRAT-uh-fuh-KAY-shun) DESTRATIFICATION

The development of vertical mixing within a lake or reservoir to eliminate (either totally or partially) separate layers of temperature, plant, or animal life This vertical mixing can be caused by mechanical means (pumps) or through the use of forced air diffusers which release air into the lower layers of the reservoir.

DETECTION LAG DETECTION LAG

The time period between the moment a change is made and the moment when such a change is finally sensed by the associated measuring instrument.

DETENTION TIME DETENTION TIME

(1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow.

(2) The actual time in hours, minutes or seconds that a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber In storage reservoirs, detention time is the length of time entering water will be held before being drafted for use (several weeks to years several months being typical).

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

DEW POINT DEW POINT

The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air.

DEWATER DEWATER

(1) To remove or separate a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of

(2) To remove or drain the water from a tank or a trench.

DIATOMACEOUS EARTH (DYE-uh-toe-MAY-shus) DIATOMACEOUS EARTH

A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid (box-like) internal structure consisting mainly of silica.

DIGITAL READOUT DIGITAL READOUT

Use of numbers to indicate the value or measurement of a variable. The readout of an instrument by a direct, numerical reading of the measured value.

DILUTE SOLUTION DILUTE SOLUTION

A solution that has been made weaker usually by the [illegible]tion of water.

DIMICTIC (die-MICK-tick) DIMICTIC

Lakes and reservoirs which freeze over and normally go through two stratification and two mixing cycles within a year.

DIRECT CURRENT (D.C.) DIRECT CURRENT (D.C.)

Electrical current flowing in one direction only and essentially free from pulsation.

DIRECT FILTRATION DIRECT FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted. Also see CONVENTIONAL FILTRATION and IN-LINE FILTRATION.

DIRECT RUNOFF DIRECT RUNOFF

Water that flows over the ground surface or through the ground directly into streams, rivers, or lakes.

DISCHARGE HEAD DISCHARGE HEAD

The pressure (in pounds per square inch or psi) measured at the centerline of a pump discharge and very close to the discharge flange, converted into feet.

Discharge Head, ft = (Discharge Pressure, psi)(2.31 ft/psi)

DISINFECTION (dis-in-FECK-shun) DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DISTILLATE (DIS-tuh-late) DISTILLATE

In the distillation of a sample, a portion is evaporated, the part that is condensed afterwards is the distillate.

DIVALENT (die-VAY-lent) DIVALENT

Having a valence of two, such as the ferrous ion, Fe^{2+}.

DIVERSION DIVERSION

Use of part of a stream flow as a water supply.

DPD (pronounce as separate letters) DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N,N-diethyl-p-phenylene-diamine.

DRAFT DRAFT

(1) The act of drawing or removing water from a tank or reservoir.

(2) The water which is drawn or removed from a tank or reservoir.

DRAWDOWN DRAWDOWN

(1) The drop in the water table or level of water in the ground when water is being pumped from a well.

(2) The amount of water used from a tank or reservoir.

(3) The drop in the water level of a tank or reservoir

DYNAMIC PRESSURE DYNAMIC PRESSURE

When a pump is operating, the vertical distance (in feet) from a reference point (such as a pump centerline) to the hydraulic grade line is the dynamic head.

Dynamic Pressure, psi = (Dynamic Head, ft) (0.433 psi/ft)

EDUCTOR (e-DUCK-ter) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump. As an injector, it is used to produce vacuum for chlorinators.

EFFECTIVE RANGE EFFECTIVE RANGE

That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy. Also see RANGE and SPAN.

EFFECTIVE SIZE (E.S.) EFFECTIVE SIZE (E.S.)

The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

EFFLUENT (EF-loo-ent) EFFLUENT

Water or other liquid — raw, partially or completely treated — flowing *FROM* a reservoir, basin, treatment process or treatment plant.

EJECTOR EJECTOR

A device used to disperse a chemical solution into water being treated.

ELECTROCHEMICAL REACTION ELECTROCHEMICAL REACTION

Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external force and cause the reaction, such as electrolysis caused by a D.C. (direct current) electric railway or the electron flow may be caused by a chemical reaction as in the galvanic action of a flashlight dry cell.

ELECTROCHEMICAL SERIES ELECTROCHEMICAL SERIES

A list of metals with the standard electrode potentials given in volts. The size and sign of the electrode potential indicates how easily these elements will take on or give up electrons, or corrode. Hydrogen is conventionally assigned a value of zero.

ELECTROLYSIS (ee-leck-TRAWL-uh-sis) ELECTROLYSIS

The decomposition of material by an outside electrical current

ELECTROLYTE (ee-LECK-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROLYTIC CELL (ee-LECK-tro-LIT-ick) ELECTROLYTIC CELL

A device in which the chemical decomposition of material causes an electric current to flow. Also, a device in which a chemical reaction occurs as a result of the flow of electric current. Chlorine and caustic (NaOH) are made from salt (NaCl) in eletrolytic cells.

ELECTROMOTIVE FORCE (E.M.F.) ELECTROMOTIVE FORCE (E.M.F.)

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See VOLTAGE.

ELECTROMOTIVE SERIES ELECTROMOTIVE SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the Galvanic Series. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

ELECTRON ELECTRON

An extremely small, negatively charged particle, the part of an atom that determines its chemical properties

ELEMENT ELEMENT

A substance which cannot be separated into its constituent parts and still retain its chemical identity For example, sodium (Na) is an element.

END BELLS END BELLS

Devices used to hold the rotor and stator of a motor in position.

END POINT END POINT

Samples are titrated to the end point This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter

ENDEMIC (en-DEM-ick) ENDEMIC

Something peculiar to a particular people or locality, such as a disease which is always present in the population.

ENDRIN (EN-drin) ENDRIN

A pesticide toxic to freshwater and marine aquatic life that produces adverse health effects in domestic water supplies.

ENERGY GRADE LINE (EGL) ENERGY GRADE LINE (EGL)

A line that represents the elevation of energy head of water flowing in a pipe, conduit or channel. The line is drawn above the hydraulic grade line (gradient) a distance equal to the velocity head ($V^2/2g$) of the water flowing at each section or point along the pipe or channel. Also see HYDRAULIC GRADE LINE.

[SEE DRAWING ON PAGE 618]

ENTERIC ENTERIC

Of intestinal origin, especially applied to wastes or bacteria.

ENTRAIN ENTRAIN

To trap bubbles in water either mechanically through turbulence or chemically through a reaction.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

E.P.A. E.P.A.

U.S. Environmental Protection Agency.

EPIDEMIC (EP-uh-DEM-ick) EPIDEMIC

A disease that occurs in a large number of people in a locality at the same time and spreads from person to person.

EPIDEMIOLOGY (EP-uh-DE-me-ALL-o-gee) EPIDEMIOLOGY

A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.

EPILIMNION (EP-uh-LIM-knee-on) EPILIMNION

The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

EQUILIBRIUM, CALCIUM CARBONATE EQUILIBRIUM, CALCIUM CARBONATE

A water is considered stable when it is just saturated with calcium carbonate. In this condition the water will neither dissolve nor deposit calcium carbonate. Thus, in this water the calcium carbonate is in equilibrium with the hydrogen ion concentration.

EQUIVALENT WEIGHT EQUIVALENT WEIGHT

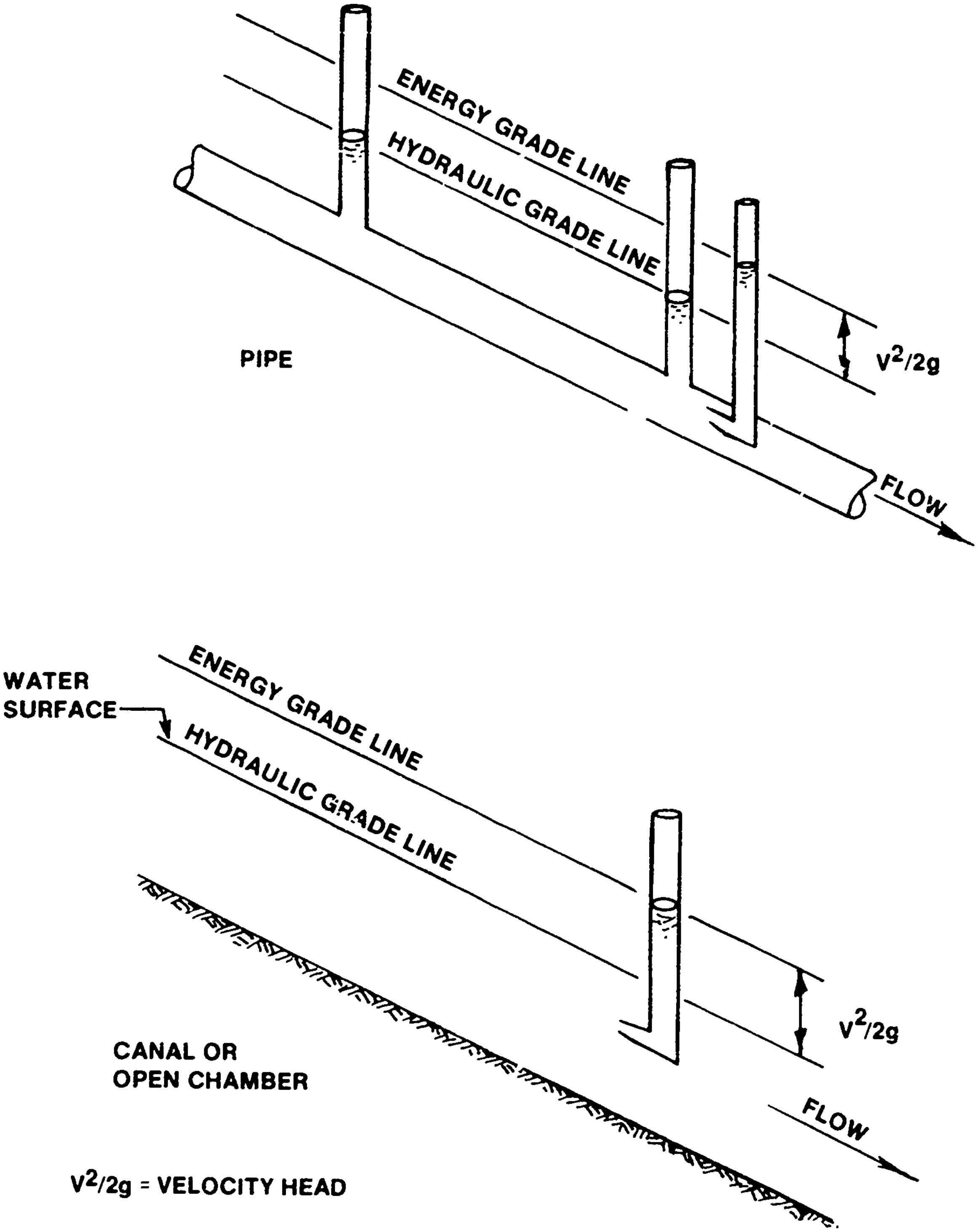
That weight which will react with, displace or is equivalent to one gram atom of hydrogen.

ESTER ESTER

A compound formed by the reaction between an acid and an alcohol with the elimination of a molecule of water.

EUTROPHIC (you-TRO-fick) EUTROPHIC

Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.



$V^2/2g$ = VELOCITY HEAD

ENERGY GRADE LINE and HYDRAULIC GRADE LINE

EUTROPHICATION (you-TRO-fi-KAY-shun)

EUTROPHICATION

The increase in the nutrient levels of a lake or other body of water, this usually causes an increase in the growth of aquatic animal and plant life

EVAPORATION

EVAPORATION

The process by which water or other liquid becomes a gas (water vapor or ammonia vapor)

EVAPOTRANSPIRATION (ee-VAP-o-TRANS-purr-A-shun)

EVAPOTRANSPIRATION

The process by which water vapor passes into the atmosphere from living plants. Also called TRANSPIRATION.

FACULTATIVE (FACK-ul-TAY-tive)

FACULTATIVE

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food material such as sulfate or nitrate ions In other words, facultative bacteria can live under aerobic or anaerobic conditions.

FEEDBACK

FEEDBACK

The circulating action between a sensor measuring a process variable and the controller which controls or adjusts the process variable

FEEDWATER

FEEDWATER

The water that is fed to a treatment process; the water that is going to be treated.

FINISHED WATER

FINISHED WATER

Water that has passed through a water treatment plant, all the treatment processes are completed or "finished." This water is ready to be delivered to consumers. Also called PRODUCT WATER.

FIX SAMPLE

FIX, SAMPLE

A sample is "fixed" in the field by adding chemicals that prevent the water quality indicators of interest in the sample from changing before final measurements are performed later in the lab.

FLAGELLATES (FLAJ-el-LATES)

FLAGELLATES

Microorganisms that move by the action of tail-like projections.

FLAME POLISHED

FLAME POLISHED

Melted by a flame to smooth out irregularities Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.

FLOAT ON SYSTEM

FLOAT ON SYSTEM

A method of operating a water storage facility Daily flow into the facility is approximately equal to the average daily demand for water When consumer demands for water are low, the storage facility will be filling. During periods of high demands, the facility will be emptying.

