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ABSTRACT

This packet, part of the instructional materials for the Oregon apprenticeship program for millwright training, contains nine modules covering boilers. The modules provide information on the following topics: fire and water tube types of boilers, construction, fittings, operation, cleaning, heat recovery systems, instruments and controls, and piping and steam traps. Each module consists of a goal, performance indicators, student study guide, vocabulary, introduction, information sheets illustrated with line drawings and photographs, an assignment sheet, a job sheet, a self-assessment test with answers, a post-assessment test with answers for the instructor, and a list of supplementary references. (Copies of supplementary references, which are sections of lectures from a correspondence course published by the Southern Alberta Institute of Technology, are included in the packets.) (KC)

ED254721

APPRENTICESHIP

MILLWRIGHT

RELATED TRAINING MODULES

7.1 - 7.9 BOILERS

CE 040 997

STATEMENT OF ASSURANCE

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APPRENTICESHIP

MILLWRIGHT
RELATED TRAINING MODULES

DRAFTING

5.1 Types of Drawing and Views
5.2 Sketching
5.3 Blueprint Reading/Working Drawings
5.4 Working Drawings for Machines and Welding
5.5 Machine and Welding Symbols
5.6 Blueprint Reading, Drafting: Basic Print Reading
5.7 Blueprint Reading, Drafting: Basic Print Reading
5.8 Blueprint Reading, Drafting: Basic Print Reading
5.9 Blueprint Reading, Drafting: Basic Print Reading
5.10 Blueprint Reading, Drafting: Basic Print Reading
5.11 Blueprint Reading, Drafting: Basic Print Reading
5.12 Blueprint Reading, Drafting: Basic Print Reading
5.13 Blueprint Reading, Drafting: Basic Print Reading
5.14 Drafting, Machine Features
5.15 Drafting, Measurement
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HUMAN RELATIONS

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6.2 Feedback
6.3 Individual Strengths
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6.12 Personal Finance

BOILERS

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7.2 Boilers - Watertube Types
7.3 Boilers - Construction
7.4 Boilers - Fittings
7.5 Boilers - Operation
7.6 Boilers - Cleaning
7.7 Boilers - Heat Recovery Systems
7.8 Boilers - Instruments and Controls
7.9 Boilers - Piping and Steam Traps

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8.2 Steam Turbines - Components
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HYDRAULICS

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17.2 Hydraulics - Transmission of Force
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METALLURGY

18.1 Included are ILS packets:
W 3010
W 3011-1
W 3011-2
MS 9001 (1-3-4-8-9-6-7-5-2-9)
MS 9200, 9201

POWER DRIVES

19.1 101. A-B-C-D-E
102. C-D-E
103. B-C-D-E
104. A-C-E-F-G-H-I-J
107. A
108. A

WELDING

20.1 602. A-B-C-D-G-I-L-M
603. A-B-F-G-I
W. 3011-1 refer to Mettallurgy 18.1
WE. MA-18

MILLWRIGHT
SUPPLEMENTARY REFERENCE DIRECTORY

Note: All reference packets are numbered on the upper right-hand corner of the respective cover page.

Supplementary Packet #	Description	Related Training Module	
1.8	Concepts & Techniques of Machine Safeguarding, U.S.D.L., O.S.H.A.	1.8	Machine Safeguarding
12.1	Correspondence Course, Lecture 1, Sec. 2, Steam Generators, Types of Boilers I, S.A.I.T., Calgary, Alberta, Canada	7.1	Boilers, Fire Tube Type
12.2	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Types of Boikers II, S.A.I.T., Calgary, Alberta, Canada	7.2	Boilers, Water Tube Type
12.3	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Boiler Construction & Erection, S.A.I.T., Calgary, Alberta, Canada	7.3	Boilers, Construction
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fittings II, S.A.I.T., Calgary, Alberta, Canada	7.4	Boilers, Fittings
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fitting I, S.A.I.T., Calgary, Alberta, Canada	7.4	Boilers, Fittings
12.5	Correspondence Course, Lecture 10, Sec. 2, Steam Generation, Boiler Operation, Maintenance, Inspection, S.A.I.T., Calgary, Alberta, Canada	7.5	Boilers, Operation
12.7	Correspondence Course, Lecture 3, Sec. 2, Steam Generation, Boiler Details, S.A.I.T., Calgary, Alberta, Canada	7.7	Boilers Heat Recovery Systems
		PUMPS	
13.1 13.2 13.4 13.6 13.7	Correspondence Course, Lecture 9, Sec. 2, Steam Generator, Power Plant Pumps, S.A.I.T., Calgary, Alberta, Canada	9.1 9.2 9.4 9.6 9.7	Types & Classifications Applications Calculating Heat & Flow Monitoring & Troubleshooting Maintenance
13.3 13.5	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Pumps, S.A.I.T., Calgary, Alberta, Canada	9.3 9.5	Construction Operation

Supplementary Packet #	Description	Related Training Module
14.3 12.8	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Steam Generator Controls, S.A.I.T., Calgary, Alberta, Canada	14.3 Steam Transport 7.8 Boilers, Instruments & Controls
14.4	Correspondence Course, Lecture 11, Sec. 2, Steam Generators, Piping II, S.A.I.T., Calgary, Alberta, Canada	14.4 Steam Purification
15.1	Correspondence Course, Lecture 1, Sec. 4, Prime Movers, & Auxiliaries, Steam Turbines, S.A.I.T., Calgary, Alberta, Canada	8.1 Steam Turbines, Types
15.2	Correspondence Course, Lecture 4, Sec. 3, Prime Movers, Steam Turbines I, S.A.I.T., Calgary, Alberta, Canada	8.2 Steam Turbines, Components
15.3	Correspondence Course, Lecture 2, Sec. 4, Prime Movers & Auxiliaries, Steam Turbine Auxiliaries, S.A.I.T., Calgary, Alberta, Canada	8.3 Steam Turbines, Auxiliaries
15.4	Correspondence Course, Lecture 6, Sec. 3, Prime Movers, Steam Turbine Operation & Maintenance, S.A.I.T., Calgary, Alberta, Canada	8.4 Steam Turbines, Operation & Maintenance
15.5	Correspondence Course, Lecture 8, Sec. 3, Prime Movers, Gas Turbines, S.A.I.T., Calgary, Alberta, Canada	8.5 Gas Turbines
16.2	Boilers Fired with Wood & Bark Residues, D.D. Junge, F.R.L., O.S.U., 1975	10.2 Combustion Types of Fuel
16.2	Correspondence Course, Lecture 5, Sec. 2, Steam Generators, Fuel Combustion, S.A.I.T., Calgary, Alberta, Canada	10.2 Combustion Types of Fuel
16.3	Correspondence Course, Lecture 5, Sec. 2, Plant Services, Fuel & Combustion, S.A.I.T., Calgary, Alberta, Canada	10.3 Combustion Air & Fuel Gases
17.1	Correspondence Course, Lecture 12, Sec. 3, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	12.1 Feedwater, Types & Operation
17.2	Correspondence Course, Lecture 12, Sec. 2, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	12.2 Feedwater, Water Treatments

Supplementary Packet #	Description	Related Training Module
17.3	Correspondence Course, Lecture 7, Sec. 2, Steam Generators, Boiler Feedwater Treatment, S.A.I.T., Calgary, Alberta, Canada	12.3 Feedwater, Testing
18.1	Correspondence Course, Lecture 2, Sec. 5, Electricity, Direct Current Machines, S.A.I.T., Calgary, Alberta, Canada	11.1 Generators, Types & Construction
18.1 18.2	Correspondence Course, Lecture 4, Sec. 5, Electricity, Alternating Current Generators, S.A.I.T., Calgary, Alberta, Canada	11.1 Generators, Types & Construction 18.2 Generators, Operation
19.1	Correspondence Course, Lecture 5, Sec. 4, Prime Movers & Auxiliaries, Air Compressor I, S.A.I.T., Calgary, Alberta, Canada	13.1 Air Compressors, Types
19.1	Correspondence Course, Lecture 6, Sec. 4, Prime Movers & Auxiliaries, Air Compressors II, S.A.I.T., Calgary, Alberta, Canada	13.1 Air Compressors, Types 13.2 Air Compressors, Operation & Maintenance
20.1	Basic Electronics, Power Transformers, EL-BE-51	15.4 Transformers
21.1	Correspondence Course, Lecture 6, Sec. 5, Electricity, Switchgear & Circuit, Protective Equipment, S.A.I.T., Calgary, Alberta, Canada	15.3 Circuit Protection
22.1	Correspondence Course, Lecture 10, Sec. 3, Prime Movers, Power Plant Erection & Installation, S.A.I.T., Calgary, Alberta, Canada	15.1 Installation Foundations

RECOMMENDATIONS FOR USING TRAINING MODULES

The following pages list modules and their corresponding numbers for this particular apprenticeship trade. As related training classroom hours vary for different reasons throughout the state, we recommend that the individual apprenticeship committees divide the total packets to fit their individual class schedules.

There are over 130 modules available. Apprentices can complete the whole set by the end of their indentured apprenticeships. Some apprentices may already have knowledge and skills that are covered in particular modules. In those cases, perhaps credit could be granted for those subjects, allowing apprentcies to advance to the remaining modules.

We suggest the the apprenticeship instructors assign the modules in numerical order to make this learning tool most effective.

SUPPLEMENTARY INFORMATION

ON CASSETTE TAPES

Tape 1: Fire Tube Boilers - Water Tube Boilers and Boiler Manholes and Safety Precautions

Tape 2: Boiler Fittings, Valves, Injectors, Pumps and Steam Traps

Tape 3: Combustion, Boiler Care and Heat Transfer and Feed Water Types

Tape 4: Boiler Safety and Steam Turbines

NOTE: The above cassette tapes are intended as additional reference material for the respective modules, as indicated, and not designated as a required assignment.

Modules 18.1, 19.1, and 20.1 have been omitted because they contain dated materials.

INSTRUCTIONAL LEARNING SYSTEMS

7.1

BOILERS -- FIRE TUBE TYPES

Goal:

The apprentice will be able to describe types of fire tube boilers.

Performance Indicators:

1. Distinguish between fire tube and water tube boilers.
2. Describe horizontal return boilers.
3. Describe scotch boilers.
4. Describe one and two-pass boilers.
5. Describe dryback and wetback types of boiler.
6. Describe packaged boilers.
7. Describe firebox boilers.
8. Describe internally fired boilers.
9. Describe shell internals of a boiler.
10. Describe safety devices and practices with fire tube boilers.

Study Guide

* Read the goal and performance indicators to determine what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Blow-off connection
* Dryback boiler
* Firetube boiler
* Horizontal return tube boiler
* Internally fired boilers
* Internal furnace boilers
* One pass boiler
* Packaged firetube boiler
* Safety valves
* Scotch boilers
* Steam dome
* Steam outlet
* Smoke box
* Smoke stack
* Tube plates
* Two-pass boiler
* Water-leg
* Watertube boiler
* Wetback boiler

Introduction

High pressure boilers can be divided into major classifications--firetube and watertube. A firetube boiler has tubes that carry flue gases from the fluebox. The tubes are surrounded with water. As the gases travel through the firetubes, the surrounding water is heated to produce steam.

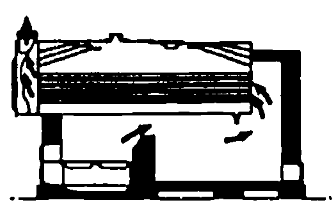
A watertube boiler circulates water through tubes instead of flue gasses. Hot flue gasses, outside the tubes, heat the water in the tubes and produce steam.

This package will describe the firetube boiler. Another package will describe watertube boilers.

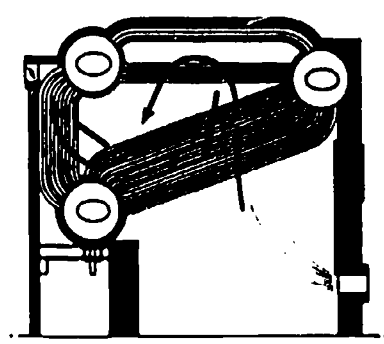
Information

A steam boiler is merely a steel container in which water can be heated to produce steam. The water is heated and evaporated into steam that drives a prime mover such as the steam turbine.

The firetube boiler uses tubes to carry the heat throughout the water. Close contact between water and heated tubes makes steam production more efficient. The principle of the firetube boiler is shown in the following diagram.



Firetube Boiler

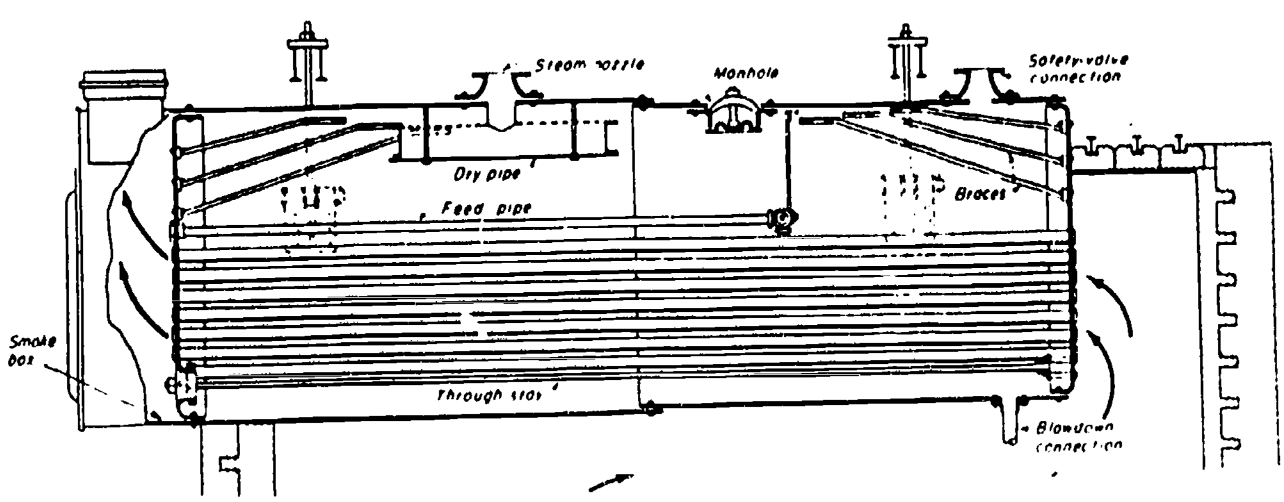


Watertube Boiler

Firetube boilers are simple in construction and low first costs make them suitable for many applications in steam generation. Many variations in design help to improve the efficiency and adaptability of the firetube boiler.

Horizontal Return Tube Boiler

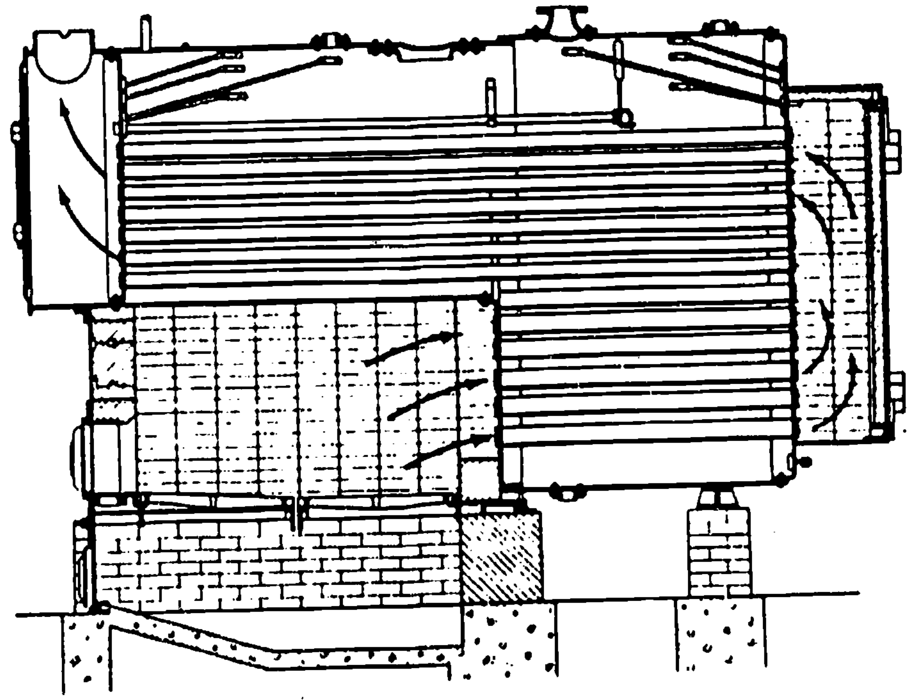
A horizontal return tube boiler has firetubes running the length of the boiler shell. The top portion of the boiler is above water level and allows steam to collect. Horizontal return tube boilers can use a variety of fuels. A diagram of the horizontal return tube boiler follows.



Information

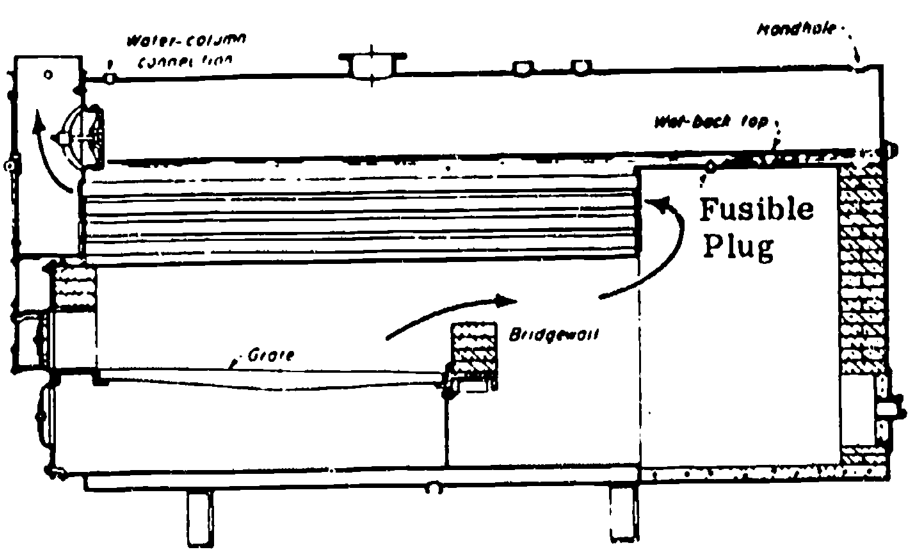
Two Pass Boilers

Two pass boilers have two sets of firetubes. The gasses pass through a short set of tubes and return back through a long set of tubes. The long tubes are smaller than the short tubes.



Dryback Boilers

In dryback type boilers, the furnace opens into a refractory lined chamber which causes the gasses to flow back through the firetubes. The chamber is dry which gives it the name "dryback". A brick lining is used for the chamber.



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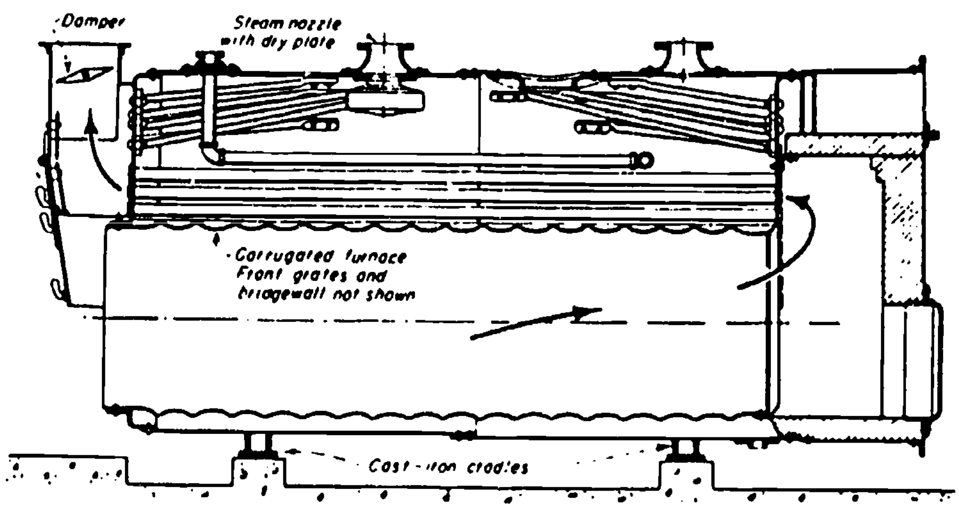
Information

Scotch Boilers

Scotch boilers are self-contained units with the firebox inside the boiler shell. The furnace is located below the firetubes. As gases are produced, they flow into a chamber at the end of the boiler and then pass through the firetubes to the smokebox. Such boilers are sometimes called internal furnace boilers. Scotch boilers are of welded construction with a refractory type rear chamber to send the gases back through the firetubes to the smokebox.



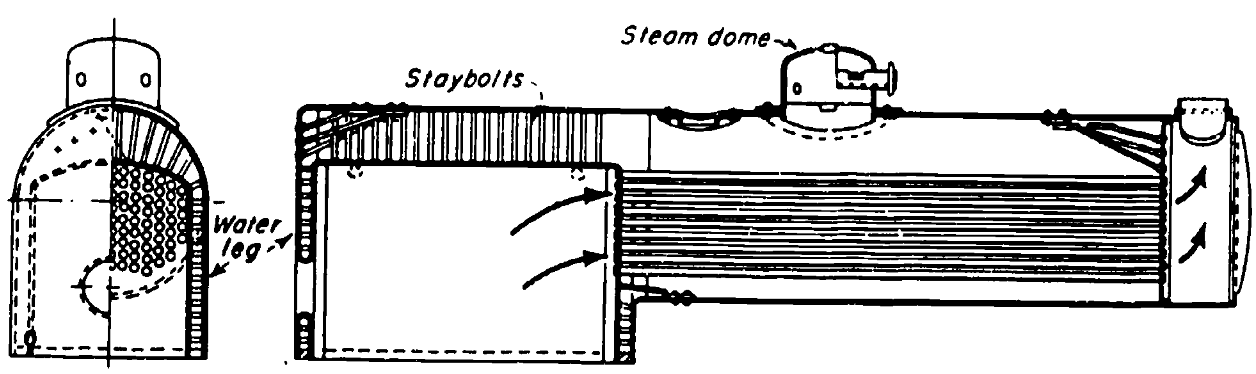
One Pass Boilers

One pass boilers have one set of firetubes that extend much of the length of the boiler shell. Gases pass through the tubes in one direction as was shown in the horizontal return tube boiler.

Information

Wetback Boilers

Wetback type boilers have a rear chamber that is submerged in water. This wetback design is also called a scotch marine boiler. The water that surrounds the rear chamber is called a water-leg.



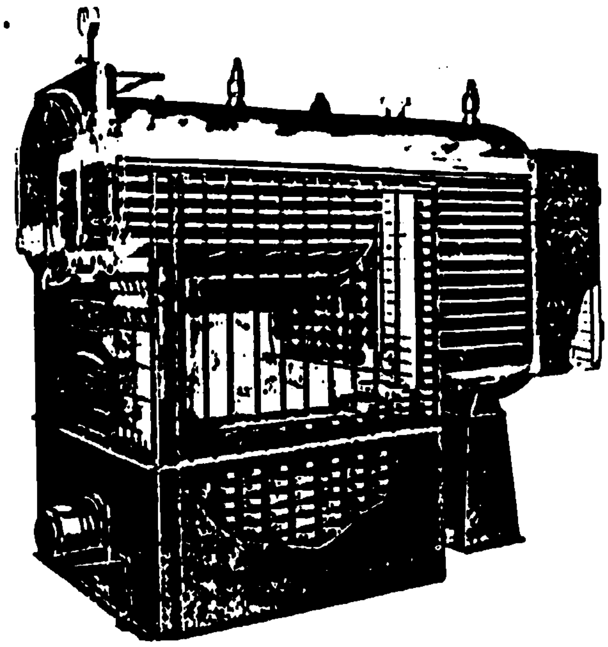
Packaged Firetube Boilers

A boiler unit that is purchased with the auxillaries and control units intact re called "packaged" boilers. Packaged boilers can be purchased in two, three d four pass designs.

Information

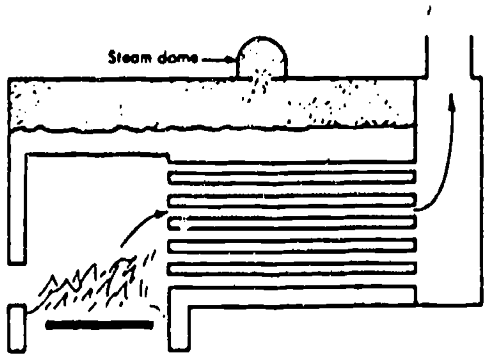
Firebox Boiler

This boiler is a low cost, efficient and compact type that is usually used as a heating boiler. The shell has two sections with two sets of firetubes. Gasses travel through tubes in the lower shell section and reverse through the upper tubes. Fireboxes are encased in brick in most firebox boilers although some designs use water to surround the firebox.



Internally Fired Boilers

Designers found that the heating surface could be increased by enclosing the furnace, as well as the firetubes, inside the boiler shell. The furnace of an internally fired boiler is almost totally surrounded by water.



Information

Shell Internals

Most boilers have cylindrical shells to resist the internal pressure of the steam. The internal shell is strengthened by the use of the diagonal stays, through bolts or tubes designed as stays. The major internal force is directed more along the length of the boiler than along its girth. A basic component of the firetube boiler is the firetubes which carry the heated gases that heat the water. The firetubes are 76 mm to 102 mm in diameter and expand at each end into tube plates. The tube plates are supported by diagonal stays or braces that attach to the boiler shell. A blow-off connection permits cleaning and draining of the boiler. Internally fired boilers have a firebox inside the shell that is surrounded by a water-leg or brick. A steam dome contains a steam outlet and safety valves. A smokebox receives the gases that emerge from the firetubes and directs them into the smoke stack for discharge from the system.

Safety Devices and Practices

The firetube boiler is much more dangerous when it explodes. Where a watertube boiler explosion is usually limited to a ruptured tube, the firetube boiler explodes completely. For safe operation of firetube boilers the operator should:

1. Make sure that the boiler conforms to ASME code in regard to materials, fabrication methods and installation of fittings.

2. Make sure that controls are responsive to changing conditions.

3. Maintain boiler in a clean condition.

4. Make periodic inspections of boiler parts.

5. Read manufacturers instructions for operation and safety of specific boiler that is being operated.

Boilers are fitted with safety valves to prevent explosions. The operator must be sure that these safety devices are functioning and that the controls are properly registering the pressures within the boilers. Damaged parts should be replaced before the boiler becomes hazardous to operate.

Assignment

* Read pages 1-21 in supplementary reference and study diagrams.
* Complete job sheet.
* Complete self-assessment and check answers.
* Complete post-assessment and ask the instructor to check your answers.

Job Sheet

INSPECT A FIRETUBE BOILER

* Carefully inspect a firetube boiler at your plant site or neighboring site.
* Is it a horizontal return tube or scotch type?
* Is it a one pass or two pass boiler?
* Is it a wetback or dryback type?
* What safety features does it have?
* Locate
  - Blow-off connections
  - Safety valves
  - Steam outlet
  - Smoke box
  - Smoke stack

Self Assessment

1. A boiler that carries heated gases through its tubes is a ______________ boiler.

2. Boilers with an internal firebox and a refractory type rear chamber are called ______________ boilers or internal furnace boilers.

3. A boiler that produces steam on one trip of gases through the firetubes is a ____________ ____________ boiler.

4. Boilers that pass gases through a short set of tubes and then reverses the flow back through a longer set of tubes is a ____________ ____________ boiler.

5. A boiler that has a brick lined rear chamber is a ____________________ type.

6. One that has a rear chamber surrounded by a water-leg is a ______________ type.

7. A scotch marine boiler is a ____________________ type.

8. Boilers that are purchased complete with auxillaries and controls are called ______________________ boilers.

9. A boiler that uses a two-section shell with short tubes in the lower section is a ____________________ boiler.

10. The ____________________ connection permits the boiler to be cleaned and drained.

Self Assessment Answers

1. Firetube
2. Scotch
3. One-pass
4. Two-pass
5. Dryback
6. Wetback
7. Wetback
8. Packaged
9. Firet
10. Blow-off

Post Assessment

Match the following boilers and boiler part descriptions with their names:

_______ 1. Dry rear chamber lined with brick.

_______ 2. Boiler unit purchased complete with controls and auxillaries.

_______ 3. Rear chamber surrounded by water-leg.

_______ 4. Receives gases from firetubes and directs them to smokestack.

_______ 5. Allows boiler to be cleaned and drained.

_______ 6. Contains a steam outlet and safety valves.

_______ 7. Boiler with both firetube and furnace enclosed in shell.

_______ 8. Boiler has a two-section shell that contains short tubes in one section and long tubes in the other section.

_______ 9. Expanded ends of a firetube.

_______ 10. A container in which water is heated to produce steam.

A. Blow-off connection

B. Internally fired boiler

C. Wetback

D. Packaged

E. Steam dome

F. Dryback

G. Tube plate

H. Smokebox

I. Steam boiler

J. Firebox boiler

Instructor Post Assessment Answers

F 1.

D 2.

C 3.

H 4.

A 5.

E 6.

B 7.

J 8.

G 9.

I 10.

Supplementary References

* Correspondence Course. Lecture 1, Section 2, Second Class Steam Generators. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

12.1

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATORS

Second Class
Lecture 1

TYPES OF BOILERS I

INTRODUCTION

Definition of a Steam Boiler

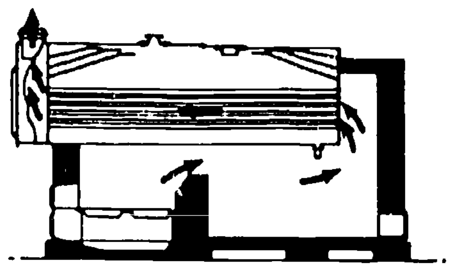
Essentially a boiler is a container into which water can be fed and, by the application of heat, evaporated continuously into steam.

Early boiler designs consisted of a simple shell with a feed water inlet and a steam outlet, mounted on a brick setting. Fuel was burned on the grate within the setting and the heat released was directed over the lower shell surface and thence up the stack.