FLOC

FLOC

Clumps of bacteria and particulate impurities that have come together and formed a cluster. Found in flocculation tanks and settling or sedimentation basins.

FLOCCULATION (FLOCK-you-LAY-shun)

FLOCCULATION

The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing.

FLUIDIZED (FLEW-id-I-zd)

FLUIDIZED

A mass of solid particles that is made to flow like a liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by backwashing water through the filter.

FLUORIDATION (FLOOR-uh-DAY-shun)

FLUORIDATION

The addition of a chemical to increase the concentration of fluoride ions in drinking water to a predetermined optimum limit to reduce the incidence (number) of dental caries (tooth decay) in children. Defluoridation is the removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth.

FLUSHING

FLUSHING

A method used to clean water distribution lines. Hydrants are opened and water with a high velocity flows through the pipes, removes deposits from the pipes, and flows out the hydrants.

FLUX

FLUX

A flowing or flow

FOOT VALVE FOOT VALVE

A special type of check valve located at the bottom end of the suction pipe on a pump This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe

FREE AVAILABLE RESIDUAL CHLORINE FREE AVAILABLE RESIDUAL CHLORINE

That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

FREE RESIDUAL CHLORINATION FREE RESIDUAL CHLORINATION

The application of chlorine to water to produce a free available chlorine residual equal to at least 80 percent of the total residual chlorine (sum of free and combined available chlorine residual).

FREEBOARD FREEBOARD

(1) The vertical distance from the normal water surface to the top of the confining wall.

(2) The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called AVAILABLE EXPANSION.

FRICTION LOSSES FRICTION LOSSES

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, and restrictions caused by fittings. Water flowing in a pipe loses pressure or energy as a result of friction losses. Also see HEAD LOSS.

FUNGI (FUN-ji) FUNGI

Mushrooms, molds, mildews, rusts, and smuts that are small non-chlorophyll-bearing plants lacking roots, stems and leaves. They occur in natural waters and grow best in the absence of light. Their decomposition may cause objectionable tastes and odors in water.

FUSE FUSE

A protective device having a strip or wire of fusible metal which, when placed in a circuit, will melt and break the electrical circuit if heated too much. High temperatures will develop in the fuse when a current flows through the fuse in excess of that which the circuit will carry safely.

GAGE PRESSURE GAGE PRESSURE

The pressure within a closed container or pipe as measured with a gage. In contrast, absolute pressure is the sum of atmospheric pressure (14.7 lbs/sq in) *PLUS* pressure within a vessel (as measured by a gage). Most pressure gages read in "gage pressure" or psig (**p**ounds per **s**quare **i**nch **g**age pressure).

GALVANIC CELL GALVANIC CELL

An eletrolytic cell capable of producing electrical energy by electrochemical action. The decomposition of materials in the cell causes an electric (electron) current to flow from cathode to anode.

GALVANIC SERIES GALVANIC SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the ELECTROMOTIVE SERIES. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

GALVANIZE GALVANIZE

To coat a metal (especially iron or steel) with zinc. Galvanization is the process of coating a metal with zinc.

GARNET (GAR-nit) GARNET

A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

GEOLOGICAL LOG GEOLOGICAL LOG

A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).

GEOPHYSICAL LOG GEOPHYSICAL LOG

A record of the structure and composition of the earth encountered when drilling a well or similar type of test hole or boring.

GERMICIDE (GERM-uh-SIDE) GERMICIDE

A substance formulated to kill germs or microorganisms. The germicidal properties of chlorine make it an effective disinfectant.

GIARDIASIS (gee-are-DYE-uh-sis) GIARDIASIS

Intestinal disease caused by an infestation of Giardia flagellates

GRAB SAMPLE GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

GRADE GRADE

(1) The elevation of the invert (lowest point) of the bottom of a pipeline, canal, culvert or similar conduit

(2) The inclination or slope of a pipeline, conduit, stream channel, or natural ground surface, usually expressed in terms of the ratio or percentage of number of units of vertical rise or fall per unit of horizontal distance A 0.5 percent grade would be a drop of one-half foot per hundred feet of pipe.

GRAVIMETRIC GRAVIMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample by WEIGHING a precipitate or residue of the sample.

GRAVIMETRIC FEEDER GRAVIMETRIC FEEDER

A dry chemical feeder which delivers a measured weight of chemical during a specific time period.

GREENSAND GREENSAND

A sand which looks like ordinary filter sand except that it is green in color. This sand is a natural ion exchange mineral which is capable of softening water and removing iron and manganese.

GROUND GROUND

An expression representing an electrical connection to earth or a large conductor which is at the earth's potential or neutral voltage.

HARD WATER HARD WATER

Water having a high concentration of calcium and magnesium ions A water may be considered hard if it has a hardness greater than the typical hardness of water from the region Some textbooks define hard water as water with a hardness of more than 100 mg/*L* as calcium carbonate.

HARDNESS, WATER HARDNESS, WATER

A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

HEAD HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

HEAD LOSS HEAD LOSS

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses. Also see FRICTION LOSSES.

HEADER HEADER

A large pipe to which a series of smaller pipes are connected. Also called a MANIFOLD.

HEAT SENSOR HEAT SENSOR

A device that opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple which generates a minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a TEMPERATURE SENSOR.

HECTARE (HECK-tar) HECTARE

A measure of area in the metric system similar to an acre. One hectare is equal to 10,000 square meters and 2.4711 acres.

HEPATITIS (HEP-up-TIE-tis) HEPATITIS

Hepatitis is an inflammation of the liver usually caused by an acute viral infection. Yellow jaundice is one symptom of hepatitis.

HERBICIDE (HERB-uh-SIDE) HERBICIDE

A compound, usually a man-made organic chemical, used to kill or control plant growth.

HERTZ HERTZ

The number of complete electromagnetic cycles or waves in one second of an electrical or electronic circuit Also called the frequency of the current Abbreviated Hz

HIGH-LINE JUMPERS HIGH-LINE JUMPERS

Pipes or hoses connected to fire hydrants and laid on top of the ground to provide emergency water service for an isolated portion of a distribution system

HOSE BIB HOSE BIB

Faucet. A location in a water line where a hose is connected

HTH (pronounce as separate letters) HTH

High Test Hypochlorite Calcium hypochlorite or $Ca(OCl)_2$

HYDRATED LIME HYDRATED LIME

Limestone that has been burned and treated with water under controlled conditions until the calcium oxide portion has been converted to calcium hydroxide ($Ca(OH)_2$) Hydrated lime is quicklime combined with water $CaO + H_2O \rightarrow Ca(OH)_2$. Also called slaked lime. Also see QUICKLIME

HYDRAULIC GRADE LINE (HGL) HYDRAULIC GRADE LINE (HGL)

The surface or profile or water flowing in an open channel or a pipe flowing partially full. If a pipe is under pressure, the hydraulic grade line is at the level water would rise to in a small vertical tube connected to the pipe Also see ENERGY GRADE LINE

[SEE DRAWING ON PAGE 618]

HYDRAULIC GRADIENT HYDRAULIC GRADIENT

The slope of the hydraulic grade line. This is the slope of the water surface in an open channel, the slope of the water surface of the groundwater table, or the slope of the water pressure for pipes under pressure.

HYDROGEOLOGIST (HI-dro-gee-ALL-uh-jist) HYDROGEOLOGIST

A person who studies and works with groundwater.

HYDROLOGIC CYCLE (HI-dro-LOJ-ick) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow) This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

A chemical reaction in which a compound is converted into another compound by taking up water

HYDROPHILIC (HI-dro-FILL-ick) HYDROPHILIC

Having a strong affinity (liking) for water. The opposite of HYDROPHOBIC.

HYDROPHOBIC (HI-dro-FOE-bick) HYDROPHOBIC

Having a strong aversion (dislike) for water The opposite of HYDROPHILIC.

HYDROPNEUMATIC (HI-dro-new-MAT-ick) HYDROPNEUMATIC

A water system, usually small, in which a water pump is automatically controlled (started and stopped) by the air pressure in a compressed-air tank.

HYDROSTATIC PRESSURE (HI-dro-STAT-ick) HYDROSTATIC PRESSURE

(1) The pressure at a specific elevation exerted by a body of water at rest, or

(2) In the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.

HYGROSCOPIC (HI-grow-SKOP-ick) HYGROSCOPIC

Absorbing or attracting moisture from the air.

HYPOCHLORINATION (HI-poe-KLOR-uh-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water for the purpose of disinfection.

HYPOCHLORINATORS (HI-poe-KLOR-uh-NAY-tors) HYPOCHLORINATORS

Chlorine pumps, chemical feed pumps or devices used to dispense chlorine solutions made from hypochlorites such as bleach (sodium hypochlorite) or calcium hypochlorite into the water being treated.

HYPOCHLORITE (HI-poe-KLOR-ite) HYPOCHLORITE

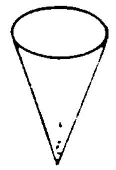
Chemical compounds containing available chlorine, used for disinfection They are available as liquids (bleach) or solids (powder, granules and pellets). Salts of hypochlorous acid.

HYPOLIMNION (HI-poe-LIM-knee-on) HYPOLIMNION

The lowest layer in a thermally stratified lake or reservoir This layer consists of colder, more dense water, has a constant temperature and no mixing occurs

IMHOFF CONE IMHOFF CONE

A clear, cone-shaped container marked with graduations. The cone is used to measure the volume of settleable solids in a specific volume (usually one liter) of water.



IMPELLER IMPELLER

A rotating set of vanes in a pump designed to pump or lift water

IMPERMEABLE (im-PURR-me-uh-BULL) IMPERMEABLE

Not easily penetrated The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water.

INDICATOR (CHEMICAL) INDICATOR (CHEMICAL)

A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

INDICATOR (INSTRUMENT) INDICATOR (INSTRUMENT)

A device which indicates the result of a measurement Most indicators in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called a RECEIVER

INFILTRATION (IN-fill-TRAY-shun) INFILTRATION

The gradual flow or movement of water into and through (to percolate or pass through) the pores of the soil. Also called PERCOLATION.

INFLUENT (IN-flu-ent) INFLUENT

Water or other liquid — raw or partially treated — flowing *INTO* a reservoir, basin, treatment process or treatment plant.

INITIAL SAMPLING INITIAL SAMPLING

The very first sampling conducted under the Safe Drinking Water Act for each of the applicable contaminant categories.

IN-LINE FILTRATION IN-LINE FILTRATION

The addition of chemical coagulants directly to the filter inlet pipe The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated This pretreatment method is commonly used in pressure filter installation. Also see CONVENTIONAL FILTRATION and DIRECT FILTRATION.

INORGANIC INORGANIC

Material such as sand, salt, iron, calcium salts and other mineral materials Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

INPUT HORSEPOWER INPUT HORSEPOWER

The total power used in operating a pump and motor.

$$\text{Input Horsepower, HP} = \frac{(\text{Brake Horsepower, HP})(100\%)}{\text{Motor Efficiency, \%}}$$

INSECTICIDE INSECTICIDE

Any substance or chemical formulated to kill or control insects

INSOLUBLE (in-SAWL-you-bull) INSOLUBLE

Something that cannot be dissolved

INTEGRATOR INTEGRATOR

A device or meter that continuously measures and calculates (adds) total flows in gallons, million gallons, cubic feet, or some other unit of volume measurement. Also called a TOTALIZER.

INTERFACE INTERFACE

The common boundary layer between two substances such as water and a solid (metal), or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

INTERLOCK INTERLOCK

An electrical switch, usually magnetically operated Used to interrupt all (local) power to a panel or device when the door is opened or the circuit exposed to service.

INTERNAL FRICTION INTERNAL FRICTION

Friction within a fluid (water) due to cohesive forces

INTERSTICE (in-TUR-stihz) INTERSTICE

A very small open space in a rock or granular material. Also called a void or void space. Also see PORE

INVERT (IN-vert) INVERT

The lowest point of the channel inside a pipe, conduit, or canal

ION ION

An electrically charged atom, radical (such as SO_4^{2}), or molecule formed by the loss or gain of one or more electrons.

ION EXCHANGE ION EXCHANGE

A water treatment process involving the reversible interchange (switching) of ions between the water being treated and the solid resin Undesirable ions in the water are switched with acceptable ions on the resin.

ION EXCHANGE RESINS ION EXCHANGE RESINS

Insoluble polymers, used in water treatment, that are capable of exchanging (switching or giving) acceptable cations or anions to the water being treated for less desirable ions.

IONIC CONCENTRATION IONIC CONCENTRATION

The concentration of any ion in solution, usually expressed in moles per liter.

IONIZATION (EYE-on-uh-ZAY-shun) IONIZATION

The splitting or dissociation (separation) of molecules into negatively and positively charged ions

JAR TEST JAR TEST

A laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with differing chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to *ESTIMATE* the minimum or ideal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of solids is observed. The dose of chemicals that provides satisfactory settling removal of turbidity and/or color is the dose used to treat the water being taken into the plant at that time When evaluating the results of a jar test, the operator should also consider the floc quality in the flocculation area and the floc loading on the filter.