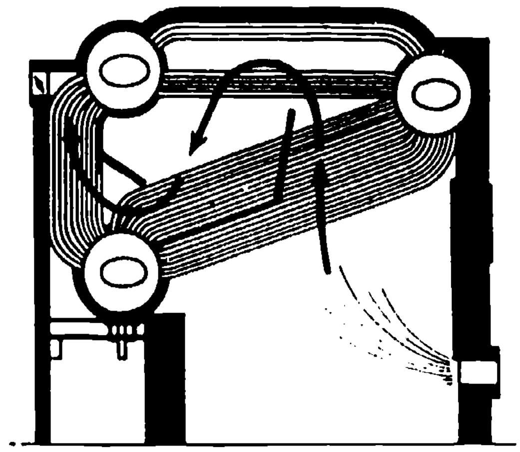
Designers soon learned that heating a single large vessel of water was remarkably inefficient and that it was necessary to bring more of the water into close contact with the heat.

One way to do this was to direct the hot combustion products through tubes within the boiler shell as in Fig. 1. This firetube design not only increased the heat surface exposed to the water but also tended to distribute steam formation more uniformly throughout the mass of water.

A second way to increase the area of contact between water and hot gases was to direct the water through tubes arranged in banks within the boiler combustion chamber; see Fig. 2. This is the watertube design which, because of the relatively small drums and the subdivision of pressure parts, lends itself more readily to high pressures and large output capacities.



Firetube Boiler
Fig. 1



Watertube Boiler
Fig. 2

All steam boilers fall into one of these two main classes, either Firetube or Watertube. They may then be subdivided into horizontal-return tube, internal furnace, dry back, wet back, straight tube, bent tube, packaged, once-through, supercritical, etc. etc., as will be shown in these lectures.

Heat Transfer

Transfer of heat from the fuel to the water and/or steam in the boiler must be carried out by one of the three methods: Conduction, Convection or Radiation. (References to these can be found in Lect. 8, Sect. 1, and should be reviewed.)

Conduction takes place through the metal of the boiler shell or tubes, from gas to water.

Convection currents carry heat within the water mass in the drum and in the gases flowing through the boiler passes.

Radiation of heat takes place within the combustion chamber direct from the fire to the exposed surfaces of drum and tubes.

In actual practice heat-transfer is a complex interaction of all types, for example, consider the familiar case of heat-transfer from flue gas to water within a tube. The gas flow is a convection current carrying heat from the furnace to the tube. Heat from the gas must then flow by conduction through the tube metal to the water. The water carries the heat away from the tube metal by convection currents and then distributes it by conduction and convection.

(PE2-2-1-2)

Boiler Heating Surface

Since a boiler turns water into steam by the application of heat, the amount and the disposition of its heating surface has a primary bearing upon its output capacity and its operating efficiency.

Firetubes added to the early shell boiler designs increased the heat-transfer surface: further developments and improvements are discussed in this lecture.

Watertube boilers have developed from the typical illustration in Fig. 2 in which almost all of the heat-transfer occurred in convection banks, to the complicated designs shown in later lectures having huge radiation surfaces and a full range of heat-saving equipment, superheaters, economizers, air heaters, etc. These boiler are described in Lecture 2 of this Section.

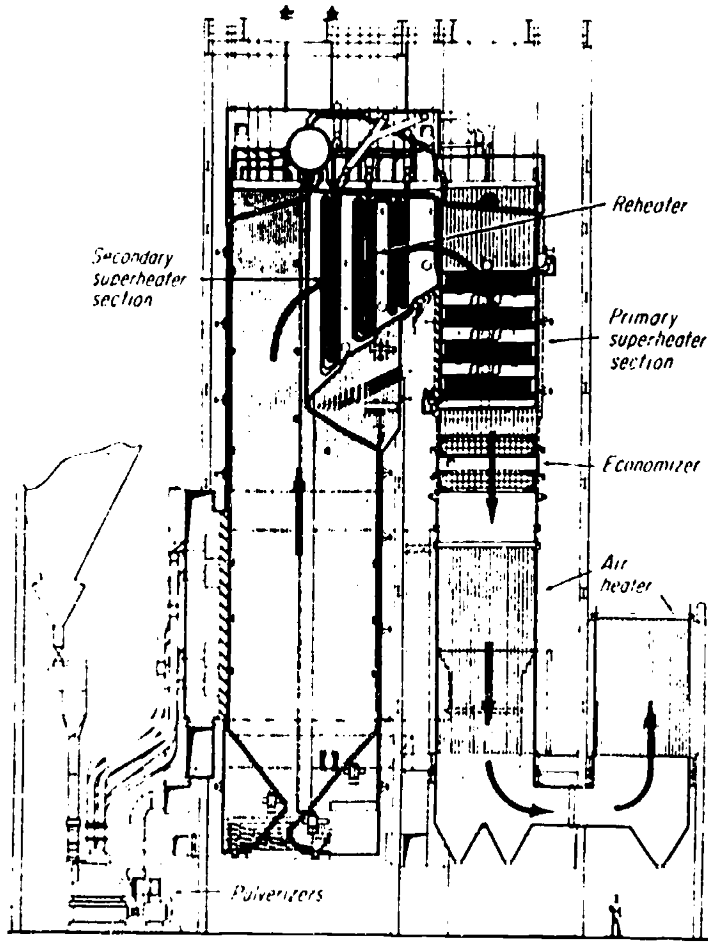
The trend of boiler design, especially for large thermal generating stations, has been towards progressively larger boilers, that is boilers with greater steam output. At the same time the pressure and temperature of the steam supply required have been increasing. A practical ceiling of about 565°C temperature has been reached and is generally not exceeded. Pressures in common use are more varied, the most popular being about 16 500 kPa.

Use of these higher steam pressures and temperatures in the more efficient steam power plant cycles has had an important effect upon boiler design.

Low-pressure boilers with small superheaters absorbed much of the heat from the combustion products in banks of convection tubes.

At higher pressures, however, the increase in saturation temperature reduces the temperature difference between the steam and the combustion gases and necessitates a greater superheater surface area to carry out the heat-transfer. Further an increase in boiler size brings a disproportionate increase in furnace wall area. The combined effect is to reduce the convection section of the boiler practically to elimination so that a modern power boiler consists of furnace, superheater, economizer and air heater only. The latent heat of vaporization is added to the boiler water as it passes through the furnace tubes.

Figure 3 shows the appearance of a modern pulverized-fuel-fired steam generator with the characteristic tall furnace and no convection banks



Here steam generation is largely by radiant energy transfer there are no boiler convection sections. Capacity from 136 000 kg/hr upwards.

Pulverized-fuel-fired Steam Generator
Fig. 3

Circulation

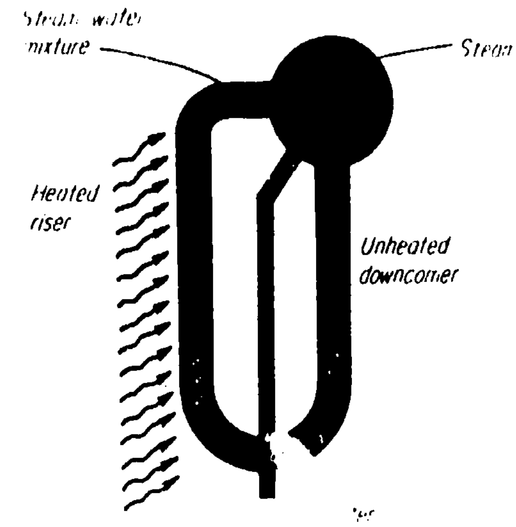
Positive circulation of the water in a boiler is highly important to its successful operation.

A shell boiler heated from beneath has obviously little or no circulation, and because of this it is not suitable for rapid steam production. The same boiler with the addition of firetubes is considerably better but the most positive circulation is achieved with a watertube boiler.

(PE2-2-1-4)

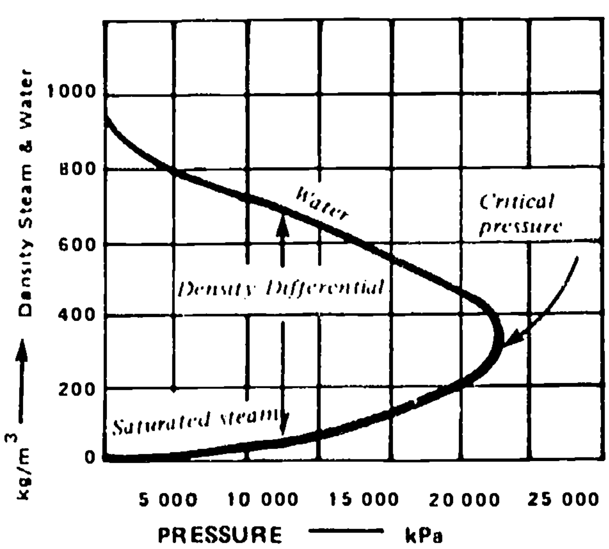
In a simple watertube circuit, as in Fig. 4, due to the positioning of the baffle the "downcomer" is unheated and the "riser" is heated.

The heated steam-water mixture has less mass than the cooler water on the unheated side and the unbalance forces the left-hand column to rise. After entering the drum the steam bubbles rise to the surface of the water and fill the steam space.



Watertube Circulation Loop
Fig. 4

The circulation in this example is produced by the difference in the mass of a column of water and a column of part steam, part water. At low steam pressures the difference between water density (kg/m^3) and steam density is very marked and the circulation produced is positive. With increase of steam pressure however the difference between the two densities decreases and boiler designers have to exercise extra care to ensure good circulation.



Pressure-Density Curve for Water and Steam
Fig. 5

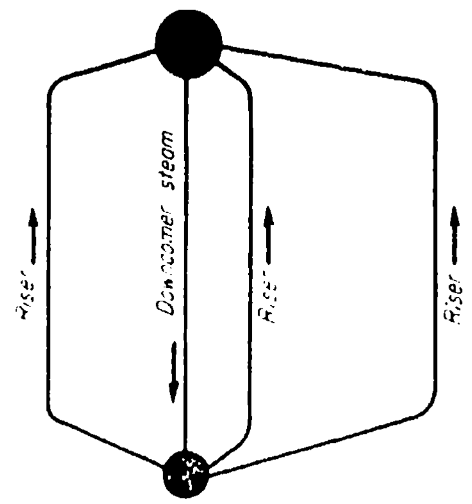
Fig. 5 illustrates this diminishing difference in densities. Note that at, and above, the critical pressure of 22 100 kPa, the density of water and steam is the same, natural circulation then becomes impossible and forced circulation is employed.

The practical power engineer should always check out very carefully the circulation system of any boiler of which he has charge. He can then fully appreciate the importance of maintaining the key baffles in the gas flow in a gas tight condition and all water passages absolutely clean.

The following figures show some examples of boiler circulation systems.

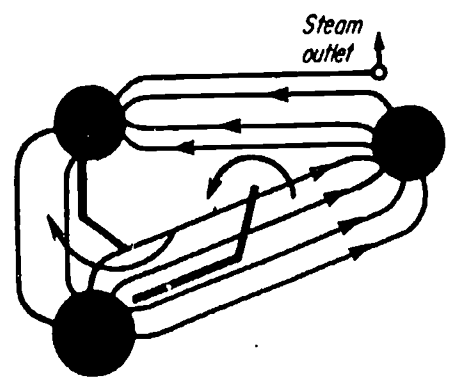
Figs. 6 and 7 are natural circulation systems.

Fig. 8 shows forced circulation using a circulating pump and Fig. 9 shows a boiler design in which the whole steam-water circuit forms one continuous pipeline from feed inlet to steam outlet. This design is known as "once-through" and is applied to boilers operating at above critical pressure.



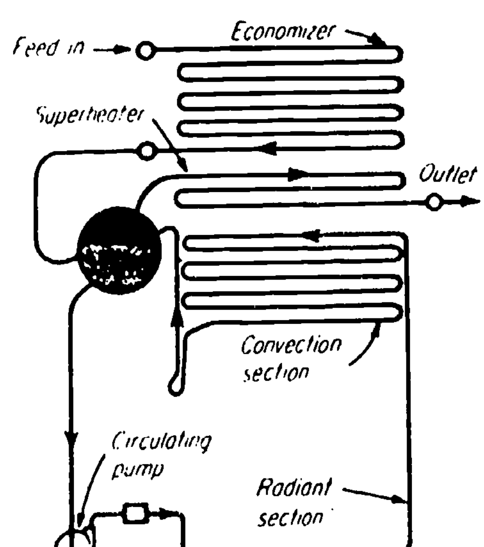
In actual natural-circulation units the principles of Figs. 4 and 5 apply, but there are usually many parallel riser circuits carrying steam-water mixture and several larger, cold downcomers.

Fig. 6



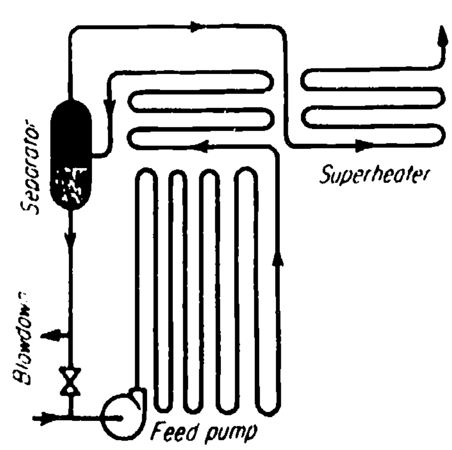
Circulation situation in a three-drum low-head boiler is more complicated. Downcomers are partially heated, there is less head difference to produce circulation, more frictional resistance.

Fig. 7



Forced circulation employs a pump to overcome resistances. It may be used at high pressures where natural circulation forces are small, or at lower pressures to gi[illegible]dom in tube layout.

Fig. 8



In once-through designs there is no recirculation; feedwater leaves the tubes as steam. When pressures are below critical, a separator may be used to remove any moisture present in steam.

Fig. 9

(PE2-2-1-6)

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It has been seen that natural circulation in a boiler is dependent upon the difference in densities between steam and water at the boiler operating pressure. This difference in density is the driving force behind the circulation; it has to overcome the resistance to flow presented by the tubes and headers in the circuit.

In general, the force available to produce circulation diminishes with increasing boiler pressures, because the densities of steam and water approach each other. This is partially offset by the fact that friction losses tend to decrease as pressure rises.

As a net result, it is possible to design high-pressure steam generators for natural circulation, but as pressure rises circulation factors demand increasingly careful consideration. This is one of the reasons some designers have turned to forced circulation, using a pump.

It is apparent that the amount of water circulated in a boiler usually greatly exceeds the amount of steam being generated. If 10 kg is circulated for each kg generated, the <u>circulation ratio</u> is 10 to 1.

The percentage of steam by mass in the steam-water mixture at the top of a riser tube where heating ceases is called <u>top dryness</u> - it varies with design but normally runs from about 5 to 20%. If percentage of the steam in the mixture becomes excessive, a condition is reached in which a film of steam exists at the inner surfaces of the boiler tubes. This condition is acceptable in superheaters, but not in wall tubes, because in this case the film is more likely to be stagnant and furthermore these tubes are exposed to higher temperature radiant heat.

Watertube boiler designs with complex circulation loops - waterwalls, screen walls, radiant platen heaters, superheaters, etc. - must be calculated to ensure that sufficient mass-flow passes through each tube, at every load, to keep the tube metal within a safe temperature limit. Mass-flow refers to the mass of fluid mixture in kg/hr passing through the tube. It is affected by velocity, density, specific heat, conductivity, fluid viscosity, tube diameter and internal surface.

Designers must be able to make a calculated guess at some of these variables for example, the percentage of steam by mass in the steam-water mixture, the "dryness-fraction" mentioned before, at various points in the circuit.

Once that approximation is made, relationship between these variables is governed by certain dimensionless numbers which have become the indispenable tool of the hydraulic engineer. Most commonly used among these numbers and applied to the gas side as well as the steam side of boiler surfaces is the Reynolds number. This brings into the picture massflow, tube diameter, fluid velocity and viscosity - all factors in flow resistance.

In contrast to natural circulation and forced circulation designs -- in which more water is circulated than steam is generated and a drum or drums serve as a collecting and steam-releasing point -- the once-through design consists in theory, of a single tube (no drum) into which goes feedwater and out of which comes saturated or superheated steam. In actual units, of course, the theoretical single circuit becomes a number of parallel circuits.

Steam Generator Ratings

The oldest measure of steam-generator capacity is the boiler horsepower. This is the amount of steam which was required to generate one horsepower in a typical steam engine at the date when this unit was adopted. In the SI System one boiler horsepower is equivalent to 9.809 kW.

It is still used as the common measure of capacity for small boilers. Larger boiler capacity is almost invariably given in the number of kg of steam evaporated per hour, with specified steam conditions.

Maximum continuous rating is the hourly evaporation that can be maintained for 24 hours. Boilers supplying steam to turbo-alternators are often rated in megawatts (MW) today, because the kg/h rating at the boiler stop valve does not take into account the large reheater sections of the boilers.

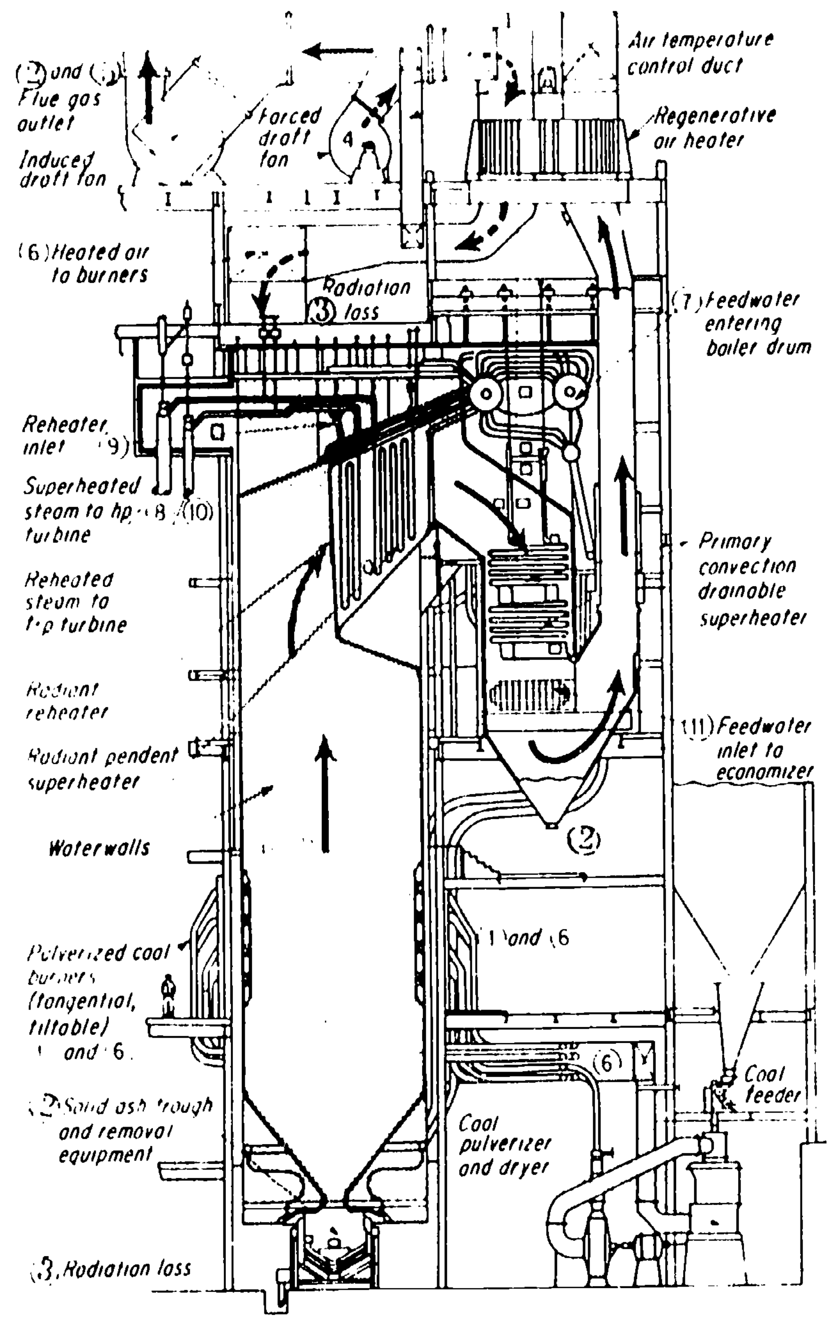
A steam-generating unit coordinates many elements. While the term "boiler" is broadly used, it should apply, strictly speaking, only to the elements in which the change of state from water to steam takes place. The term "steam generator" embraces the many combinations of heating surfaces, such as water-walls, superheaters, reheaters, economizers, and air heaters. A "steam-generating unit" consists of a steam generator and its associated equipment, including fuel burning, ash removal, and draft systems. Such a steam-generating unit is pictured in Fig. 10.

It can be seen that a complete steam-generating unit represents a combination of many elements, all of which must be integrated properly if the unit's operation is to be efficient.

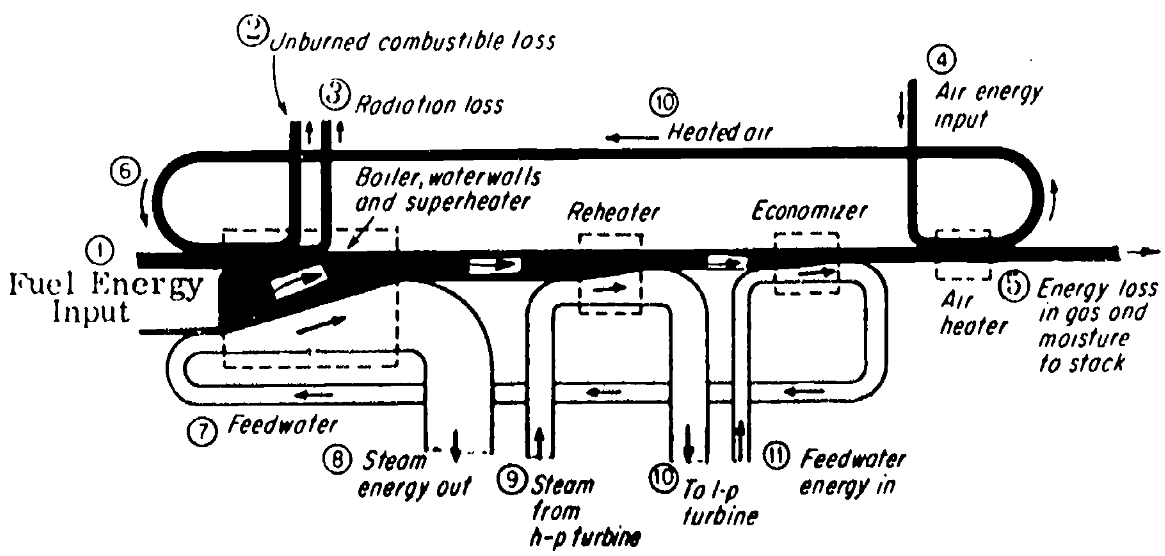
Expressed another way, performance of the total unit can be affected by limitations of any of the systems external to the steam generator - inadequate draft, for example, or fuel-burning equipment that does not supply the heat release on which steam-generator design was predicated. Thus, there is an increasing tendency for the manufacturer of the steam generator to be responsible for coordinating the entire unit.

Fig. 10 shows a sectional arrangement of a typical high-pressure, high-temperature steam-generating unit.

Fig. 11 is a diagrammatic illustration of the energy flows which occur in the unit from the fuel input (1) to the steam outputs Nos. (8) and (10). The numbers given on Fig. 10 show the location of these energy flows.



Typical High-pressure Steam-generating Unit
Fig. 10



Energy Flow Diagram relating to Fig. 10
Fig. 11
(Circled numbers show location of energy entry or exit) (PE2-2-1-9)

FIRETUBE BOILERS

The term "firetube" is derived from the fact that the hot combustion gases are carried in tubes through the water space. Firetube boilers may also be called "shell" boilers because the whole of the steam-producing elements are housed within a single outer shell.

Although the ideal shape to resist internal pressure is a sphere, practical consideration leads to the use of basically cylindrical shells. Non-cylindrical sections and flat surfaces are given added resistance to internal pressure by various means: diagonal stays, through-bolts, or tubes which are themselves designed to be used as stays.

In such a shell the force tending to burst it along the length is twice that tending to burst it around the girth. In the critical longitudinal direction the strength required to resist bursting is proportional to the product of the pressure and the diameter. It can be seen that high pressures and large diameters would lead to extremely thick shell plates. Hence, there is a definite economical limit on pressure and capacity that can be reached with shell-type boilers.

An operating pressure of 1725 kPa may be considered the practical ceiling, and on this continent, capacity rarely exceeds 11 500 kg/h of steam roughly 7500 kW boiler. In Europe, where larger firetube boilers have always been popular and economics and boiler-code conditions are different, units of 13 500 kg/h are not unusual.

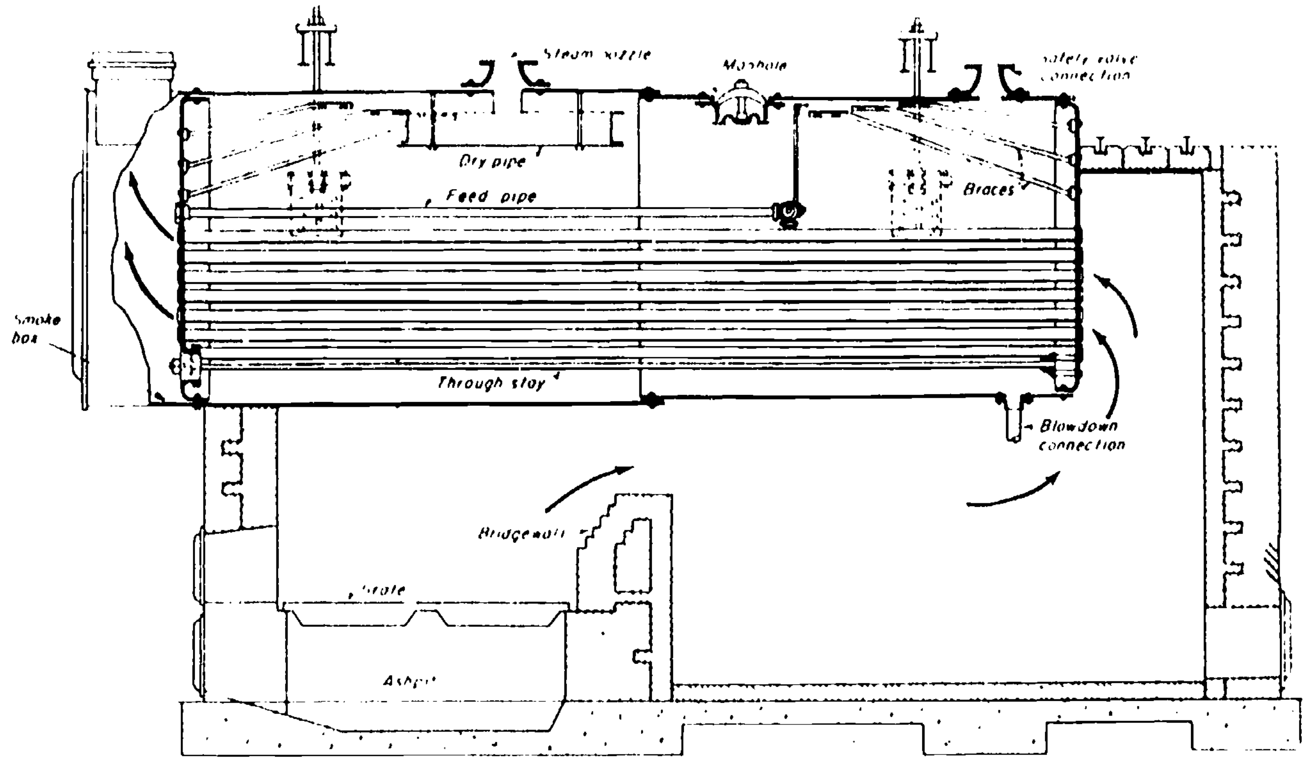
As a class, firetube boilers feature simple and rugged construction and relatively low first cost. Their charactistically large water capacity makes them somewhat slow in coming up to operating pressure but provides some accumulator action that makes it possible to meet load changes quickly.

Horizontal return-tubular boilers, Fig. 12, consist of a cylindrical shell, now usually fusion-welded, with tubes of identical diameter running the length of the shell throughout the water space. Space above the water level serves for steam separation and storage. A baffle plate or dry pipe is ordinarily provided near the steam outlet to obtain greater steam dryness. Feedwater is generally brought in along the top of the steam space and the blowdown connection is at the back.

Because the brick setting may be designed to accommodate many kinds of firing equipment, horizontal return-tubular boilers can handle many types of fuels. This may be an asset, for example, where waste fuels are available.

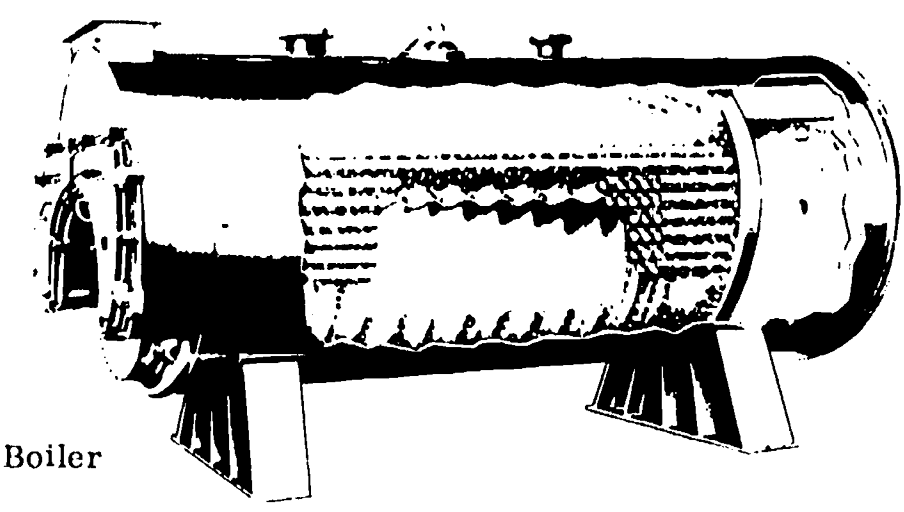
Brick-set boilers may also employ a two-pass construction. In these designs the cylindrical front portion of the shell fits into a larger cylindrical or oval rear section. Combustion products enter short tubes in the lower part of the rear section and then reverse to flow forward through the upper full-length tubes.

Internal furnace boilers of the so-called Scotch type are essentially self-contained. Combustion takes place in a cylindrical furnace within the shell. Firetubes run the length of the shell at the sides of, and above, the internal furnace. Gas from the furnace reverses direction in a chamber at the rear and travels forward through the tubes to a smokebox located at the front.