JOGGING JOGGING

The frequent starting and stopping of an electric motor.

JOULE (jewel) JOULE

A measure of energy, work or quantity of heat. One joule is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of force

KELLY KELLY

The square section of a rod which causes the rotation of the drill bit. Torque from a drive table is applied to tne square rod to cause the rotary motion. The drive table is chain or gear driven by an engine.

KILO KILO

(1) Kilogram.

(2) Kilometer.

(3) A prefix meaning "thousand' used in the metric system and other scientific systems of measurement

KINETIC ENERGY KINETIC ENERGY

Energy possessed by a moving body of matter, such as water, as a result of its motion.

KJELDAHL NITROGEN (KELL-doll) KJELDAHL NITROGEN

Nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl Method.

LANGELIER INDEX (L.I.) LANGELIER INDEX (L.I.)

An index reflecting the equilibrium pH of a water with respect to calcium and alkalinity. This index is used in stabilizing water to control both corrosion and the deposition of scale.

Langelier Index = $pH - pH_s$
where pH = actual pH of the water, and
pH_s = pH at which water having the same alkalinity and calcium content is just saturated with calcium carbonate.

LAUNDERING WEIR (LAWN-der-ing weer) LAUNDERING WEIR

Sedimentation basin overflow weir. A plate with V-notches along the top to assure a uniform flow rate and avoid short-circuiting.

LAUNDERS (LAWN-ders) LAUNDERS

Sedimentation basin and filter discharge channel consisting of overflow weir plates (in sedimentation basins) and conveying troughs.

LEAD (LEE-d) LEAD

A wire or conductor that can carry electricity.

LEATHERS LEATHERS

O rings or gaskets used with piston pumps to provide a seal between the piston and the side wall.

LEVEL CONTROL LEVEL CONTROL

A float device (or pressure switch) which senses changes in a measured variable and opens or closes a switch in response to that change. In its simplest form, this control might be a floating ball connected mechanically to a switch or valve such as is used to stop water flow into a toilet when the tank is full.

LINDANE (LYNN-dane) LINDANE

A pesticide that causes adverse health effects in domestic water supplies and also is toxic to freshwater and marine aquatic life.

LINEARITY (LYNN-ee-AIR-it-ee) LINEARITY

How closely an instrument measures actual values of a variable through its effective range, a measure used to determine the accuracy of an instrument.

LITTORAL ZONE (LIT-or-al) LITTORAL ZONE

(1) That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants.

(2) The strip of land along the shoreline between the high and low water levels.

LOGARITHM (LOG-a-rith-m) LOGARITHM

The exponent that indicates the power to which a number must be raised to produce a given number. For example, if $B^2 = N$, the 2 is the logarithm of N (to the base B), or $10^2 = 100$ and $\log_{10} 100 = 2$. Also abbreviated to "log."

LOGGING, ELECTRICAL LOGGING, ELECTRICAL

A procedure used to determine the porosity (spaces or voids) of formations in search of water-bearing formations (aquifers). Electrical probes are lowered into wells, an electrical current is induced at various depths and the resistance measured of various formations indicates the porosity of the material.

M or MOLAR **M** or MOLAR

A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A one *M* solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MACROSCOPIC (MACK-row-SKAWP-ick) ORGANISMS MACROSCOPIC ORGANISMS

Organisms big enough to be seen by the eye without the aid of a microscope.

MANDREL (MAN-drill) MANDREL

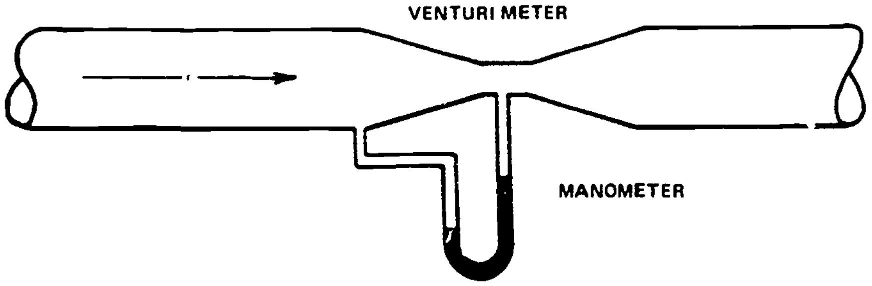
A special tool used to push bearings in or to pull sleeves out.

MANIFOLD MANIFOLD

A large pipe to which a series of smaller pipes are connected. Also called a HEADER.

MANOMETER (man-NAH-mut-ter) MANOMETER

An instrument for measuring pressure Usually, a manometer is a glass tube filled with a liquid that is used to measure the difference in pressure across a flow-measuring device such as an orifice or Venturi meter. The instrument used to measure blood pressure is a type of manometer.



MAXIMUM CONTAMINANT LEVEL (MCL) MAXIMUM CONTAMINANT LEVEL (MCL)

See MCL.

MBAS MBAS

Methylene - Blue - Active Substances. These substances are used in surfactants or detergents.

MCL MCL

Maximum Contaminant Level The largest allowable amount. MCLs for various water quality indicators are specified in the National Interim Primary Drinking Water Regulations (NIPDWR)

MEASURED VARIABLE MEASURED VARIABLE

A characteristic or component part that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

MECHANICAL JOINT MECHANICAL JOINT

A flexible device that joins pipes or fittings together by the use of lugs and bolts.

MEG MEG

A procedure used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEGGER.

MEGGER (from megohm) MEGGER

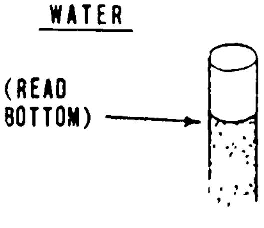
An instrument used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEG.

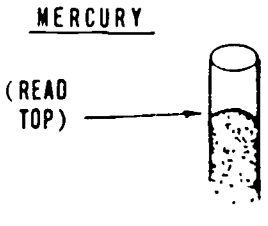
MEGOHM MEGOHM

Meg means one million, so 5 megohms means 5 million ohms. A megger reads in millions of ohms.

MENISCUS (meh-NIS-cuss) MENISCUS

The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.





MESH MESH

One of the openings or spaces in a screen or woven fabric The value of the mesh is usually given as the number of openings per inch This value does not consider the diameter of the wire or fabric, therefore, the mesh number does not always have a definite relationship to the size of the hole.

MESOTROPHIC (MESS-o-TRO-fick) MESOTROPHIC

Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

METABOLISM (meh-TAB-uh-LIZ-um) METABOLISM

(1) The biochemical processes in which food is used and wastes are formed by living organisms.

(2) All biochemical reactions involved in cell formation and growth.

METALIMNION (MET uh-LIM-knee-on) METALIMNION

The middle layer in a thermally stratified lake or reservoir In this layer there is a rapid decrease in temperature with depth. Also called the THERMOCLINE.

METHOXYCHLOR (meth-OXY-klor) METHOXYCHLOR

A pesticide which causes adverse health effects in domestic water supplies and is also toxic to freshwater and marine aquatic life. The chemical name for methoxychlor is 2,2-bis (p-methoxyphenol)-1,1,1-trichloroethane.

METHYL ORANGE ALKALINITY METHYL ORANGE ALKALINITY

A measure of the total alkalinity in a water sample The alkalinity is measured by the amount of standard sulfuric acid required to lower the pH of the water to a pH level of 4.5, as indicated by the change in color of methyl orange from orange to pink. Methyl orange alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

mg/*L* mg/*L*

See MILLIGRAMS PER LITER.

MICROBIAL GROWTH (my-KROW-bee-ul) MICROBIAL GROWTH

The activity and growth of microorganisms such as bacteria, algae, diatoms, plankton and fungi

MICRON (MY-kron) MICRON

A unit of length. One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

MICROORGANISMS (MY-crow-OR-gan-IS-zums) MICROORGANISMS

Living organisms that can be seen individually only with the aid of a microscope.

MIL MIL

A unit of length equal to 0.001 of an inch. The diameter of wires and tubing is measured in mils, as is the thickness of plastic sheeting.

MILLIGRAMS PER LITER, mg/*L* MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/*L* of a substance in fresh water is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/*L*), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).

MILLIMICRON (MILL-uh-MY-kron) MILLIMICRON

A unit of length equal to $10^{-3}\mu$ (one thousandth of a micron), 10^{-6} millimeters, or 10^{-9} meters, correctly called a nanometer, nm.

MOLAR MOLAR

See **M** for MOLAR.

MOLE MOLE

The molecular weight of a substance, usually expressed in grams.

MOLECULAR WEIGHT MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

MOLECULE (MOLL-uh-KULE) MOLECULE

The smallest division of a compound that still retains or exhibits all the properties of the substance.

MONOMER (MON-o-MER) MONOMER

A molecule of low molecular weight capable of reacting with identical or different monomers to form polymers.

MONOMICTIC (mo-no-MICK-tick) MONOMICTIC

Lakes and reservoirs which are relatively deep, do not freeze over during the winter months, and undergo a single stratification and mixing cycle during the year These lakes and reservoirs usually become destratified during the mixing cycle, usually in the fall of the year.

MONOVALENT MONOVALENT

Having a valence of one, such as the cuprous (copper) ion, Cu^+.

MOST PROBABLE NUMBER (MPN) MOST PROBABLE NUMBER (MPN)

See MPN.

MOTILE (MO-till) MOTILE

Capable of self-propelled movement A term that is sometimes used to distinguish between certain types of organisms found in water

MOTOR EFFICIENCY MOTOR EFFICIENCY

The ratio of energy delivered by a motor to the energy supplied to it during a fixed period or cycle. Motor efficiency ratings will vary depending upon motor manufacturer and usually will range from 88.9 to 90.0 percent

MPN (pronounce as separate letters) MPN

MPN is the Most Probable Number of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 *mL* of sample water.

MUDBALLS MUDBALLS

Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.

MULTI-STAGE PUMP MULTI-STAGE PUMP

A pump that has more than one impeller. A single-stage pump has one impeller

N or NORMAL **N** or NORMAL

A normal solution contains one gram equivalent weight of reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A one *N* solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

NATIONAL ENVIRONMENTAL TRAINING ASSOCIATION NATIONAL ENVIRONMENTAL TRAINING ASSOCIATION

A professional organizaiton devoted to serving the environmental trainer and promoting better operation of waterworks and pollution control facilities For information on NETA membership and publications, contact NETA, P.O. Box 346, Valparaiso, Indiana 46383.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH

See NIOSH.

NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

Commonly referred to as NIPDWR.

NATIONAL SAFE DRINKING WATER REGULATIONS NATIONAL SAFE DRINKING WATER REGULATIONS

Commonly referred to as NSDWR.

NEPHELOMETRIC (NEFF-el-o-MET-rick) NEPHELOMETRIC

A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

NETA NETA

See **N**ational **E**nvironmental **T**raining **A**ssociation.

NEWTON NEWTON

A force which, when applied to a body having a mass of one kilogram, gives it an acceleration of one meter per second per second.

NIOSH NIOSH

The National Institute of Occupational Safety and Health is an organization that tests and approves safety equipment for particular applications NIOSH is the primary Federal agency engaged in research in the national effort to eliminate on-the-job hazards to the health and safety of working people. The NIOSH Publications Catalog contains a listing of NIOSH publications mainly on industrial hygiene and occupational health To obtain a copy of the catalog, write to NIOSH Publications, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

NIPDWR NIPDWR

National Interim Primary Drinking Water Regulations.

NITROGENOUS (nye-TRAH-jen-us) NITROGENOUS

A term used to describe chemical compounds (usually organic) containing nitrogen in combined forms. Proteins and nitrates are nitrogenous compounds.

NOBLE METAL NOBLE METAL

A chemically inactive metal (such as gold) A metal that does not corrode easily and is much scarcer (and more valuable) than the so-called useful or base metals. Also see BASE METAL.

NOMINAL DIAMETER NOMINAL DIAMETER

An approximate measurement of the diameter of a pipe. Although the nominal diameter is used to describe the size or diameter of a pipe, it is usually not the exact inside diameter of the pipe.

NONIONIC POLYMER (NON-eye-ON-ick) NONIONIC POLYMER

A polymer that has no net electrical charge.

NONPOINT SOURCE NONPOINT SOURCE

A runoff or discharge from a field or similar source A point source refers to a discharge that comes out the end of a pipe.

NONPOTABLE (non-POE-tuh-bull) NONPOTABLE

Water that may contain objectionable pollution, contamination, minerals, or infective agents and is considered unsafe and/or unpalatable for drinking.

NORMAL NORMAL

See **N** for NORMAL.

NPDES PERMIT NPDES PERMIT

National **P**ollutant **D**ischarge **E**limination **S**ystem permit is the regulatory agency document designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

NSDWR NSDWR

National **S**afe **D**rinking **W**ater **R**egulations

NUTRIENT NUTRIENT

Any substance that is assimilated (taken in) by organisms and promotes growth. Nitrogen and phosphorous are nutrients which promote the growth of algae. There are other essential and trace elements which are also considered nutrients.

OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970 OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970

See OSHA.

ODOR THRESHOLD ODOR THRESHOLD

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called THRESHOLD ODOR.

OFFSET (or DROOP) OFFSET

The difference between the actual value and the desired value (or set point), characteristic of proportional controllers that do not incorporate reset action.

OHM OHM

The unit of electrical resistance. The resistance of a conductor in which one volt produces a current of one ampere.

OLFACTORY FATIGUE (oh-FAK-tore-ee) OLFACTORY FATIGUE

A condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor.

OLIGOTROPHIC (AH-lig-o-TRO-fick) OLIGOTROPHIC

Reservoirs and lakes which are nutrient poor and contain little aquatic plant or animal life.

ORGANIC ORGANIC

Substances that come from animal or plant sources Organic substances always contain carbon (Inorganic materials are chemical substances of mineral origin) Also see INORGANIC.

ORGANICS ORGANICS

(1) A term used to refer to chemical compounds made from carbon molecules These compounds may be natural materials (such as animal or plant sources) or man-made materials (such as synthetic organics). Also see ORGANIC.

(2) Any form of animal of plant life Also see BACTERIA.

ORGANISM ORGANISM

Any form of animal or plant life. Also see BACTERIA.

ORIFICE (OR-uh-fiss) ORIFICE

An opening (hole) in a plate, wall or partition An orifice flange or plate placed in a pipe consists of a slot or a calibrated circular hole smaller than the pipe diameter The difference in pressure in the pipe above and at the orifice may be used to determine the flow in the pipe.

ORP ORP

Oxidation-Reduction Potential The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant), used as a qualitative measure of the state of oxidation in water treatment systems.

ORTHOTOLIDINE (or-tho-TOL-uh-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual If chlorine is present, a yellow-colored compound is produced. This reagent is no longer approved for chemical analysis

OSHA (O-shuh) OSHA

The Williams-Steiger Occupational Safety and Health Act of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

OSMOSIS (oz-MOE-sis) OSMOSIS

The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane. The membrane allows the passage of the water (solvent) but not the dissolved solids (solutes) This process tends to equalize the conditions on either side of the membrane.

OVERALL EFFICIENCY, PUMP OVERALL EFFICIENCY, PUMP

The combined efficiency of a pump and motor together Also called the WIRE-TO-WATER EFFICIENCY.

OVERDRAFT OVERDRAFT

The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin. This pumping results in a depletion or "mining" of the groundwater in the basin.

OVERFLOW RATE OVERFLOW RATE

One of the guidelines for the design of settling tanks and clarifiers in treatment plants Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called SURFACE LOADING.

$$\text{Overflow Rate, GDP/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

OVERTURN OVERTURN

The almost spontaneous mixing of all layers of water in a reservoir or lake when the water temperature becomes similar from top to bottom This may occur in the fall/winter when the surface waters cool to the same temperature as the bottom waters and also in the spring when the surface waters warm after the ice melts.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant), used as a qualitative measure of the state of oxidation in water treatment systems.

OXIDIZING AGENT OXIDIZING AGENT

Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons The opposite is a REDUCING AGENT

OXYGEN DEFICIENCY OXYGEN DEFICIENCY

An atmosphere containing oxygen at a concentration of less than 19.5 percent by volume.

OZONATION (O-zoe-NAY-shun) OZONATION

The application of ozone to water for disinfection or for taste and odor control

PACKER ASSEMBLY PACKER ASSEMBLY

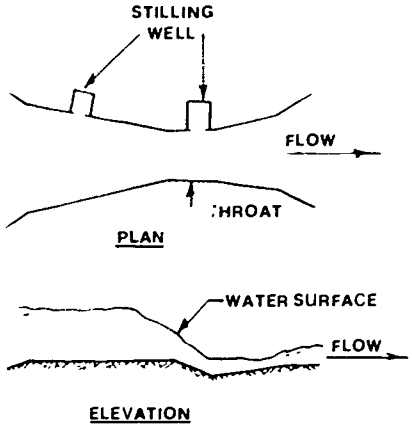
An inflatable device used to seal the tremie pipe inside the well casing to prevent the grout from entering the inside of the conductor casing.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity Pleasing to the senses.

PARSHALL FLUME PARSHALL FLUME

A device used to measure the flow in an open channel. The flume narrows to a throat of fixed dimensions and then expands again The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.



PARTICLE COUNT PARTICLE COUNT

The results of a microscopic examination of treated water with a special particle counter which classifies suspended particles by number and size

PARTICULATE (par-TICK-you-let) PARTICULATE

A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

PARTS PER MILLION (PPM) PARTS PER MILLION (PPM)

Parts per million parts, a measurement of concentration on a weight or volume basis This term is equivalent to milligrams per liter (mg/L) which is the preferred term

PASCAL PASCAL

The pressure or stress of one newton per square meter. (Abbreviated Pa)

1 psi = 6895 Pa = 6.895 kN/sq m = 0.0703 kg/sq cm

PATHOGENIC ORGANISMS (path-o-JEN-ick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person) There are many types of organisms which do *NOT* cause disease. These organisms are called non-pathogenic.

PATHOGENS (PATH-o-jens) PATHOGENS

Pathogenic or disease-causing organisms

PCBs PCBs

See POLYCHLORINATED BIPHENYLS.

pCi/L pCi/L

PicoCurie per Liter A picoCurie is a measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second.

PEAK DEMAND PEAK DEMAND

The maximum momentary load placed on a water treatment plant, pumping station or distribution system. This demand is usually the maximum average load in one hour or less, but may be specified as the instantaneous or with some other short time period.

PERCENT SATURATION PERCENT SATURATION

The amount of a substance that is dissolved in a solution compared with the amount that could be dissolved in the solution, expressed as a percent.

$$\text{Percent Saturation, \%} = \frac{\text{Amount of Substance That is Dissolved}}{\text{Amount That Could Be Dissolved in Solution}} \times 100\%$$

PERCOLATING WATER (PURR-co-LAY-ting) PERCOLATING WATER

Water that passes through soil or rocks under the force of gravity.

PERCOLATION (PURR-ko-LAY-shun) PERCOLATION

The slow passage of water through a filter medium; or, the gradual penetration of soil and rocks by water.

PERIPHYTON (puh-RIF-uh-tawn) PERIPHYTON

Microscopic plants and animals that are firmly attached to solid surfaces under water such as rocks, logs, pilings and other structures.

PERMEABILITY (PURR-me-uh-BILL-uh-tee) PERMEABILITY

The property of a material or soil that permits considerable movement of water through it when it is saturated.

PERMEATE (PURR-me-ate) PERMEATE

(1) To penetrate and pass through, as water penetrates and passes through soil and other porous materials.

(2) The demineralized water.

PESTICIDE PESTICIDE

Any substance or chemical designed or formulated to kill or control weeds or animal pests Also see ALGICIDE, HERBICIDE, INSECTICIDE,and RODENTICIDE.

PET COCK PET COCK

A small valve or faucet used to drain a cylinder or fitting.

pH (pronounce as separate letters) pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \text{Log}\ \frac{1}{(H^{+})}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral Natural waters usually have a pH between 6.5 and 8.5.

PHENOLIC COMPOUNDS (FEE-noll-LICK) PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene.

PHENOLPHTHALEIN ALKALINITY (FEE-nol-THAY-leen) PHENOLPHTHALEIN ALKALINITY

The alkalinity in a water sample measured by the amount of standard acid required to lower the pH to a level of 8.3, as indicated by the change in color of phenolphthalein from pink to clear. Phenolphthalein alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

PHOTOSYNTHESIS (foe-tow-SIN-thuh-sis) PHOTOSYNTHESIS

A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen and additional plant material, using sunlight for energy. All green plants grow by this process.

PHYTOPLANKTON (FI-tow-PLANK-ton) PHYTOPLANKTON

Small, usually microscopic plants (such as algae), found in lakes, reservoirs, and other bodies of water.

PICO PICO

A prefix used in the metric system and other scientific systems of measurement which means 10^{-12} or 0.000 000 000 001.

PICOCURIE PICOCURIE

A measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second.

PITLESS ADAPTER PITLESS ADAPTER

A fitting which allows the well casing to be extended above ground while having a discharge connection located below the frost line. Advantages of using a pitless adapter include the elimination of the need for a pit or pump house and it is a water-tight design, which helps maintain a sanitary water supply.

PLAN VIEW PLAN VIEW

A diagram or photo showing a facility as it would appear when looking down on top of it.

PLANKTON PLANKTON

(1) Small, usually microscopic, plants (phytoplankton) and animals (zooplankton) in aquatic systems.

(2) All of the smaller floating, suspended or self-propelled organisms in a body of water.

PLUG FLOW PLUG FLOW

A type of flow that occurs in tanks, basins or reactors when a slug of water moves through a tank without ever dispersing or mixing with the rest of the water flowing through the tank.

PMCLs PMCLs

Primary Maximum Contaminant Levels. Primary MCLs for various water quality indicators are established to protect public health.

POINT SOURCE POINT SOURCE

A discharge that comes out of the end of a pipe. A nonpoint source refers to runoff or a discharge from a field or similar source.

POLE SHADER POLE SHADER

A copper bar circling the laminated iron core inside the coil of a magnetic starter.

POLLUTION POLLUTION

The impairment (reduction) of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes), to a degree that has an adverse effect on any beneficial use of water.

POLYCHLORINATED BIPHENYLS POLYCHLORINATED BIPHENYLS

A class of organic compounds that cause adverse health effects in domestic water supplies.

POLYELECTROLYTE (POLY-ee-LECK-tro-lite) POLYELECTROLYTE

A high-molecular-weight (relatively heavy) substance having points of positive or negative electrical charges that is formed by either natural or man-made processes. Natural polyelectrolytes may be of biological origin or derived from starch products and cellulose derivatives. Man-made polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Often called a POLYMER.

POLYMER POLYMER

A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

PORE PORE

A very small open space in a rock or granular material. Also see INTERSTICE.

POROSITY POROSITY

(1) A measure of the spaces or voids in a material or aquifer.

(2) The ratio of the volume of spaces in a rock or soil to the total volume. This ratio is usually expressed as a percentage.

$$\text{Porosity, \%} = \frac{(\text{Volume of Spaces})(100\%)}{\text{Total Volume}}$$

POSITIVE BACTERIOLOGICAL SAMPLE POSITIVE BACTERIOLOGICAL SAMPLE

A water sample in which gas is produced by coliform organisms during incubation in the multiple tube fermentation test. See Chapter 11, Lab Procedures, "Coliform Test," for details.

POSITIVE DISPLACEMENT PUMP POSITIVE DISPLACEMENT PUMP

A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. Positive displacement pumps are used as chemical solution feeders.

POSTCHLORINATION POSTCHLORINATION

The addition of chlorine to the plant effluent, *FOLLOWING* plant treatment, for disinfection purposes.

POTABLE WATER (POE-tuh-buli) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

POWER FACTOR POWER FACTOR

The ratio of the true power passing through an electric circuit to the product of the voltage and amperage in the circuit. This is a measure of the lag or load of the current with respect to the voltage.

PPM PPM

See PARTS PER MILLION.

PRECHLORINATION PRECHLORINATION

The addition of chlorine at the headworks of the plant *PRIOR TO* other treatment processes mainly for disinfection and control of tastes, odors and aquatic growths. Also applied to aid in coagulation and settling.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

PRECIPITATION (pre-SIP-uh-TAY-shun) PRECIPITATION

(1) The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, or other forms of moisture.

(2) The chemical transformation of a substance in solution into an insoluble form (precipitate).

PRECISION PRECISION

The ability of an instrument to measure a process variable and to repeatedly obtain the same result. The ability of an instrument to reproduce the same results.

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they *MUST* be present in order for THMs to form.

PRESCRIPTIVE (pre-SKRIP-tive) PRESCRIPTIVE

Water rights which are acquired by diverting water and putting it to use in accordance with specified procedures. These procedures include filing a request to use unused water in a stream, river or lake with a state agency.

PRESSURE CONTROL PRESSURE CONTROL

A switch which operates on changes in pressure. Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).

PRESSURE HEAD PRESSURE HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

PRESTRESSED PRESTRESSED

A prestressed pipe has been reinforced with wire strands (which are under tension) to give the pipe an active resistance to loads or pressures on it.

PRIMARY ELEMENT PRIMARY ELEMENT

The hydraulic structure used to measure flows. In open channels, weirs and flumes are primary elements or devices. Venturi meters and orifice plates are the primary elements in pipes or pressure conduits.

PRIME PRIME

The action of filling a pump casing with water to remove the air Most pumps must be primed before startup or they will not pump any water.

PROCESS VARIABLE PROCESS VARIABLE

A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

PRODUCT WATER PRODUCT WATER

Water that has passed through a water treatment plant All the treatment processes are completed or finished. This water is the product from the water treatment plant and is ready to be delivered to the consumers. Also called FINISHED WATER.

PROFILE PROFILE

A drawing showing elevation plotted against distance, such as the vertical section or side view of a pipeline.

PRUSSIAN BLUE PRUSSIAN BLUE

A blue paste or liquid (often on a paper like carbon paper) used to show a contact area. Used to determine if gate valve seats fit properly.