Horizontal Return-tubular (HRT) Boiler
Fig. 12

HRT boilers are probably the most common of the firetube types. They normally have brick settings and are fired from the front end. Hot gas flows along the bottom of the shell, which is also exposed to radiation, returning through fire-tubes and out through a smokebox at the front.



Scotch-type Boiler
Fig. 13

This type of boiler employs welded construction. Combustion occurs in the corrugated internal furnace; dryback refractory-lined rear chamber reverses flow, directs gas forward through tubes to smoke-box at the front.

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The Scotch boiler illustrated in Fig. 13 (previous page) is a dryback design, with a refractory-lined rear chamber. When the rear chamber is submerged in the water space - wetback design - it is known as the Scotch Marine boiler.

The internal furnace is subject to compressive forces and so must be designed to resist them. Furnaces of relatively small diameter and short length may be self-supporting if wall thickness is adequate. For larger furnaces, one of four methods of support may be employed:

(1) corrugating the furnace walls;

(2) dividing the furnace length into sections with a stiffening flange (Adamson ring) between sections;

(3) using welded stiffening rings, and

(4) installing staybolts between the furnace and the outer shell.

If solid fuel is to be fired, a bridgewall may be built into the furnace at the end of the grate section.

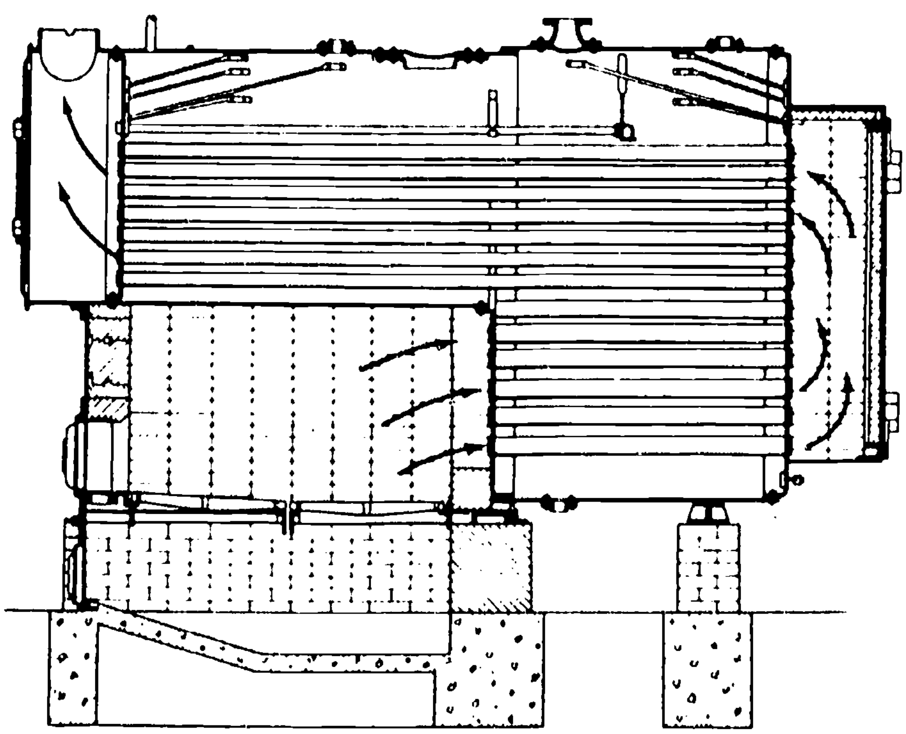
Also essentially self-contained are the several firebox boiler types. The firebox is lined on all sides with a water-cooled shell (waterleg) constructed of flat plate stayed to withstand internal pressure. "Locomotive" and other firebox boilers are often used as portable units.

Figs. 14 to 18 inclusive, on the following pages, show examples of Horizontal Return-tube, Scotch Marine and Locomotive types of firetube boilers.

Two-Pass Boiler
Fig. 14

These boilers usually have a short set of large tubes for a first pass and longer smaller tubes for a second pass.

This design, which is known as the "Economic" type, has cylindrical shell fitted into an oval casing which contains the short first-pass tubes in its lower section.



(PE2-2-1-12)

Packaged Firetube Boilers

Packaged firetube boilers represent the bulk of firetube boilers being manufactured today; they are basically a Scotch boiler having 2-pass, 3-pass or 4 pass design and either dry or wetback.

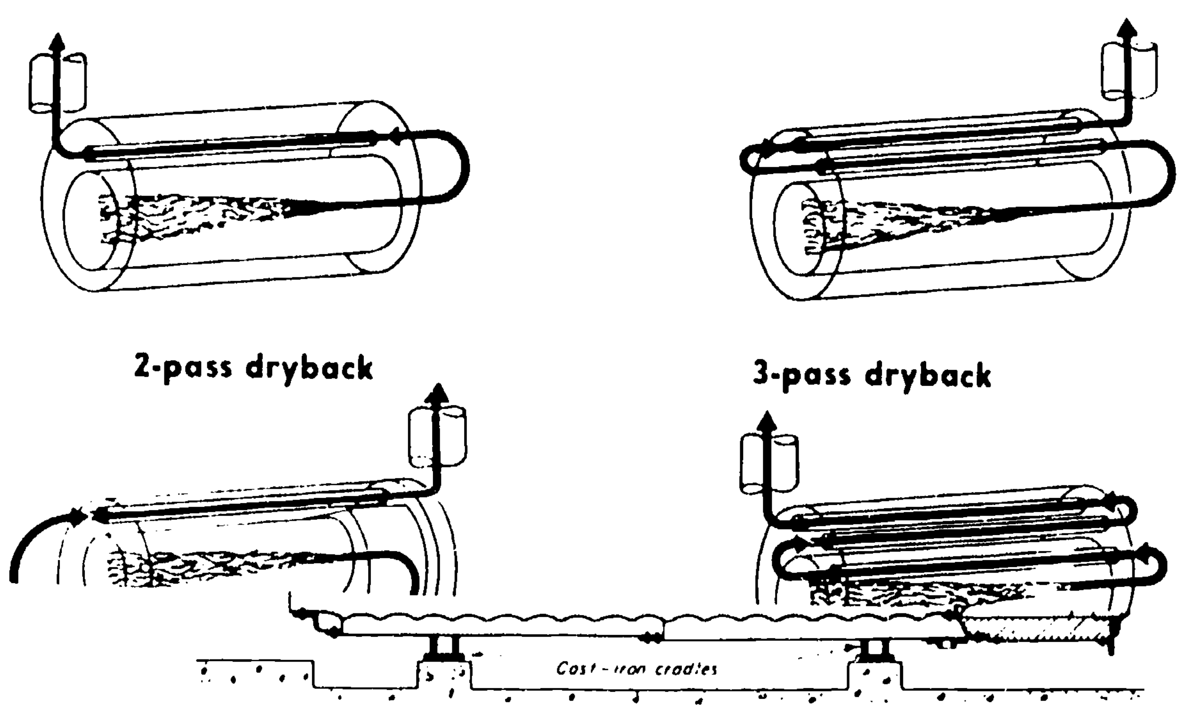
The American Boiler Manufacturing Association defines a packaged firetube boiler as "a modified Scotch-type boiler unit, engineered, built and fire-tested before shipment and guaranteed in material, workmanship and performance by one firm, with one manufacturer furnishing and assuming responsibility for all components in the assembled unit".

The diagrams, Fig. 19, show the basic gas-flow patterns used today. All use an internal furnace or firebox as a first pass, then route the gases into various tube layouts.

Like the basic Scotch type, the 2-pass construction needs no baffles at rear tube sheet. It can be dryback or wetback design.

For longer gas travel, flow is turned again. The rear chamber of dryback 3-pass units has a refractory baffle to reverse gas; in wetback units the submerged rear chamber effects the reversal.

To further increase length of the gas path, direction may be reversed again constituting the 4-pass design.



Scotch Marine Boiler
Fig. 16

As already mentioned these boilers are characterized by internal furnaces. In the dryback type, the furnace opens into a refractory-lined chamber at the rear; gas then flows to the front through firetubes. Corrugated furnace walls increase resistance to buckling.

(PE2 -2-1-13)

Locomotive-type Boiler
Fig. 18

Locomotive-type Boilers have a firebox built into the boiler. A water leg, or water-cooled surface, completely surrounds the furnace, and refractory lining is not required. Rugged construction makes this unit suitable for portable service.

(PE2-2-1-14)

Packaged Firetube Boilers

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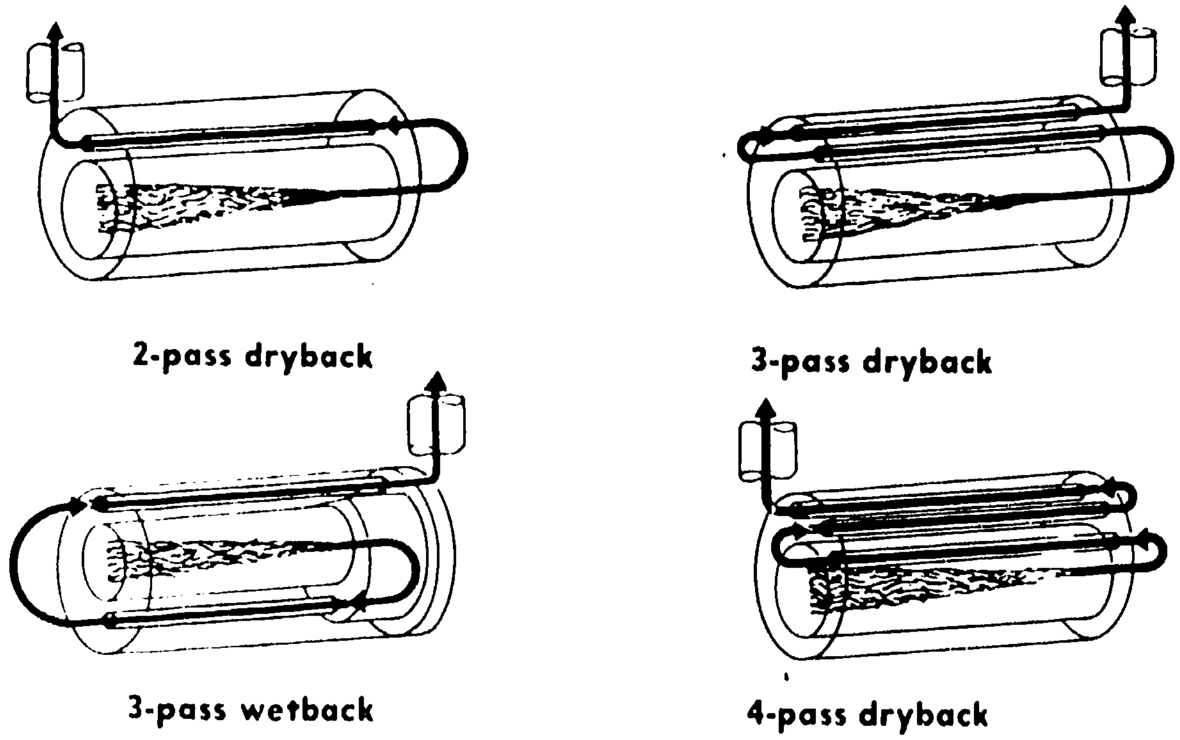


Boiler Gas-flow Patterns
Fig. 19

(PE2-2-1-15)

Two Pass Designs

These boilers tend to be simplest in design and other things being equal, may be somewhat lower in first cost. A variety of arrangements are employed to extract most of the heat from the combustion gas during the relatively short travel time between the burner and stack. For one thing, designers put great emphasis on maximum heat-transfer from the furnace tube, usually by imparting a vigorous swirl or turbulence to the flame and the combustion products.

Designers also give attention to the number and arrangement of the second-pass tubes. While waterside inspection and cleaning are easier when tubes are lined up vertically and horizontally, a staggered layout tends to give a more circuitous flow of water around these tubes, promoting increased heat-transfer. One builder seeks improved transfer from gas to water by using slip-in fittings at the tube inlets to impart a swirl to the hot gas.

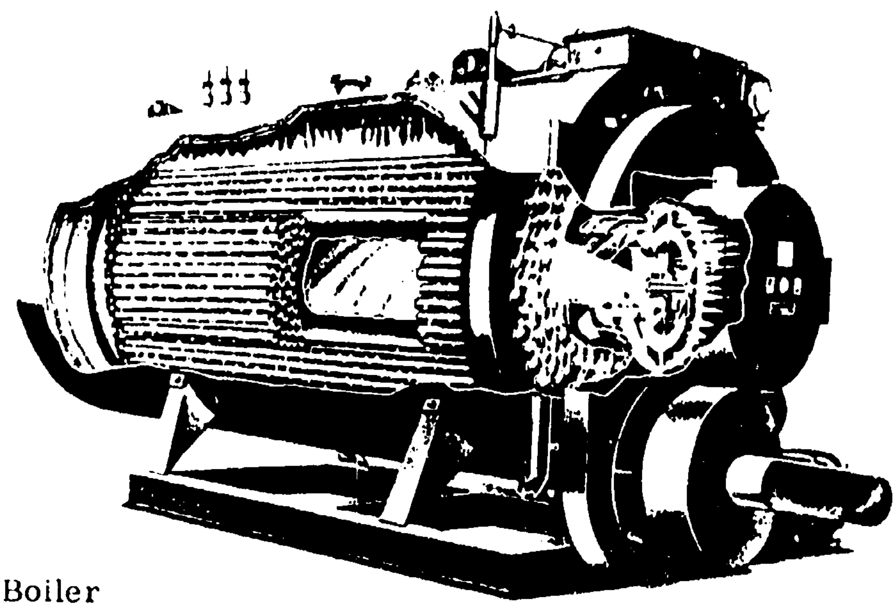
Figs. 20 and 21 illustrate "2-pass" design boilers.

Three-Pass Designs

Judging by the variety of these boilers on the market, the "3-pass" design offers a popular approach. It adds another boiler length to the travel of the hot gas at the cost of some added complexity. In the case of dryback units, the rear chamber must be baffled with refractory to separate the gas being directed into the second-pass tubes, from the gas being discharged out of the third-pass tubes. In wetback units this is accomplished by the design of the submerged rear chamber, Fig. 22.