PSIG PSIG

Pounds per **S**quare **I**nch **G**age pressure The pressure within a closed container or pipe measured with a gage in pounds per square inch. See GAGE PRESSURE.

PUMPING WATER LEVEL PUMPING WATER LEVEL

The vertical distance in feet from the centerline of the pump discharge to the level of the free pool while water is being drawn from the pool.

PURVEYOR, WATER (purr-VAY-or) PURVEYOR, WATER

An agency or person that supplies water (usually potable water).

PUTREFACTION (PEW-truh-FACK-shun) PUTREFACTION

Biological decomposition of organic matter, with the production of ill-smelling and tasting products, associated with anaerobic (no oxygen present) conditions.

QUICKLIME QUICKLIME

A material that is mostly calcium oxide (CaO) or calcium oxide in natural association with a lesser amount of magnesium oxide. Quicklime is capable of combining with water to form hydrated lime. Also see HYDRATED LIME

RADIAL TO IMPELLER RADIAL TO IMPELLER

Perpendicular to the impeller shaft. Material being pumped flows at a right angle to the impeller.

RADICAL RADICAL

A group of atoms that is capable of remaining unchanged during a series of chemical reactions. Such combinations (radicals) exist in the molecules of many organic compounds; sulfate (SO_4^{2}) is an inorganic radical.

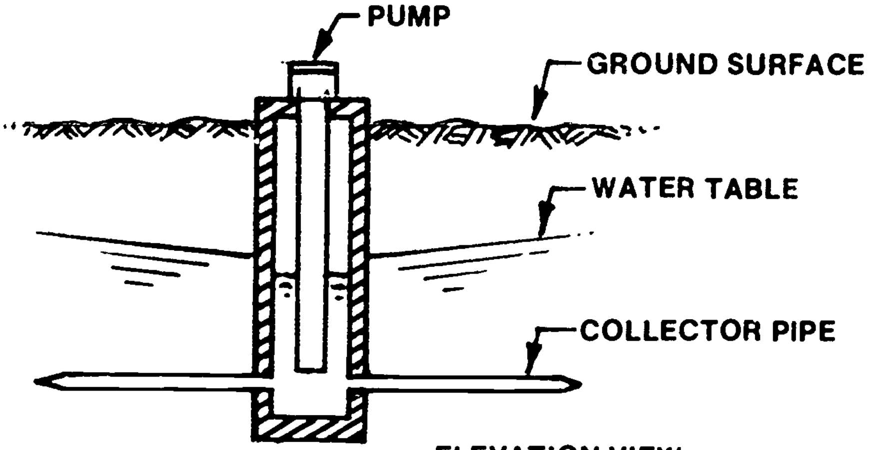
RANGE RANGE

The spread from minimum to maximum values that an instrument is designed to measure. Also see SPAN and EFFECTIVE RANGE.

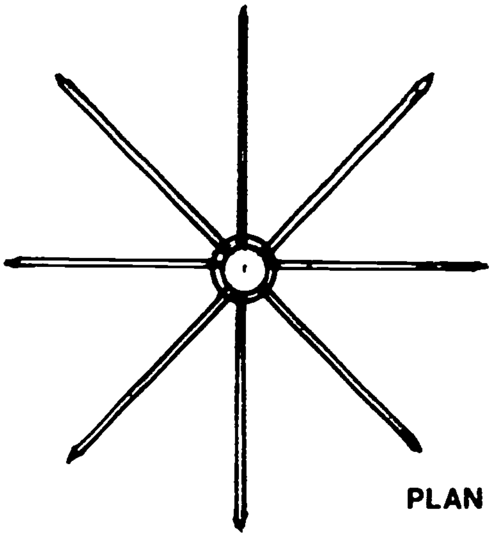
RANNEY COLLECTOR RANNEY COLLECTOR

This water collector is constructed as a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a caisson near the bank of a river or lake Screens are driven radially and approximately horizontally from this well into the sand and the gravel deposits underlying the river.

[SEE DRAWING ON PAGE 636]



ELEVATION VIEW



PLAN VIEW OF COLLECTOR PIPES

RANNEY COLLECTOR

RAW WATER RAW WATER

(1) Water in its natural state, prior to any treatment.

(2) Usually the water entering the first treatment process of a water treatment plant.

REAERATION (RE-air-A-shun) REAERATION

The introduction of air through forced air diffusers into the lower layers of the reservoir. As the air bubbles form and rise through the water, oxygen from the air dissolves into the water and replenishes the dissolved oxygen. The rising bubbles also cause the lower waters to rise to the surface where oxygen from the atmosphere is transferred to the water. This is sometimes called surface reaeration.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

RECARBONATION (re-CAR-bun-NAY-shun) RECARBONATION

A process in which carbon dioxide is bubbled into the water being treated to lower the pH. The pH may also be lowered by the addition of acid. Recarbonation is the final stage in the lime-soda ash softening process. This process converts carbonate ions to bicarbonate ions and stabilizes the solution against the precipitation of carbonate compounds.

RECEIVER RECEIVER

A device which indicates the value of a measurement. Most receivers in the water utility field use either a fixed scale and movable indicator (pointer) such as pressure gage or a moving chart with movable pen such as on a circular-flow recording chart. Also called an INDICATOR.

RECORDER RECORDER

A device that creates a permanent record, on a paper chart or magnetic tape, of the changes of some measured variable.

REDUCING AGENT REDUCING AGENT

Any substance, such as base metal (iron) or the sulfide ion (S^{2-}) that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present) sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

REFERENCE REFERENCE

A physical or chemical quantity whose value is known exactly, and thus is used to calibrate or standardize instruments.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

RESIDUAL CHLORINE RESIDUAL CHLORINE

The amount of free and/or available chlorine remaining after a given contact time under specified conditions

RESIDUE RESIDUE

The dry solids remaining after the evaporation of a sample of water or sludge. Also see TOTAL DISSOLVED SOLIDS.

RESINS RESINS

See ION EXCHANGE RESINS.

RESISTANCE RESISTANCE

That property of a conductor or wire that opposes the passage of a current, thus causing electrical energy to be transformed into heat.

RESPIRATION RESPIRATION

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

REVERSE OSMOSIS (oz-MOE-sis) REVERSE OSMOSIS

The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the water (solvent) but not the dissolved solids (solutes). The liquid produced is a demineralized water. Also see OSMOSIS.

RIPARIAN (ri-PAIR-ee-an) RIPARIAN

Water rights which are acquired together with title to the land bordering a source of surface water. The right to put to beneficial use surface water adjacent to your land

RODENTICIDE (row-DENT-uh-SIDE) RODENTICIDE

Any substance or chemical used to kill or control rodents.

ROTAMETER (RODE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.

ROTOR ROTOR

The rotating part of a machine. The rotor is surrounded by the stationary (non-moving) parts (stator) of the machine.

ROUTINE SAMPLING ROUTINE SAMPLING

Sampling repeated on a regular basis.

SACRIFICIAL ANODE SACRIFICIAL ANODE

An easily corroded material deliberately installed in a pipe or tank. The intent of such an installation is to give up (sacrifice) this anode to corrosion while the water supply facilities remain relatively corrosion free

SAFE DRINKING WATER ACT SAFE DRINKING WATER ACT

Commonly referred to as SDWA An Act passed by the U S Congress in 1974. The Act establishes a cooperative program among local, state and federal agencies to insure safe drinking water for consumers.

SAFE WATER SAFE WATER

Water that does not contain harmful bacteria, or toxic materials or chemicals. Water may have taste and odor problems, color and certain mineral problems and still be considered safe for drinking.

SAFE YIELD SAFE YIELD

The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source permanently (beyond its ability to be replenished naturally in "wet years").

SALINITY SALINITY

(1) The relative concentration of dissolved salts, usualy sodium chloride, in a given water.

(2) A measure of the concentration of dissolved mineral substances in water.

SANITARY SURVEY SANITARY SURVEY

A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, treatment and distribution facilities to insure its protection from all pollution sources.

SAPROPHYTES (SAP-row-FIGHTS) SAPROPHYTES

Organisms living on dead or decaying organic matter. They help natural decomposition of organic matter in water.

SATURATION SATURATION

The condition of a liquid (water) when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

SATURATOR (SAT-you-RAY-tore) SATURATOR

A device which produces a fluoride solution for the fluoridation process The device is usually a cylindrical container with granular sodium fluoride on the bottom Water flows either upward or downward through the sodium fluoride to produce the fluoride solution

SCFM SCFM

Cubic Feet of air per Minute at Standard conditions of temperature, pressure and humidity (0°C / 14.7 psia / 50% relative humidity).

SDWA SDWA

See **SAFE DRINKING WATER ACT**.

SECCHI DISC (SECK-key) SECCHI DISC

A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.

SEDIMENTATION (SED-uh-men-TAY-shun) SEDIMENTATION

A water treatment process in which solid particles settle out of the water being treated in a large clarifier or sedimentation basin.

SEIZE UP SEIZE UP

Seize up occurs when an engine overheats and a part expands to the point where the engine will not run Also called "freezing."

SENSOR SENSOR

An instrument that measure (senses) a physical condition or variable of interest. Floats and thermocouples are examples of sensors.

SEPTIC (SEP-tick) SEPTIC

A condition produced by bacteria when all oxygen supplies are depleted If severe, bottom deposits and water turn black, give off foul odors, and the water has a greatly increased chlorine demand.

SEQUESTRATION (SEE-kwes-TRAY-shun)

SEQUESTRATION

A chemical complexing (forming or joining together) of metallic ions (such as iron) with certain inorganic compounds, such as phosphate. Sequestration prevents the precipitation of the metals (iron). Also see CHELATION

SERVICE PIPE

SERVICE PIPE

The pipeline extending from the water main to the building served or to the consumer's system

SET POINT

SET POINT

The position at which the control or controller is set. This is the same as the desired value of the process variable.

SEWAGE

SEWAGE

The used water and solids that flow from homes through sewers to a wastewater treatment plant. The preferred term is WASTEWATER.

SHEAVE (SHE-v)

SHEAVE

V-belt drive pulley which is commonly made of cast iron or steel.

SHIM

SHIM

Thin metal sheets which are inserted between two surfaces to align or space the surfaces correctly. Shims can be used anywhere a spacer is needed. Usually shims are 0.001 to 0.020 inches thick.

SHOCK LOAD

SHOCK LOAD

The arrival at a water treatment plant of raw water containing unusual amounts of algae, colloidal matter, color, suspended solids, turbidity, or other pollutants.

SHORT-CIRCUITING

SHORT-CIRCUITING

A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

SIMULATE

SIMULATE

To reproduce the action of some process, usually on a smaller scale.

SINGLE-STAGE PUMP

SINGLE-STAGE PUMP

A pump that has only one impeller. A multi-stage pump has more than one impeller.

SLAKE

SLAKE

To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.

SLAKED LIME

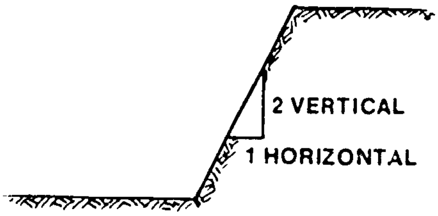
SLAKED LIME

See HYDRATED LIME.

SLOPE

SLOPE

The slope or inclination of a trench bottom or a trench side wall is the ratio of the vertical distance to the horizontal distance or "rise over run." Also see GRADE (2).



2:1 SLOPE

SLUDGE (sluj)

SLUDGE

The settleable solids separated from water during processing.

SLURRY (SLUR-e)

SLURRY

A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SMCLs SMCLs

Secondary Maximum Contaminant Levels Secondary MCLs for various water quality indicators are established to protect public welfare

SNARL SNARL

Suggested No Adverse Response Level The concentration of a chemical in water that is expected not to cause an adverse health effect

SOFTWARE PROGRAMS SOFTWARE PROGRAMS

Computer programs, the list of instructions that tell a computer how to perform a given task or tasks.

SOFT WATER SOFT WATER

Water having a low concentration of calcium and magnesium ions According to U S. Geological Survey guidelines, soft water is water having a hardness of 60 milligrams per liter or less.

SOLENOID (SO-luh-noid) SOLENOID

A magnetically (electrical coil) operated mechanical device. Solenoids can operate pilot valves or electrical switches.

SOLUTION SOLUTION

A liquid mixture of dissolved substances In a solution it is impossible to see all the separate parts.

SOUNDING TUBE SOUNDING TUBE

A pipe or tube used for measuring the depths of water.

SPAN SPAN

The scale or range of values an instrument is designed to measure. Also see RANGE.

SPECIFIC CONDUCTANCE SPECIFIC CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called CONDUCTANCE.

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle, substance, or chemical solution in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (39°F) Particulates in raw water may have a specific gravity of 1.005 to 2.5.

SPECIFIC YIELD SPECIFIC YIELD

The quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity. Specific yield may be expressed as a ratio or as a percentage by volume.

SPOIL SPOIL

Excavated material such as soil from the trench of a water main.

SPORE SPORE

The reproductive body of an organism which is capable of giving rise to a new organism either directly or indirectly. A viable (able to live and grow) body regarded as the resting stage of an organism. A spore is usually more resistant to disinfectants and heat than most organisms.

SPRING LINE SPRING LINE

Theoretical center of a pipeline. Also, the guideline for laying a course of bricks.

STALE WATER STALE WATER

Water which has not flowed recently and may have picked up tastes and odors from distribution lines or storage facilities.

STANDARD STANDARD

A physical or chemical quantity whose value is known exactly, and is used to calibrate or standardize instruments. Also see REFERENCE.

STANDARD METHODS STANDARD METHODS

STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. A joint publication of the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation which outlines the procedures used to analyze the impurities in water and wastewater.

STANDARD SOLUTION STANDARD SOLUTION

A solution in which the exact concentration of a chemical or compound is known.

STANDARDIZE STANDARDIZE

To compare with a standard.

(1) In wet chemistry, to find out the exact strength of a solution by comparing it with a standard of known strength.

(2) To set up an instrument or device to read a standard This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

STARTERS STARTERS

Devices used to start up large motors gradually to avoid severe mechanical shock to a driven machine and to prevent disturbance to the electrical lines (causing dimming and flickering of lights).

STATIC HEAD STATIC HEAD

When water is not moving, the vertical distance (in feet) from a specific point to the water surface is the static head. (The static pressure in psi is the static head in feet times 0.433 psi/ft.) Also see DYNAMIC PRESSURE and STATIC PRESSURE.

STATIC PRESSURE STATIC PRESSURE

When water is not moving, the vertical distance (in feet) from a specific point to the water surface is the static head. The static pressure in psi is the static head in feet times 0.433 psi/ft. Also see DYNAMIC PRESSURE and STATIC HEAD.

STATIC WATER DEPTH STATIC WATER DEPTH

The vertical distance in feet from the centerline of the pump discharge down to the surface level of the free pool while no water is being drawn from the pool or water table.

STATIC WATER LEVEL STATIC WATER LEVEL

(1) The elevation or level of the water table in a well when the pump is not operating.

(2) The level or elevation to which water would rise in a tube connected to an artesian aquifer, or basin, or conduit under pressure.

STATOR STATOR

That portion of a machine which contains the stationary (non-moving) parts that surround the moving parts (rotor).

STERILIZATION (STARE-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

STETHOSCOPE STETHOSCOPE

An instrument used to magnify sounds and convey them to the ear.

STRATIFICATION (STRAT-uh-fuh-KAY-shun) STRATIFICATION

The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature. Also see THERMAL STRATIFICATION.

SUBMERGENCE SUBMERGENCE

The distance between the water surface and the media surface in a filter.

SUBSIDENCE (sub-SIDE-ence) SUBSIDENCE

The dropping or lowering of the ground surface as a result of removing excess water (overdraft or over pumping) from an aquifer. After excess water has been removed, the soil will settle, become compacted and the ground surface will drop.

SUCTION LIFT SUCTION LIFT

The *NEGATIVE* pressure [in feet (meters) of water or inches (centimeters) of mercury vacuum] on the suction side of the pump. The pressure can be measured from the centerline of the pump *DOWN TO* (lift) the elevation of the hydraulic grade line on the suction side of the pump.

SUPERCHLORINATION (SUE-per-KLOR-uh-NAY-shun) SUPERCHLORINATION

Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

SUPERSATURATED SUPERSATURATED

An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance

SURFACE LOADING SURFACE LOADING

One of the guidelines for the design of settling tanks and clarifiers in treatment plants Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called OVERFLOW RATE.

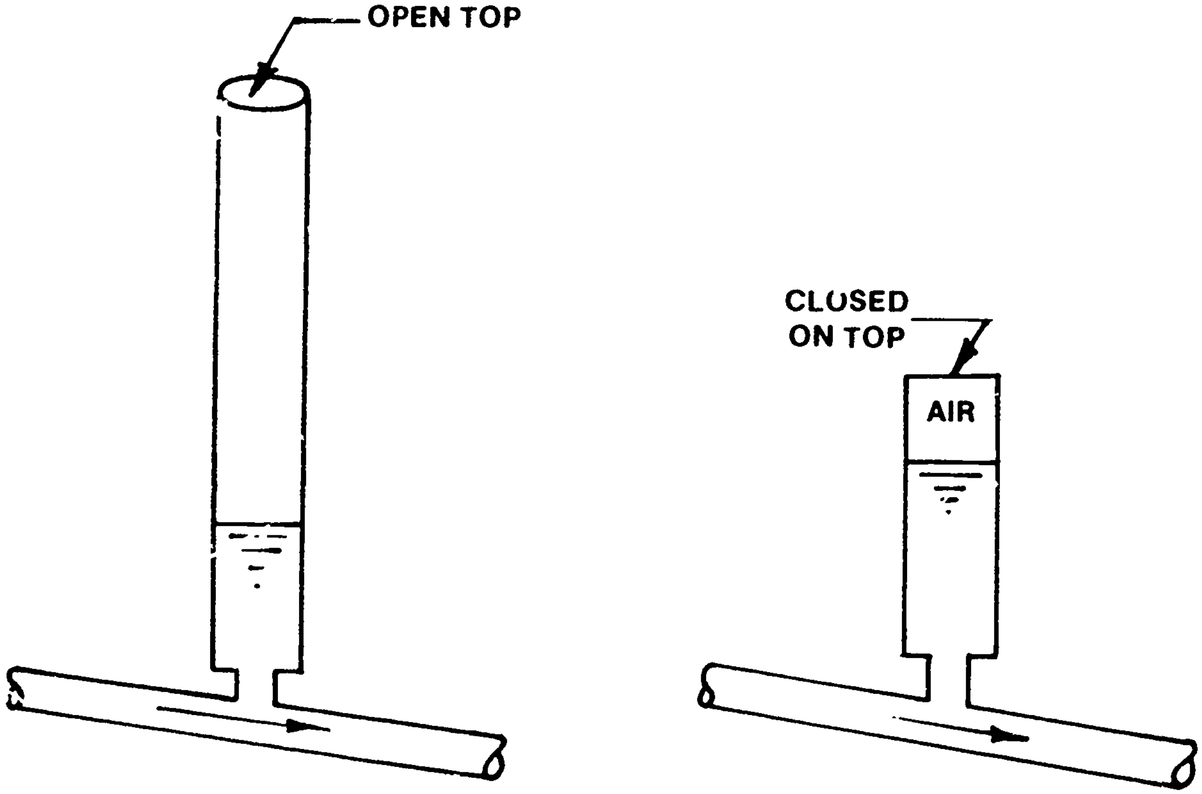
$$\text{Surface Loading, GPD/sq ft} = \frac{\text{Flow, gallon/day}}{\text{Surface Area, sq ft}}$$

SURFACTANT (sir-FAC-tent) SURFACTANT

Abbreviation for surface-active agent The active agent in detergents that possesses a high cleaning ability.

SURGE CHAMBER SURGE CHAMBER

A chamber or tank connected to a pipe and located at or near a valve that may quickly open or close or a pump that may suddenly start or stop When the flow of water in a pipe starts or stops quickly, the surge chamber allows water to flow into or out of the pipe and minimize any sudden positive or negative pressure waves or surges in the pipe.



TYPES OF SURGE CHAMBERS

SURGE CHAMBER

SUSPENDED SOLIDS SUSPENDED SOLIDS

(1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering.

(2) The quantity of material removed from water in a laboratory test, as prescribed in *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER* and referred to as nonfilterable residue.

TAILGATE SAFETY MEETING TAILGATE SAFETY MEETING

The term *TAILGATE* comes from the safety meetings regularly held by the construction industry around the tailgate of a truck.

TCE TCE

See TRICHLOROETHANE.

TDS TDS

See TOTAL DISSOLVED SOLIDS.

TELEMETRY (tel-LEM-uh-tree) TELEMETRY

The electrical link between the transmitter and the receiver Telephone lines are commonly used to serve as the electrical line.

TEMPERATURE SENSOR TEMPERATURE SENSOR

A device that opens and closes a switch in response to changes in the temperature This device might be a metal contact, or a thermocouple that generates minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a HEAT SENSOR.

THERMAL STRATIFICATION (STRAT-uh-fuh-KAY-shun) THERMAL STRATIFICATION

The formation of layers of different temperatures in a lake or reservoir. Also see STRATIFICATION.

THERMOCLINE (THUR-moe-KLINE) THERMOCLINE

The middle layer in a thermally stratified lake or reservoir In this layer there is a rapid decrease in temperature with depth. Also called the METALIMNION.

THERMOCOUPLE THERMOCOUPLE

A heat-sensing device made of two conductors of different metals joined at their ends. An electric current is produced when there is a difference in temperature between the ends.

THICKENING THICKENING

Treatment to remove water from the sludge mass to reduce the volume that must be handled.

THM THM

See TRIHALOMETHANES.

THM PRECURSOR THM PRECURSOR

See PRECURSOR, THM.

THRESHOLD ODOR THRESHOLD ODOR

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called ODOR THRESHOLD.

THRESHOLD ODOR NUMBER THRESHOLD ODOR NUMBER

TON. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.

THRUST BLOCK THRUST BLOCK

A mass of concrete or similar material appropriately placed around a pipe to prevent movement when the pipe is carrying water. Usually placed at bends and valve structures.

TIME LAG TIME LAG

The time required for processes and control systems to respond to a signal or to reach a desired level.

TIMER TIMER

A device for automatically starting or stopping a machine or other device at a given time.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TOPOGRAPHY TOPOGRAPHY

The arrangement of hills and valleys in a geographic area.

TOTAL DISSOLVED SOLIDS (TDS) TOTAL DISSOLVED SOLIDS (TDS)

All of the dissolved solids in a water TDS is measured on a sample of water that has passed through a very fine mesh filter to remove suspended solids The water passing through the filter is evaporated and the residue represents the dissolved solids. Also see SPECIFIC CONDUCTANCE.

TOTAL DYNAMIC HEAD (TDH) TOTAL DYNAMIC HEAD (TDH)

When a pump is lifting or pumping water, the vertical distance (in feet) from the elevation of the energy grade line on the suction side of the pump to the elevation of the energy grade line on the discharge side of the pump.

TOTAL RESIDUAL CHLORINE TOTAL RESIDUAL CHLORINE

The amount of available chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE

TOTALIZER TOTALIZER

A device or meter that continuously measures and calculates (adds) total flows in gallons, million gallons, cubic feet, or some other unit of volume measurement. Also called an INTEGRATOR.

TOXAPHENE (TOX-uh-FEEN) TOXAPHENE

A chemical that causes adverse health effects in domestic water supplies and also is toxic to freshwater and marine aquatic life.

TOXIC (TOX-ick) TOXIC

A substance which is poisonous to an organism.

TRANSDUCER (trans-DUE-sir) TRANSDUCER

A device which senses some varying condition and converts it to an electrical or other signal for transmission to some other device (a receiver) for processing or decision making.

TRANSMISSION LINES TRANSMISSION LINES

Pipelines that transport raw water from its source to a water treatment plant. After treatment, water is usually pumped into pipelines (transmission lines) that are connected to a distribution grid system.

TRANSMISSIVITY (TRANS-miss-SIV-it-tee) TRANSMISSIVITY

A measure of the ability to transmit (as in the ability of an aquifer to transmit water)

TRANSPIRATION (TRAN-spur-RAY-shun) TRANSPIRATION

The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.

TREMIE (TREH-me) TREMIE

A device used to place concrete or grout under water

TRICHLOROETHANE (TCE) (try-KLOR-o-ETH-hane) TRICHLOROETHANE (TCE)

An organic chemical used as a cleaning solvent that causes adverse health effects in domestic water supplies.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TUBE SETTLER TUBE SETTLER

A device that uses bundles of small bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. The tubes may come in a variety of shapes including circular and rectangular As water rises within the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tubes and settles to the bottom of the basin for removal by conventional sludge collection means Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve particle removal.

TUBERCLE (TOO-burr-cull) TUBERCLE

A protective crust of corrosion products (rust) which builds up over a pit caused by the loss of metal due to corrosion.

TUBERCULATION (too-BURR-que-LAY-shun) TUBERCULATION

The development or formation of small mounds of corrosion products (rust) on the inside of iron pipe. These mounds (tubercules) increase the roughness of the inside of the pipe thus increasing resistance to water flow (increases the C Factor).

TURBID TURBID

Having a cloudy or muddy appearance.

TURBIDIMETER TURBIDIMETER

See TURBIDITY METER.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY METER TURBIDITY METER

An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

TURBIDITY UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

TURN-DOWN RATIO TURN-DOWN RATIO

The ratio of the design range to the range of acceptable accuracy or precision of an instrument. Also see EFFECTIVE RANGE.

UNCONSOLIDATED FORMATION UNCONSOLIDATED FORMATION

A sediment that is loosely arranged or unstratified (not in layers) or whose particles are not cemented together (soft rock); occurring either at the ground surface or at a depth below the surface. Also see CONSOLIDATED FORMATION.

UNIFORMITY COEFFICIENT (U.C.) UNIFORMITY COEFFICIENT (U.C.)

The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through.