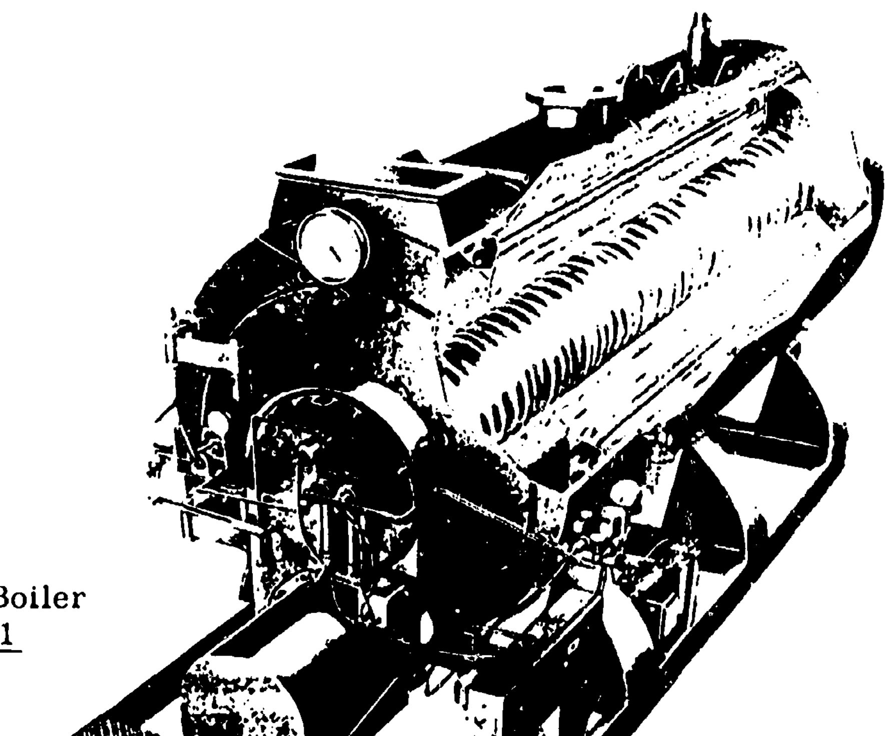
Models differ not only in rear chamber construction but in number, size and placing of tubes. Thus, relatively-small-diameter furnace tubes may be surrounded by a multiplicity of firetubes while other units feature large furnace tubes with fewer firetubes. There seems to be little agreement on the best ratio of primary surface (exposed to fire) and secondary surface (heated by flue gas).

In the "3-pass" category, a number of designs that are basically firebox boilers as distinguished from the internal-furnace type with its cylindrical furnace tube, are to be considered. Typical units have a firebox with a flat bottom and vertical sides going into an arched crown sheet that forms the top, as shown in Fig. 23.



2-Pass Boiler
Fig. 20

The first pass in this unit is a centrally-located corrugated furnace with a spinning flame pattern. The second pass consists of a multiplicity of tubes in a staggered layout. "Impellers" at tube entrances impart spiral gas action.



2-Pass Boiler
Fig. 21

This 2-pass design features a corrugated furnace of generous proportions to minimize radiant transfer from a highly turbulent flame. The second pass consists of two staggered rows of relatively widely spaced return tubes.

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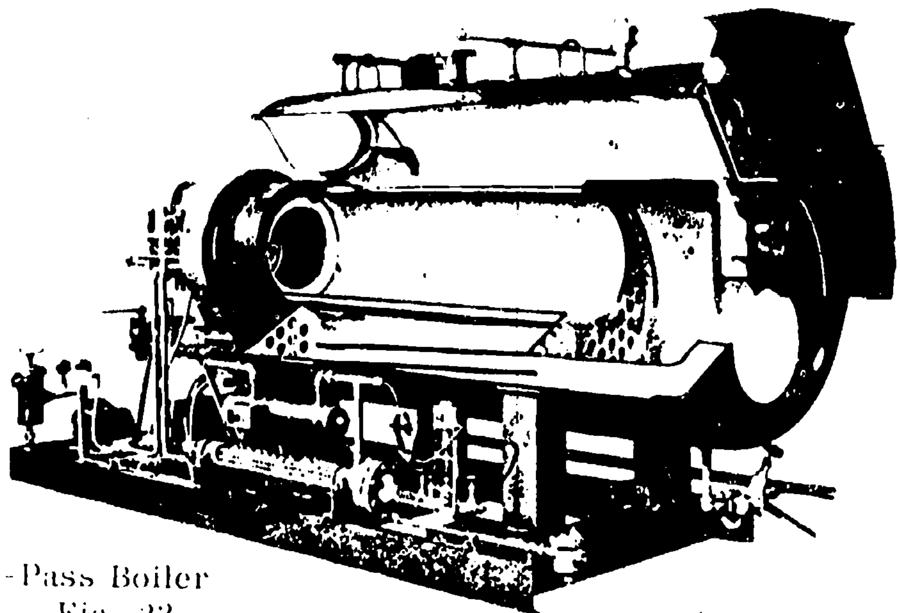
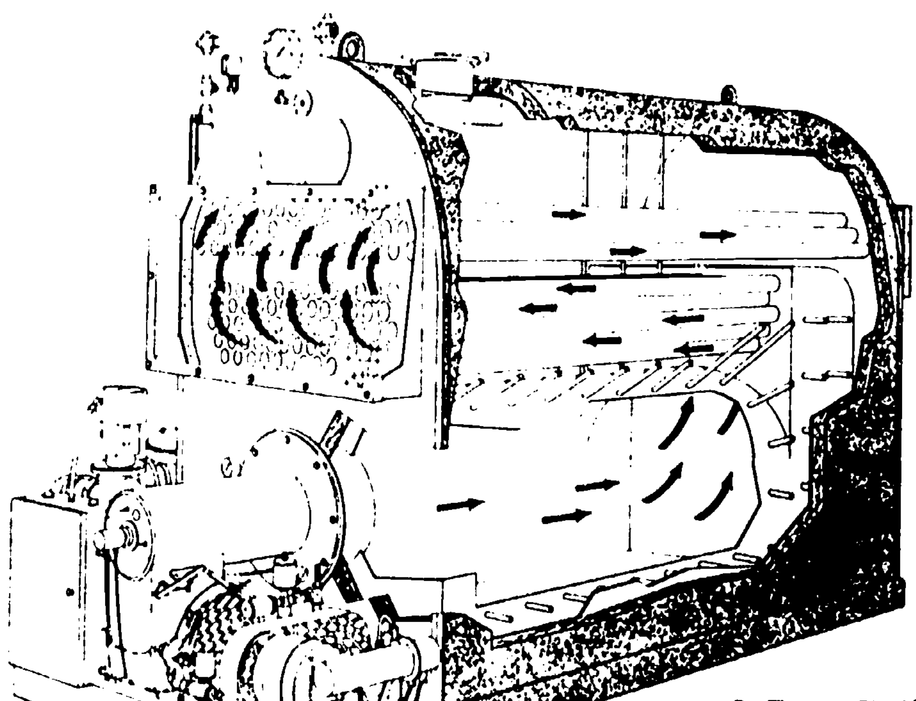


3-Pass Boiler
Fig. 22

The reversing chamber at the rear of this 3-pass wetback unit is surrounded by water. From it gas flows forward through tubes mainly in the lower part of the water space. Then gas flows to the rear through third-pass tubes.



3-Pass Boiler
Fig. 23

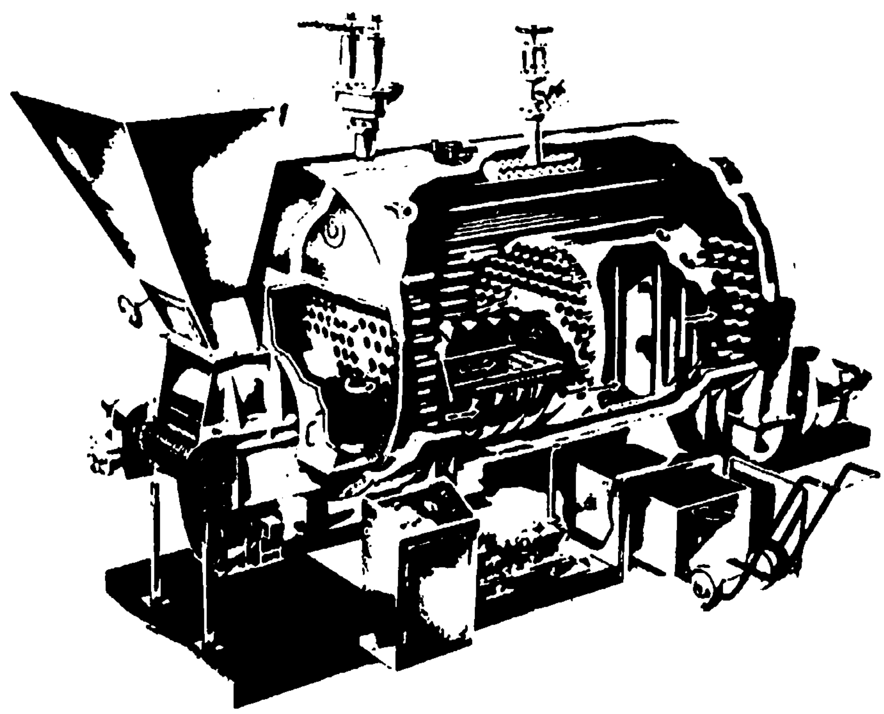
The large stayed firebox of this 3-pass unit has an arched crown sheet; the rear reversing chamber has stayed waterlegs at sides with a submerged top. Flow is forward in short second-pass tubes, to the rear in the longer third-pass tubes. This furnace shape requires stays, as do the waterlegs at the sides of the rear chamber into which the firebox discharges. Here the aim of the designer is for a large combustion space and a higher ratio of furnace-to-tubular surface.

(PE2-2-1-18)

In this country packaged firetube boilers are almost invariably designed for firing oil or gas, both of which lend themselves to compact, automatically-controlled units.

In European practice and in England particularly, the internal-furnace boiler is frequently fired with coal.

Fig. 24 illustrates an interesting packaged unit built in England for stoker firing. The travelling grate is fitted into the internal furnace that forms the first pass of a 3-pass design.



3-Pass Boiler
Fig. 24

Packaged 3-pass firetube unit with corrugated furnace fitted with a travelling-grate stoker. The ash dumps into a submerged rear chamber. Inner tube bank forms the second pass, outer bank a third pass. Note the induced-draft fan.

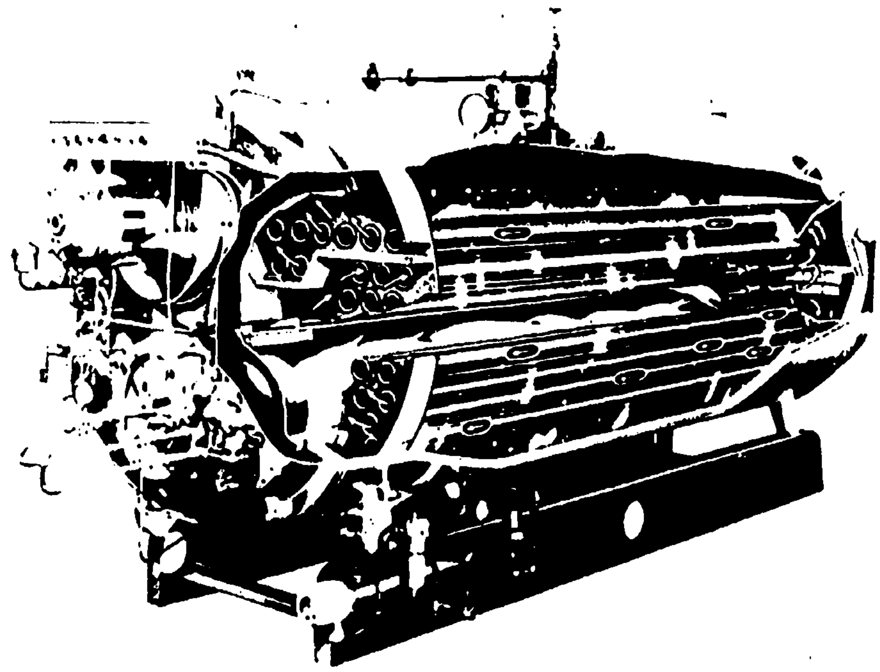
4 Pass Designs

In the effort to further increase the travel of gas from furnace to stack and hence increase efficiency, designers turn to the 4-pass construction. In some units the flow of gas is upward from the second-pass tubes into higher third-pass tubes and still higher fourth-pass tubes.

Other builders prefer the "downdraft" design in which flow is generally downward from second-pass tubes above the furnace tube. Downdraft construction allows the fourth-pass tubes to be between the bottom of the furnace and the shell, and facilitates the use of an induced-draft fan. This can be located on the base, at the front, where the fourth pass discharges in this type.

While careful proportioning of the tube surfaces is important in all units, it is obviously of greatest significance in the 4-pass design. To maintain high gas velocities throughout the extended travel path, builders decreased the total cross-sectional area of each succeeding pass. This is usually accomplished by reducing the number of tubes in each of the successive passes.

Fig. 25 illustrates the 4-pass design.



4-Pass Boiler
Fig. 25

For maximum travel of hot gas and high efficiency, the 4-pass design is employed. In this boiler, gas velocity is maintained by a decrease in the number of tubes to give each succeeding pass a smaller cross-sectional area.

Theoretically there is nothing to prevent the use of additional passes beyond four. The fact that four represents a practical current limit is an example of the economic balances that always concern the boiler designer. He must weigh the need for greater fan power, increased complexity of construction, perhaps a larger shell diameter and hence thicker shell plates against the performance advantages to be gained by going from two to three or to four passes. In like fashion, the boiler purchaser must weigh possible performance gains against possible higher first costs and strike the best economic balance for his conditions.

General Features

Thus far consideration has been given mainly to the boiler proper and particularly such items as furnace and tube arrangement, gas flow, etc. Now some characteristics will be considered which have been developed in recent years as applied to packaged firetube boilers.

A number of the construction changes reflect efforts to produce more compact and less costly packages. Skillful design has made it possible, however, to achieve these objectives while maintaining desirable performance characteristics. For example, the general tendency to make shells longer rather than larger in diameter has permitted the use of thinner plate and has made possible other advances in fabrication procedures that yielded economies in cost without in any way jeopardizing safety. Similarly, the use of welded construction has effected many economies and simplifications and at the same time increased structural integrity of the finished product.

More skillful use of heating surface with higher rates of heat-transfer makes it possible to secure more output from a given number of square metres of surface. Most of today's packaged units, for example, are designed to develop a boiler kW from $0.7\ m^2$ of heating surface.

One inevitable result of working heat exchange surfaces harder has been to make it imperative to keep both fireside and waterside clean. This puts a greater premium on good water treatment and on maintenance. More compact designs, however, tend to make surfaces less accessible for inspection and cleaning. Thus, builders have given increasing attention to improving access by means of larger openings and by hinging or davit-mounting rear heads and sometimes front heads including burners and controls. Modern units are encased and insulated so effectively that radiation losses have been reduced to a minimum.

Some packaged firetube units employ induced-draft fans, but the majority use forced draft, either integrated with the burner or mounted separately. Combustion-control equipment has been continuously improved, and an increasing number of units employ modulating control, some with plug-in type circuits for easy maintenance and replacement of parts. This means that major control repairs can be handled by the manufacturer in his shop rather than in the field.

(PE2-2-1-21)

Second Class
Sect. 2, Lect. 1

POWER ENGINEERING

1. Define the following terms:

    (a) Firetube boiler
    (b) Watertube boiler
    (c) Horizontal return tube boiler
    (d) Dry-back and wet-back Scotch boiler
    (e) Packaged boiler
    (f) Once-through boiler.

2. (a) Explain the theory of heat transfer.
   (b) Describe the heat transfer in a two-pass firetube boiler.
   (c) Describe the heat transfer in a three-drum Stirling type watertube boiler.

3. (a) Explain, with the aid of a sketch, the natural water circulation in a steam boiler.
   (b) Why is forced circulation a necessity for very high-pressure boilers.

4. Explain the following terms applied to water circulation in watertube boilers:

    (a) Circulation ratio
    (b) Top dryness.

5. Sketch and describe an energy flow diagram for a high-pressure steam generator.

6. Name the different heat transfer surfaces and explain their location in a large high-pressure steam generator.

7. Make front- and side-view sketches of a four-pass firetube boiler, showing position of baffles and tube banks.

8. Discuss the advantages and disadvantages of modern firetube boilers.

9. Describe in detail your own boiler plant or one with which you are familiar, stating manufacturer, type, capacity, and steam conditions. Include auxilliaries such as firing equipment, feed pumps, fans, ash removal equipment, etc.