$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter}_{60\%}}{\text{Particle Diameter}_{10\%}}$$

VARIABLE FREQUENCY DRIVE VARIABLE FREQUENCY DRIVE

A control system that allows the frequency of the current applied to a motor to be varied. The motor is connected to a low-frequency source while standing still; the frequency is then increased gradually until the motor and pump (or other driven machine) is at the desired speed.

VARIABLE, MEASURED VARIABLE, MEASURED

A factor (flow, temperature) that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor

VARIABLE, PROCESS VARIABLE, PROCESS

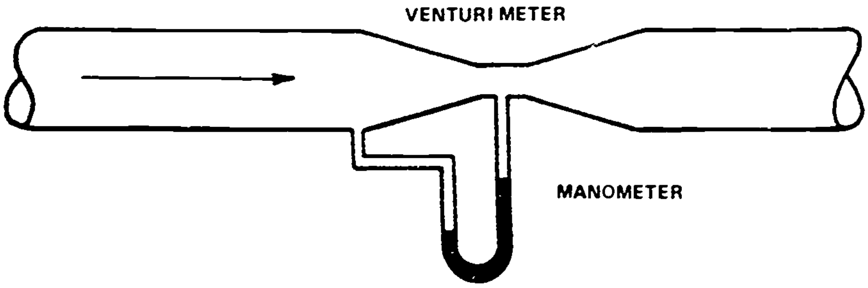
A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

VELOCITY HEAD VELOCITY HEAD

The energy in flowing water as determined by a vertical height (in feet or meters) equal to the square of the velocity of flowing water divided by twice the acceleration due to gravity ($V^2/2g$).

VENTURI METER VENTURI METER

A flow measuring device placed in a pipe. The device consists of a tube whose diameter gradually decreases to a throat and then gradually expands to the diameter of the pipe. The flow is determined on the basis of the differences in pressure (caused by different velocity heads) between the entrance and throat of the Venturi meter.



NOTE Most Venturi meters have pressure sensing taps rather than a manometer to measure the pressure difference. The upstream tap is the high pressure tap or side of the monometer.

VISCOSITY (vis-KOSS-uh-tee) VISCOSITY

A property of water, or any other fluid, which resists efforts to change its shape or flow. Syrup is more viscous (has a higher viscosity) than water. The viscosity of water increases significantly as temperatures decrease. Motor oil is rated by how thick (viscous) it is; 20 weight oil is considered relatively thin while 50 weight oil is relatively thick or viscous.

VOID VOID

A pore or open space in rock, soil or other granular material, not occupied by solid matter. The pore or open space may be occupied by air, water, or other gaseous or liquid material. Also called a void space or interstice.

VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

VOLATILE ACIDS VOLATILE ACIDS

Acids produced during digestion. Fatty acids which are soluble in water and can be steam-distilled at atmospheric pressure. Also called "organic acids." Volatile acids are commonly reported as equivalent to acetic acid.

VOLATILE LIQUIDS VOLATILE LIQUIDS

Liquids which easily vaporize or evaporate at room temperatures.

VOLATILE SOLIDS VOLATILE SOLIDS

Those solids in water or other liquids that are lost on ignition of the dry solids at 550°C.

VOLTAGE VOLTAGE

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See ELECTROMOTIVE FORCE (E.M.F.).

VOLUMETRIC VOLUMETRIC

A measurement based on the volume of some factor. Volumetric titration is a means of measuring unknown concentrations of water quality indicators in a sample by determining the volume of titrant or liquid reagent needed to complete particular reactions.

VOLUMETRIC FEEDER VOLUMETRIC FEEDER

A dry chemical feeder which delivers a measured volume of chemical during a specific time period.

VORTEX VORTEX

A revolving mass of water which forms a whirlpool. This whirlpool is caused by water flowing out of a small opening in the bottom of a basin or reservoir. A funnel-shaped opening is created downward from the water surface.

WASTEWATER WASTEWATER

The used water and solids from a community (including used water from industrial processes) that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a wastewater treatment plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "wastewater."

WATER HAMMER

WATER HAMMER

The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.

WATER PURVEYOR (purr-VAY-or)

WATER PURVEYOR

An agency or person that supplies water (usually potable water).

WATER TABLE

WATER TABLE

The upper surface of the zone of saturation of groundwater in an unconfined aquifer.

WATT

WATT

A unit of power equal to one joule per second The power of a current of one ampere flowing across a potential difference of one volt.

WEIR (weer)

WEIR

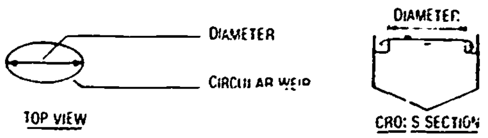
(1) A wall or plate placed in an open channel and used to measure the flow of water. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used.

(2) A wall or obstruction used to control flow (from settling tanks and clarifiers) to assure uniform flow rate and avoid short-circuiting.

WEIR DIAMETER (weer)

WEIR DIAMETER

Many circular clarifiers have a circular weir within the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. The diameter . the weir is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.



WEIR LOADING

WEIR LOADING

A guideline used to determine the length of weir needed on settling tanks and clarifiers in treatment plants. Used by operators to determine if weirs are hydraulically (flow) overloaded.

$$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Length of Weir, ft}}$$

WELL LOG

WELL LOG

A record of the thickness and characteristics of the soil, rock and water-bearing formations encountered during the drilling (sinking) of a well.

WET CHEMISTRY

WET CHEMISTRY

Laboratory procedures used to analyze a sample of water using liquid chemical solutions (wet) instead of, or in addition to, laboratory instruments.

WHOLESOME WATER

WHOLESOME WATER

A water that is safe and palatable for human consumption.

WIRE-TO-WATER EFFICIENCY

WIRE-TO-WATER EFFICIENCY

The efficiency of a pump and motor together. Also called the OVERALL EFFICIENCY.

YIELD

YIELD

The quantity of water (expressed as a rate of flow — GPM, GPH, GPD, or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. Also see SAFE YIELD.

ZEOLITE

ZEOLITE

A type of ion exchange material used to soften water. Natural zeolites are siliceous compounds (made of silica) which remove calcium and magnesium from hard water and replace them with sodium. Synthetic or organic zeolites are ion exchange materials which remove calcium or magnesium and replace them with either sodium or hydrogen.

ZETA POTENTIAL	ZETA POTENTIAL

In coagulation and flocculation procedures, the difference in the electrical charge between the dense layer of ions surrounding the particle and the charge of the bulk of the suspended fluid surrounding this particle. The zeta potential is usually measured in millivolts.

ZONE OF AERATION	ZONE OF AERATION

The comparatively dry soil or rock located between the ground surface and the top of the water table.

ZONE OF SATURATION	ZONE OF SATURATION

The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.

ZOOPLANKTON (ZOE-PLANK-ton)	ZOOPLANKTON

Small, usually microscopic animals (such as protozoans), found in lakes and reservoirs.

SUBJECT INDEX

INTERIM PRIMARY DRINKING WATER REGULATIONS

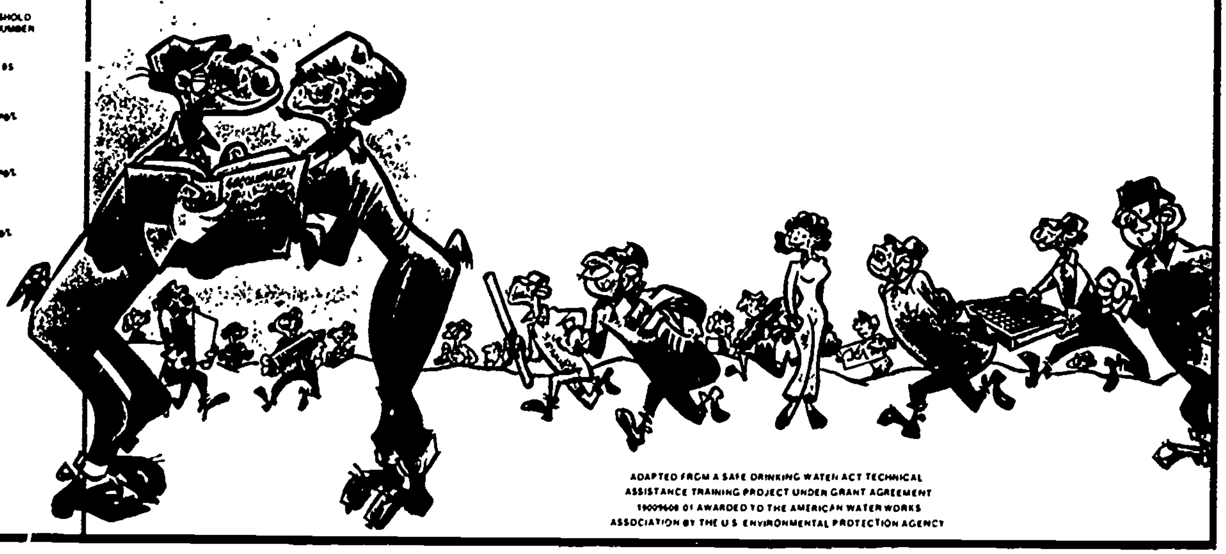
INORGANIC CHEMICALS	ARSENIC	0.05 mg/L	FOR ALL INORGANIC CONTAMINANTS LISTED SURFACE WATERS EVERY YEAR GROUNDWATERS EVERY 3 YEARS	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	FOR ALL INORGANIC CONTAMINANTS LISTED EXCEPT NITRATE IF ANY CONTAMINANT EXCEEDS THE MCL THIS MUST BE REPORTED TO THE STATE WITHIN 7 DAYS AND THREE ADDITIONAL SAMPLES (CALLED CHECK SAMPLES) MUST BE TAKEN WITHIN ONE MONTH	FOR ALL INORGANIC CONTAMINANTS LISTED EXCEPT NITRATE NOTIFY STATE WITHIN 7 DAYS IF MCL IS EXCEEDED AND INITIATE CHECK SAMPLING WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES STILL EXCEEDS THE MCL THIS MUST BE REPORTED TO THE STATE WITHIN 48 HRS	FOR ALL INORGANIC CONTAMINANTS LISTED EXCEPT NITRATE WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES EXCEEDS THE MCL THE PUBLIC MUST BE NOTIFIED
	BARIUM	1 mg/L					
	CADMIUM	0.010 mg/L					
	CHROMIUM	0.05 mg/L					
	LEAD	0.05 mg/L					
	MERCURY	0.0002 mg/L					
	SELENIUM	0.01 mg/L					
	SILVER	0.05 mg/L					
	SODIUM						
	FLOURIDE	4 mg/L					
	NITRATE (AS N)	10 mg/L			FOR NITRATE ONLY WHEN THE CONCENTRATION EXCEEDS THE MCL A CHECK SAMPLE MUST BE TAKEN WITHIN 24 HRS	FOR NITRATE ONLY IF THE AVERAGE OF THE ORIGINAL SAMPLE AND THE CHECK SAMPLE EXCEEDS THE MCL REPORT TO THE STATE WITHIN 48 HRS	FOR NITRATE ONLY WHEN THE AVERAGE OF THE ORIGINAL AND THE CHECK SAMPLE EXCEEDS THE MCL THE PUBLIC MUST BE NOTIFIED
	CHLORINATED HYDROCARBONS PESTICIDES						
ORGANIC CHEMICALS	ENDRIN	0.0002 mg/L	SURFACE WATERS EVERY 3 YEARS STATE OPTION FOR GROUNDWATERS	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	ANY CONTAMINANT EXCEEDING MCL MUST BE REPORTED TO STATE WITHIN 7 DAYS AND THREE ADDITIONAL (CHECK) SAMPLES TO BE TAKEN WITHIN ONE MONTH	WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES STILL EXCEEDS THE MCL THIS MUST BE REPORTED TO THE STATE WITHIN 48 HRS	WHEN THE AVERAGE OF THE ORIGINAL AND THREE ADDITIONAL CHECK SAMPLES STILL EXCEEDS THE MCL THE PUBLIC MUST BE NOTIFIED
	LINDANE	0.004 mg/L					
	METHOXYCHLOR	0.1 mg/L					
	TOXAPHENE	0.005 mg/L					
	CHLOROPHENOXYS-HERBICIDES						
	2 4,5-TP (SILVEX)	0.01 mg/L					
	2 4-D	0.1 mg/L					
	VOLATILE ORGANIC CHEMICALS		EVERY 5 YEARS	STATE DISCRETION	WHEN CONCENTRATION EXCEEDS MCL CHECK SAMPLES MUST BE OBTAINED QUARTERLY	STATE DISCRETION	WHEN AVERAGE OF QUARTERLY SAMPLES EXCEEDS MCL THE PUBLIC MUST BE NOTIFIED
	BENZENE	0.005 mg/L					
	CARBON TETRACHLORIDE	0.005 mg/L					
	P DICHLOROBENZENE	0.075 mg/L					
	1,2 DICHLOROETHANE	0.005 mg/L					
	1 1 DICHLOROETHYLENE	0.007 mg/L					
	1 1 1 TRICHLOROETHANE	0.2 mg/L					
	TRICHLOROETHYLENE	0.005 mg/L					
	VINYL CHLORIDE	0.002 mg/L					
	TOTAL TRIHALOMETHANES	0.10 mg/L					
	TOTAL TRIHALOMETHANES	0.10 mg/L	QUARTERLY CHLORINATED SURFACE AND GROUNDWATERS	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING	AT LEAST ONE CHECK SAMPLE TO CONFIRM RESULTS OF REDUCED MONITORING SAMPLING VIOLATION	WHEN RUNNING ANNUAL AVERAGE EXCEEDS MCL REPORT TO STATE WITHIN 48 HRS	AVERAGE OF ANY 12 MO WHICH EXCEEDS MCL MUST NOTIFY PUBLI

TURBIDITY	TURBIDITY	1 TU MONTHLY AVERAGE (5 TU MONTHLY AVERAGE MAY APPLY AT STATE OPTION PROVIDED IT DOES NOT INTERFERE WITH 1 DISINFECTION 2 MAINTENANCE OF EFFECTIVE Cl_2 RESIDUAL 3 BACTERIOLOGICAL TESTS) OR 5 TU AVG OF 2 CONSECUTIVE DAYS	SAMPLE SURFACE WATERS DAILY	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	IF A TURBIDITY SAMPLE EXCEEDS 1 TU CHECK SAMPLE WITHIN 1 HR IF CHECK SAMPLE CONFIRMS THE MCL IS EXCEEDED REPORT TO THE STATE WITHIN 48 HRS	USING THE CHECK SAMPLE TO CALCULATE AN AVERAGE IF THE MONTHLY AVERAGE OF 1 TU OR 2 DAY AVERAGE OF 5 TU IS EXCEEDED REPORT TO THE STATE WITHIN 48 HRS	WHEN MONTHLY AVERAGE 1 TU OR 2 DAY AVERAGE OF 5 TU IS EXCEEDED THE PUBLIC MUST BE NOTIFIED
MICRO-BIOLOGICAL CONTAMINANTS	COLIFORM BACTERIA	MEMBRANE FILTER COLIFORM SHALL NOT EXCEED 1 PER 100 mL FOR THE AVERAGE OF ALL MONTHLY SAMPLES OR 4 PER 100 mL IN MORE THAN ONE SAMPLE IF LESS THAN 20 SAMPLES COLLECTED PER MONTH OR 4 PER 100 ml IN MORE THAN 5% OF SAMPLES IF 20 OR MORE SAMPLES EXAMINED PER MONTH FERMENTATION TUBE — 10 mL PORTION COLIFORMS SHALL NOT BE PRESENT IN MORE THAN 10% OF PORTIONS PER MONTH NOT MORE THAN 1 SAMPLE MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN LESS THAN 20 SAMPLES ARE EXAMINED PER MONTH OR NOT MORE THAN 5% OF SAMPLES MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN 20 OR MORE SAMPLES ARE EXAMINED PER MONTH * IF 100 mL PORTIONS ARE USED SEE REGULATIONS PAGE 59571	THE TOTAL NUMBER OF SAMPLES ARE BASED ON THE POPULATION TABLE FOR EXAMPLE ** POPULATION SERVED — MINIMUM NUMBER OF SAMPLES PER MONTH 25 to 1 000 — 1 1 001 to 2 500 — 2 2 501 to 3 300 — 3 * THE ENTIRE POPULATION TABLE IS IN APPENDIX IN MANUAL CHLORINE RESIDUAL SUBSTITUTION • STATE APPROVAL • 75% OF THE REQUIRED COLIFORM TESTS MAY BE SUBSTITUTED • FOR EACH COLIFORM TEST TO BE SUBSTITUTED 4 Cl_2 RESIDUAL TESTS MUST BE CONDUCTED BUT AT LEAST 1 Cl_2 TEST PER DAY • MINIMUM FREE RESIDUAL 0 2 mg L • METHOD DPD	MUST BE FOLLOWED BY TWO CONSECUTIVE NEGATIVE CHECK SAMPLES UNDER CERTAIN CONDITIONS A SYSTEM TAKING 10 OR FEWER SAMPLES MAY EXCLUDE ONE POSITIVE ROUTINE FROM CALCULATIONS REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	MEMBRANE FILTER IF A SINGLE SAMPLE EXCEEDS 4 PER 100 mL INITIATE AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES FROM SAME SAMPLING POINT COLLECT ADDITIONAL SAMPLES DAILY OR AS DIRECTED BY THE STATE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW LESS THAN 1 PER 100 mL FERMENTATION TUBE - 10 mL PORTION* IF A SINGLE SAMPLE CONTAINS COLIFORM IN 3 OR MORE 10 ml PORTIONS INITIATE CHECK SAMPLING AS ABOVE AND CONTINUE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW NO POSITIVE TUBES * IF 100 mL PORTIONS ARE USED SEE REGULATIONS PAGE 59571	MEMBRANE FILTER IF ANY MCL IS EXCEEDED THE STATE MUST BE NOTIFIED IN 48 HRS IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM REPORT TO THE STATE WITHIN 48 HRS FERMENTATION TUBE IF ANY MCL IS EXCEEDED THE STATE MUST BE NOTIFIED IN 48 HRS IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM REPORT TO THE STATE WITHIN 48 HRS CHLORINE RESIDUAL SUBSTITUTION IF DEFICIENT RESIDUAL IS CONFIRMED REPORT TO STATE WITHIN 48 HRS AND COLLECT COLIFORM BACTERIA SAMPLE WITHIN 1 HR REPORT BACTERIAL RESULTS TO STATE WITHIN 48 HRS OF COMPLETION OF ANALYSIS	IF ANY MCL IS EXCEEDED THE PUBLIC MUST BE NOTIFIED PUBLIC NOTICE DOES NOT APPLY TO DEFICIENT CHLORINE RESIDUAL SINCE THE RESIDUAL IS NOT A MAXIMUM CONTAMINANT LEVEL
RADIOLOGICAL CONTAMINANTS	NATURAL GROSS ALPHA COMBINED Ra 226 AND Ra 228 MAN MADE GROSS BETA ACTIVITY TRITIUM STRONTIUM 90	NATURAL SCREENING IF GROSS ALPHA EXCEEDS 5 pCi L THEN TEST FOR Ra 228 IF Ra226 EXCEEDS 3pCi L TEST FOR Ra228 Ra226 + Ra228 5pCi L MAN MADE GROSS BETA 50pCi L TRITIUM 20 000 pCi L STRONTIUM 90 8 pCi L	EVERY 4 YEARS (COMPLIANCE WITH MCL BASED ON AVERAGE OF ANALYSIS OF FOUR CONSECUTIVE QUARTERS)	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	STATE OPTION STATE OPTION	WHEN THE ANNUAL AVERAGE MCL IS EXCEEDED THIS MUST BE REPORTED TO THE STATE WITHIN 48 HRS	WHEN THE AVERAGE OF THE ORIGINAL EXCEEDS THE MCL THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE
INORGANIC CHEMICALS	NITRATE (AS N)	10 mg L MAY ALLOW UP TO 20 mg L UNDER CONDITIONS WHERE NO ADVERSE HEALTH EFFECTS WILL RESULT	STATE OPTION	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	WHEN THE CONCENTRATION EXCEEDS THE MCL A CHECK SAMPLE MUST BE TAKEN WITHIN 24 HRS	IF THE AVERAGE OF THE ORIGINAL SAMPLE AND THE CHECK SAMPLE EXCEEDS THE MCL REPORT TO THE STATE WITHIN 48 HRS	WHEN THE AVERAGE OF THE ORIGINAL AND THE CHECK SAMPLE EXCEEDS THE MCL THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE
TURBIDITY	TURBIDITY	STATE OPTION A 1 TU MONTHLY AVERAGE (5 TU MONTHLY AVERAGE MAY APPLY AT STATE OPTION PROVIDED IT DOES NOT INTERFERE WITH 1 DISINFECTION 2 MAINTENANCE OF EFFECTIVE Cl_2 RESIDUAL 3 BACTERIOLOGICAL TESTS) OR B 5 TU AVG OF 2 CONSECUTIVE DAYS	SAMPLE SURFACE WATERS DAILY	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	IF A TURBIDITY SAMPLE EXCEEDS 1 TU CHECK SAMPLE WITHIN 1 HR IF CHECK SAMPLE CONFIRMS THE MCL IS EXCEEDED REPORT TO THE STATE WITHIN 48 HRS	USING THE CHECK SAMPLE TO CALCULATE AN AVERAGE IF THE MONTHLY AVERAGE OF 1 TU OR 2 DAY AVERAGE OF 5 TU IS EXCEEDED REPORT TO THE STATE WITHIN 48 HRS	IF THE MONTHLY AVERAGE OF 1 TU OR THE 2 DAY AVERAGE OF 5 TU IS EXCEEDED THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE
MICRO-BIOLOGICAL CONTAMINANTS	COLIFORM BACTERIA	MEMBRANE FILTER COLIFORM SHALL NOT EXCEED 1 PER 100 mL FOR THE AVERAGE OF ALL MONTHLY SAMPLES OR 4 PER 100 mL IN MORE THAN ONE SAMPLE IF LESS THAN 20 SAMPLES COLLECTED PER MONTH OR 4 PER 100 mL IN MORE THAN 5% OF SAMPLES IF 20 OR MORE SAMPLES EXAMINED PER MONTH FERMENTATION TUBE 10 mL PORTION* COLIFORMS SHALL NOT BE PRESENT IN MORE THAN 10% OF PORTIONS PER MONTH NOT MORE THAN 1 SAMPLE MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN LESS THAN 20 SAMPLES ARE EXAMINED PER MONTH OR NOT MORE THAN 5% OF SAMPLES MAY HAVE 3 OR MORE PORTIONS POSITIVE WHEN 20 OR MORE SAMPLES ARE EXAMINED PER MONTH * IF 100 mL PORTIONS ARE USED SEE REGULATIONS PAGE 59571	AT LEAST ONE SAMPLE PER QUARTER (THE STATE MAY SPECIFY AN ALTERNATE FREQUENCY ON THE BASIS OF A SANITARY SURVEY)	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER	MEMBRANE FILTER IF A SINGLE SAMPLE EXCEEDS 4 PER 100 mL INITIATE AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES FROM SAME SAMPLING POINT COLLECT ADDITIONAL SAMPLES DAILY OR AS DIRECTED BY THE STATE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW LESS THAN 1 PER 100 mL FERMENTATION TUBE - 10 mL PORTION* IF A SINGLE SAMPLE CONTAINS COLIFORM IN 3 OR MORE 10 mL PORTIONS INITIATE CHECK SAMPLING AS ABOVE AND CONTINUE UNTIL AT LEAST 2 CONSECUTIVE DAILY CHECK SAMPLES SHOW NO POSITIVE TUBES * IF 100 mL PORTIONS ARE USED SEE REGULATIONS PAGE 59571	MEMBRANE FILTER IF ANY MCL IS EXCEEDED THE STATE MUST BE NOTIFIED IN 48 HRS IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM REPORT TO THE STATE WITHIN 48 HRS FERMENTATION TUBE IF ANY MCL IS EXCEEDED THE STATE MUST BE NOTIFIED IN 48 HRS IF ANY CHECK SAMPLE CONFIRMS THE PRESENCE OF COLIFORM REPORT TO THE STATE WITHIN 48 HRS	IF ANY MCL IS EXCEEDED THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE IF ANY MCL IS EXCEEDED THE PUBLIC MUST BE NOTIFIED IN A MANNER ACCEPTABLE TO THE STATE

NOTE CORROSIVITY MONITORING REQUIRED ACCORDING TO SECTION 141 47 OF NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

SECONDARY DRINKING WATER REGULATIONS (STATE OPTION)

NAME OF CONTAINMENT	SMCL	MONITORING REQUIREMENTS ROUTINE SAMPLING AND TESTING	RECOMMENDED ROUTINE REPORTING
CHLORIDE	250 mg/L	FOR ALL CONTAMINANTS LISTED STATE MAY DIRECT MORE FREQUENT MONITORING OF SPECIFIC PARAMETERS NO LESS FREQUENT THAN THE MONITORING PERFORMANCE FOR INORGANIC CHEMICALS CONTAMINANTS IN THE NIPDWR	REPORT RESULTS WITHIN 10 DAYS AFTER COMPLETION OF TEST OR WITHIN (A) FIRST 10 DAYS FOLLOWING THE MONTH IN WHICH THE RESULT IS RECEIVED (B) FIRST 10 DAYS FOLLOWING END OF THE REQUIRED MONITORING PERIOD WHICHEVER IS SHORTER
COLOR	15 COLOR UNITS		
COPPER	1 mg/L		
CORROSIVITY	NON-CORROSIVE		
FLOURIDE	2 mg/L		
FOAMING AGENTS	0.5 mg/L		
IRON	0.3 mg/L		
MANGANESE	0.05 mg/L		
ODOR	3 THRESHOLD ODOR NUMBER		
pH	6.5 8.5		
SULFATE	250 mg/L		
TOTAL DISSOLVED SOLIDS TDS	500 mg/L		
ZINC	5 mg/L		



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