(PE2-2-1-Q)

7.2

BOILERS -- WATERTUBE TYPE

Goal:

The apprentice will be able to describe types of watertube boilers.

Performance Indicators:

1. Describe straight and bent tube type boilers.
2. Describe horizontal and cross drum boilers.
3. Describe vertical, box and inclined headers.
4. Describe furnace baffles and refractory furnaces.
5. Describe waterwalls.
6. Describe stirling type boilers.
7. Describe lower drum/headers.
8. Describe drum internals.
9. Describe safety devices and practices.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.

* Read the vocabulary list to find new words that will be used in package.

* Read the introduction and information sheets.

* Complete the job sheet.

* Complete self-assessment.

* Complete post-assessment.

Vocabulary

* Bent tube
* Blow-off connection
* Box headers
* Cross baffles
* Cross drum
* Curved baffles
* Downcomers
* Drums
* Feedwater inlet
* Furnace baffles
* Horizontal drum
* Inclined headers
* Longitudinal baffles
* Lower drums/headers
* Packaged boilers
* Refractory furnace
* Risers
* Steam inlet
* Stirling type
* Straight tube
* Tube nipple
* Vertical headers
* Waterwalk

Introduction

Watertube boilers use their system of tubing to carry water instead of gases. The hot gases flow over the tubes and heat the water that is inside the tubes. Designers have improved watertube boilers during the past few years until they are very competitive with the firetube type. The need for high pressures have given the watertube boiler an advantage. A second advantage is the safety factor. Watertube boilers are not as dangerous when exploding. Normally they rupture a watertube internally rather than blowing out the entire boiler shell. The watertube boiler has greater flexibility and requires less space than firetube boilers of the same capacity.

Information

Watertube Boilers

Watertube boilers can be divided into two types:

1. Straight tube
2. Bent tube

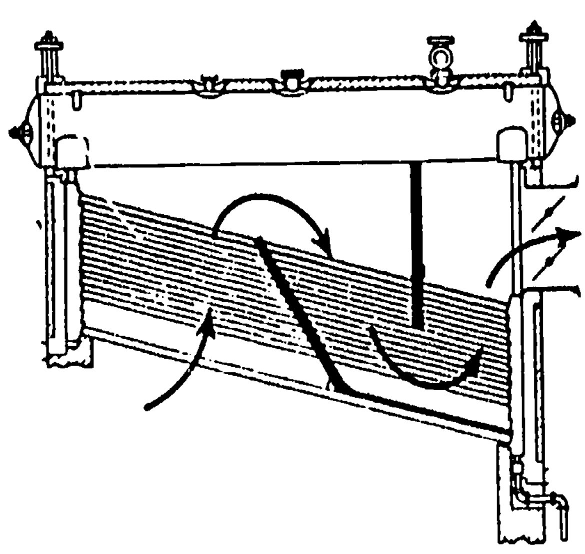
Straight tube boilers are not widely used in today's steam plants. Some old boilers of straight tube design are still in operation today but very few new ones are being made. The bent tube design has advantages that make it the popular choice. Drums are used to collect and separate water and steam. The bent tubes connect to the drums.

Packaged Watertube Boilers

A boiler that is shipped complete with fuel burning and draft equipment and automatic controls and accessories is a "packaged" boiler.

Horizontal Drum

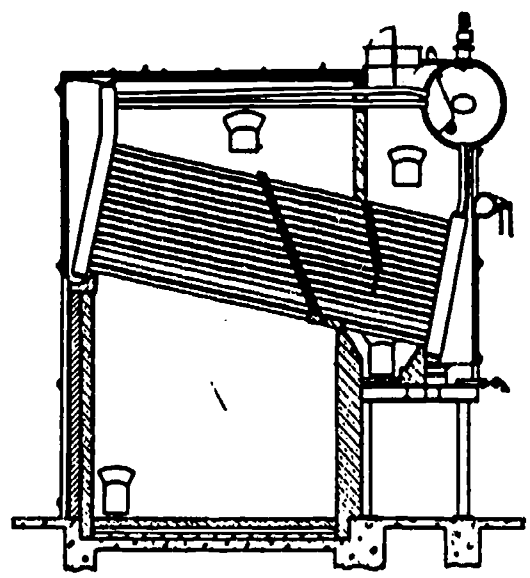
A horizontal drum boiler is one that has a drum that is located in a horizontal plane and lies in the same direction as the straight tubes. The tubes and mud drum are connected by a tube nipple. The drum is located overhead and collects steam from the tubes.



Information

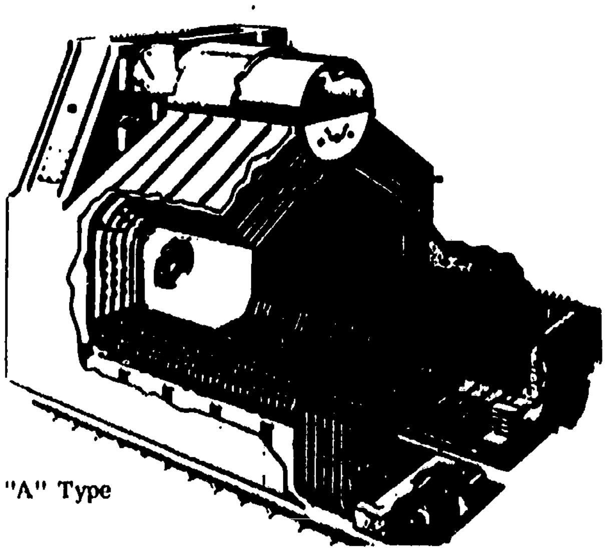
Cross Drum

The cross drum is another configuration for straight tube boilers. The drum lies at right angles to the tubes.

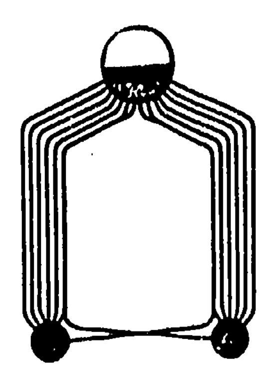


Bent Tube Boilers

Bent tubes allow more surface exposure to the heat. They can be built in configurations that give a more desirable size and can usually be built cheaper than a straight tube boiler. Older boilers may have four or five drums but new models use only one or two drums. Improvements in design and fluid handling have reduced the number of drums needed in a unit. A bent type of structure shows the tubes and rums arrangement.



"A" Type



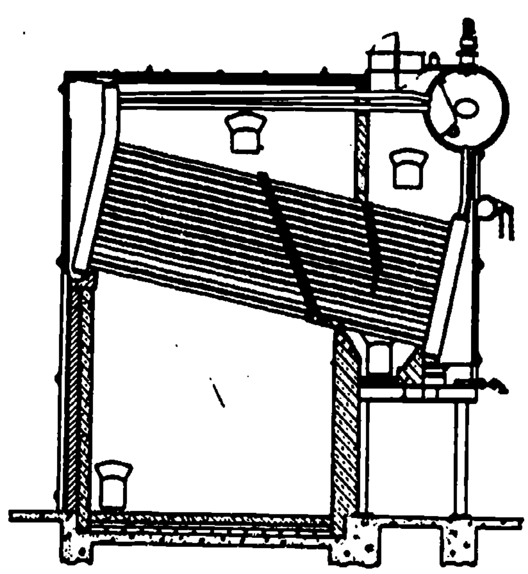
Information

Inclined Headers

Headers are found at each end of the watertubes. These headers carry the water back to the drum. The headers can be aligned in either a vertical or inclined position in relation to the tubes and drum. Inclined headers are usually associated with a cross drum arrangement of a straight tube boiler. A header is a manifold that collects water from the tubes and carries it back to the drums.

Vertical Headers

Vertical headers are used on both cross drum and horizontal drum designs. The tubes run between vertical headers which are connected to the drum.



Box Headers

Box headers are used in some of the older straight tube boilers. A box at the bottom of a header forms the mud drum of the boiler. Each header connects to the mud drum with a tube nipple. Box headers are formed in the shape of a box.

Furnace Baffles

Baffles are used to create a flow of gases back and forth over the tubes while the water makes the needed number of passes. Baffles are made of brick, tile or other refractory material. If placed so that gases flow at right angles to the tubes, they are called <u>cross baffles</u>. <u>Longitudinal baffles</u> cause gases to flow in parallel with the tubes. <u>Curved baffles</u> reduce the friction which cause eddy currents.

Information

Refractory Furnace

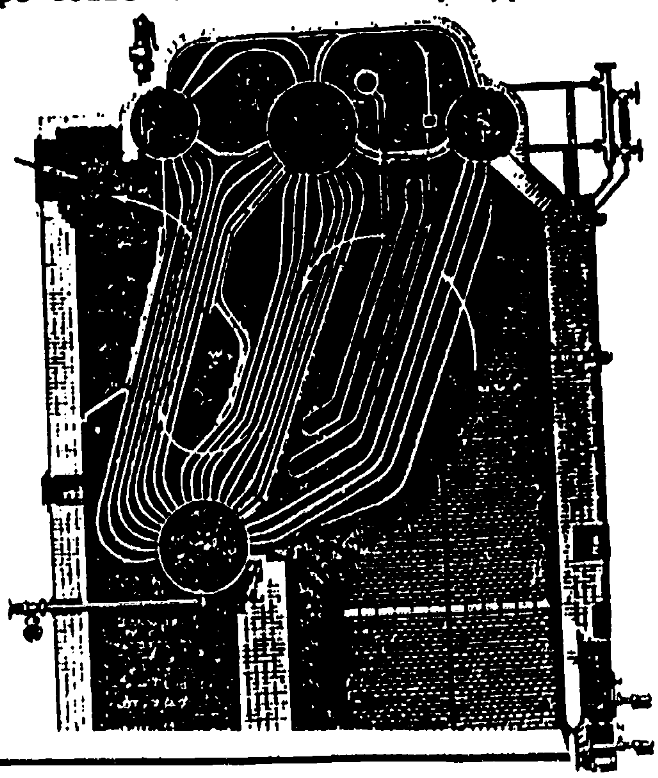
A refractory furnace is one that is lined with brick or other refractory material.

Waterwalls

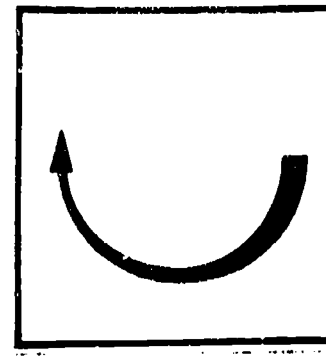
Waterwalls or water legs are often used to provide a heat absorbing surface about the furnace. It serves the same purpose as brick in a refractory furnace. Almost 50% of the total furnace heat is absorbed by the waterwall. Waterwalls are also used to surround the tubes and carry steam to the top drum. As water and steam rise from the mud drum upward to the drum, convection tubes serve either as risers or downcomers. The risers carry steam upward to the drum. Downcomers carry water and steam downward to the mud drum and it is recirculated. A waterwall captures much of the furnace heat and uses it in the formation of steam.

Stirling Type Boiler

The Stirling type is a four drum bent tube boiler. The boiler has three upper drums and a mud drum. The upper drums are connected to the mud drum by bent watertubes. The upper drums are partially filled with water. The drum space above the water level is used to capture steam. A steam outlet and safety valves are part of the upper drum arrangement. Also a feedwater inlet is part of the upper drum. The Stirling type boiler has a refractory type furnace. The mud drum contains water.

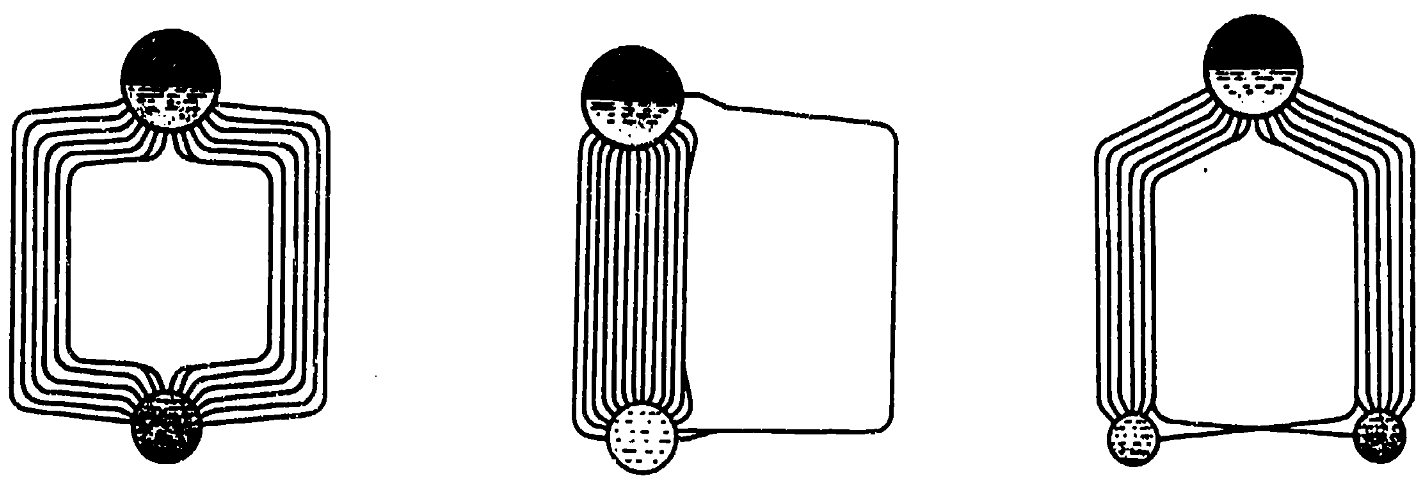


Information



Lower Drums Headers

On many new models of watertube boilers, the lower drums are completely filled with water. Actually they serve as headers to direct water into the risers and collect water from the downcomers.

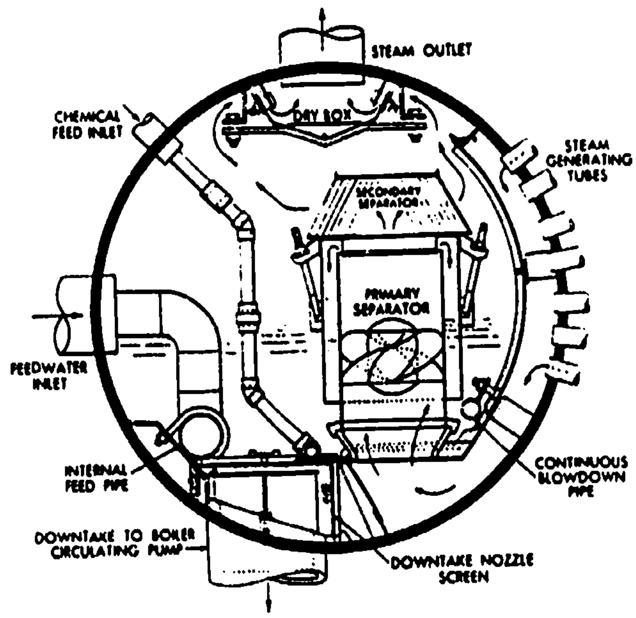


"O" Type "D" Type "A" Type

Drum Internals

Several devices are installed inside the steam drum of the boiler. Among those devices are steam separators, steam washers, chemical feed lines, boiler feedwater lines and blow-off lines. Steam separators separate the water and steam that enters the drum through the risers. Some separators use centrifugal force to separate the water from steam. Others use plates and baffles to separate the moisture. Primary separators are often of the cyclone type with a corrugated scrubber for a secondary separator. Steam washers rinse the steam between primary and secondary separations. Washing gets rid of vaporized silica which will foul turbine blades. An internal feedline distributes feedwater within the drum. A perforated pipe that distributes chemicals to prevent scale and corrosion is part of the drum internals. Blow-Off lines are of two types. A continuous blow-off line is located well below the water line and draws off sludge. A surface blow-off line is used to extract impurities at the water surface.

Information



Safety Devices and Practices

A boiler excplosion creates danger from flying parts from the steam force. When the drum ruptures, some of its water is converted to steam. The volume of water in the drum determines the force of the explosion--not pressure of the boiler. The watertube boiler is much safer than the firetube boiler in regard to explosions.

Safety valves prevent the boiler from exceeding pressures for which it was designed. Code requires that each boiler have at least one safety valve and more if the heating surface exceeds 47 square meters.

Pressure relief valves are another type of safety device. It is triggered when pressures exceed a preset level.

Each superheater is required to have at least one safety valve.

The operator can maintain a safe operation by:

1. Assuring that the boiler design conforms to ASME code for construction.

2. Following specific safety instructions of the boiler manufacturer.

3. Assuring that safety equipment and controls are responsive to changing conditions.

Assignment

* Read pages 1 - 27 in supplementary reference. Pay close attention to illustrations.

* Complete job sheet.

* Complete self-assessment and check answers.

* Complete post-assessment and have instructor check answers.

Job Sheet

INSPECT A WATERTUBE BOILER

* Locate and secure permission to inspect a watertube boiler.

* Examine the boiler and its components.

  - What is the drum arrangement?
  - Is it straight or bent tube type?
  - Does it have headers? What type?
  - Does it have waterwalls?
  - Is the furnace lined with refractory material?
  - Can you locate the feedwater inlet?
  - Can you locate the steam outlet?
  - Can you locate the blow-off connection for boiler cleaning?

* Write a short description of the boiler: Manufacturer, type, descriptive features.

* Check description with instructor to make sure that your observations were on target.

Self Assessment

1. Water and steam are collected and separated in the __________.

2. A boiler that comes complete with automatic controls, fuel burning and draft equipment is called a __________ boiler.

3. A boiler that has a drum lying at right angles to the watertubes is called a __________ __________ type.

4. A __________ __________ boiler allows the watertubes more surface exposure to the heated gasses.

5. A __________ is a manifold that collects water from the tubes and carries it back to the drum.

6. __________ are used to divert the flow of gases back toward the watertubes.

7. A __________ uses water to absorb the heat of the furnace.

8. __________ tubes carry steam upward to the drum.

9. __________ tubes carry water and steam downward to the mud drum.

10. The Stirling type boiler has a __________ type furnace.

Self Assessment Answers

1. Drum
2. Packaged
3. Cross drum
4. Bent tube
5. Header
6. Baffles
7. Waterwall
8. Risers
9. Downcomers
10. Refractory

Post Assessment

Match the following terms and phrases

______ 1. Header

______ 2. Waterwall

______ 3. Cross drum

______ 4. Bent tube

______ 5. Drum

______ 6. Stirling type

______ 7. Riser

______ 8. Downcomer

______ 9. Blow-off connection

______ 10. Steam outlet

A. Collects and separates water and steam.

B. Lies at right angle to watertubes.

C. Allows more surface exposure of tubes to heat.

D. Acts as a manifold that collects water from tubes and returns it to drums.

E. A waterfilled tube or column that surrounds the furnace area.

F. Fitting in mud drum.

G. Fitting in upper drum.

H. Carries water and steam downward.

I. A four drum bent-tube boiler with three upper drums and a mud drum.

J. Carries steam upward.

Instructor Post Assessment Answers

D	1.
E	2.
B	3.
C	4.
A	5.
I	6.
J	7.
H	8.
F	9.
G	10.

Supplementary References

* Correspondence Course, Lecture 2, Section 2, Second Class. Steam Generators. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATORS

Second Class
Lecture 2

TYPES OF BOILERS II

WATERTUBE BOILERS

Watertube boilers came into extensive use in the 19th century but the changes in design which have occurred since that time, and more particularly in the last 25 years, have left little similarity between those old boilers and the present-day steam generators.

The following pages trace these developments and give illustrations of some typical boilers.

Advantages of Watertube Boilers

The comparisons given below are between watertube and Scotch type firetube boilers for equivalent output ratings.

1. Saving in Mass
   The relative mass of Scotch to watertube boiler installations for equivalent m^2 of heating surface with water at working level is approximately 3 to 1.

2. Use of High Pressures
   The demands of steam-driven machinery for ever-higher pressures and temperature could only be met by the use of watertube boilers with their small steam drums. The limit of working pressure for Scotch boilers for practical reasons, such as shell thickness and lack of flexibility, is limited to about 1725 to 2070 kPa.

3. Greater Mechanical Flexibility

The boiler is not so sensitive to fluctuating pressures. The Scotch boiler. with its poor circulation, especially when raising steam, is very prone to mechanical straining and subsequent grooving in its many flange attachments. These defects do not exist in the watertube boiler with its rapid circulation and structural flexibility.

4. Rapid Steam Raising

The superior heat-transfer qualities together with positive circulation reduce the time required for raising steam in a watertube boiler to a fraction of that required by a Scotch boiler.

5 Saving in Space

The good circulation and ability to withstand forcing and higher pressures enable high outputs to be obtained from watertube boilers of very small dimensions when compared to the Scotch type.

Note that some of the above comparisons are not so sharply defined in the case of modern packaged firetube boilers.

6 Safer in the Event of Serious Rupture

The damage done when a boiler explodes is due to the propulsion of the boiler parts by the issuing steam jet. The steam jet itself is produced from the body of water in contact with the failed drum. Collapse of pressure causes a proportion of the water to flash off into steam.

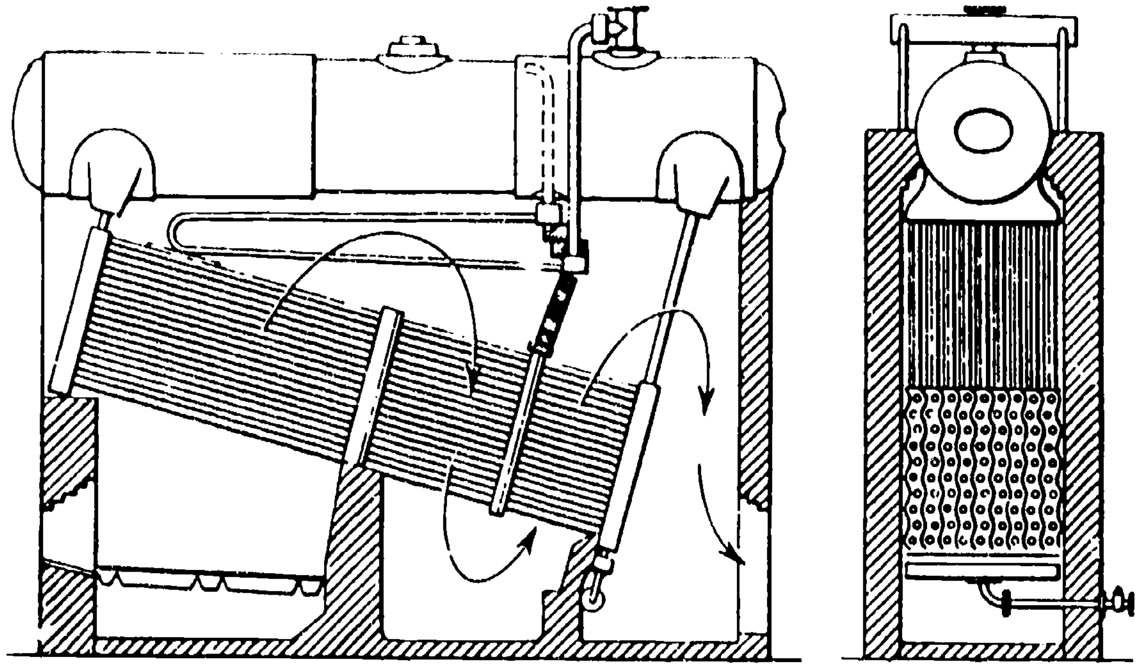
So it can be argued that the potential danger which a steaming boiler presents is proportional to the quantity of water in any one of its drums Note that the pressure makes little difference; the vital item is water quantity. Hence a watertube boiler, even when operating at very high pressures is considerably less hazardous than a shell-type boiler having a much greater water content at a low pressure.

Types of Watertube Boilers

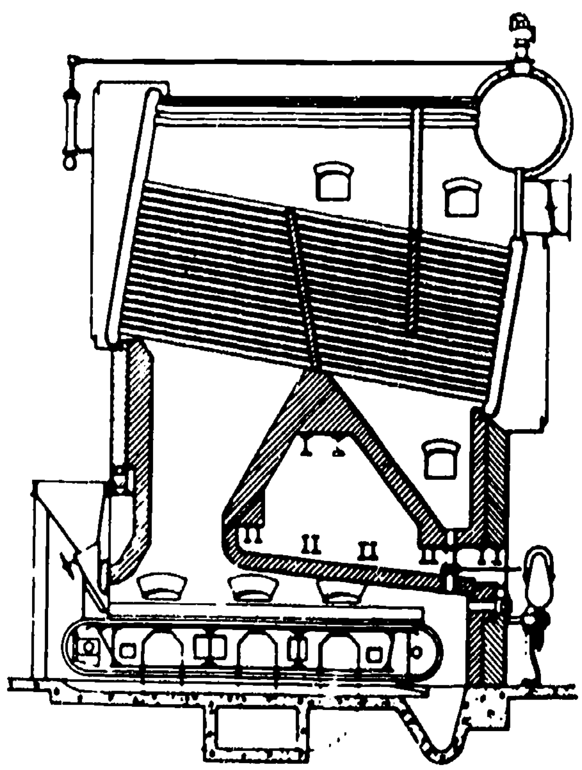
Watertube boilers at one time could be divided into "straight-tube" and "bent-tube" types. However the bent-tube designs have been so universally adopted that "straight-tube" watertube boilers are very rarely, if ever, built today

Fig. 1 shows an early watertube boiler design. This is an inclined (straight) tube design, with sectional-cast iron vertical headers. The transverse box at the bottom of the rear headers forms the mud drum. Each header is connected to the mud drum by a tube nipple. The vertical headers were usually "sinuous" to allow better tube spacing. This basic watertube boiler design was used extensively for almost a hundred years, many being still in service today.

Fig. 2 shows another old design fired by a travelling grate stoker. In this case the steam drum is set at right angles to the axis of the tubes.



Early BABCOCK Boiler
Fig. 1



Cross-drum Box-header
Fig. 2

This early design was fired by a travelling-grate stoker. Note the suspended furnace arches and refractory walls.

(PE2-2-2-3)

Bent-tube boilers were found to be more flexible in their design requirements. Where headroom is limited they can be made wide and low, or narrow and high where floor space is at a premium. Also, bent-tube boilers allow more of the surface to be exposed to radian heat of the furnace. As a final factor, they can be built at a lower cost.

Drums serve as convenient collecting points in the steam-water circuit and for separation of steam and water. Thus, boilers with two, three and sometimes four drums were popular up through the mid 1920's. Fig. 3 shows a bent-tube type.

As boilers grew in size, the demand for more active furnace cooling increased. It was then that waterwalls and other changes in design came into the picture. A better knowledge of fluid dynamics resulted in improved methods for the calculation and monitoring of circulation of waterwall fluids - both on the gas side and the steam side. In short order, it became practical to eliminate one, sometimes two drums. Two-drum boilers, even boilers with only one drum at the top and one or two large headers at the bottom, became common designs; one is shown in Fig. 4.

Thousands of boilers of the vertical-header type and of the multi-drum bent-tube variety are still operating satisfactorily today. Many feel that the average life of a well-designed, properly installed and adequately maintained boiler can be as much as 50 years.

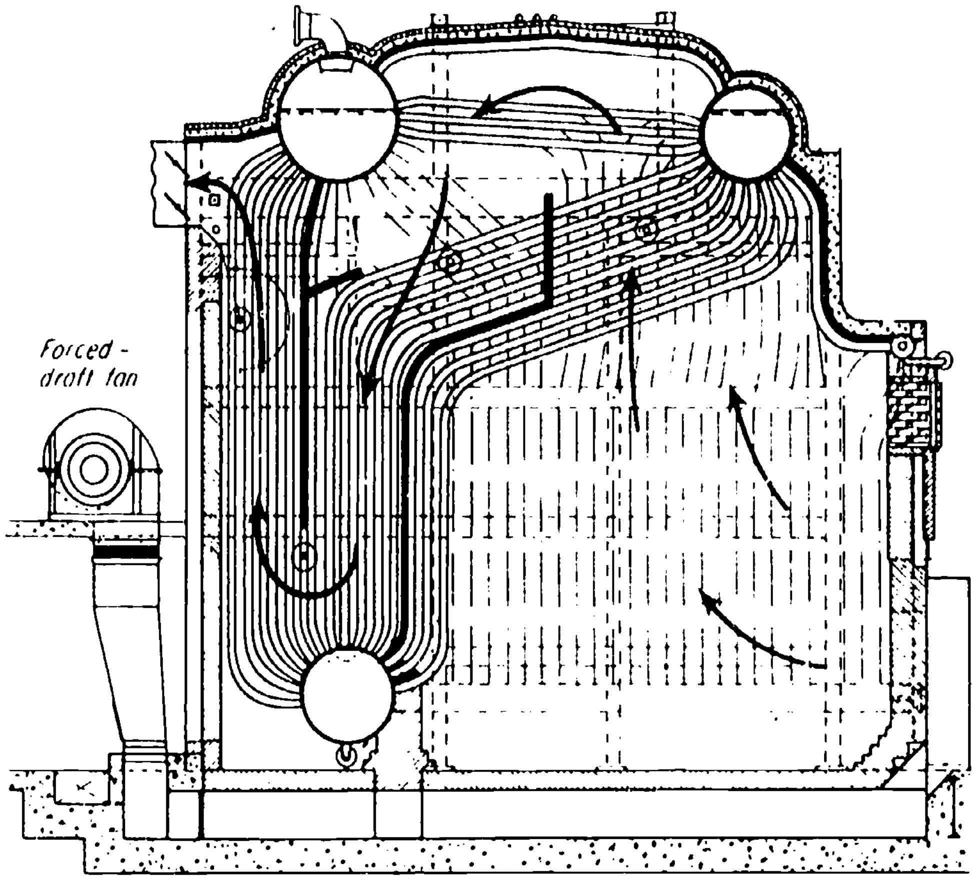
Modern designs have eliminated the rivetting of boiler seams and the use of cast-iron for header boxes. Welding replaced rivetting for boiler construction in the early 1930's. Welding methods have improved significantly; today, covered electrodes are used for continuous automatic metal deposition.

The use of furnace water-wall surfaces has been extended to provide maximum utilization of radiant heat. Exposed refractory surfaces have been reduced to a minimum and often replaced altogether by either tangent tube walls or membrane walls.

Boiler casings are being made more air and gas-tight and there is a trend towards pressurized furnaces and elimination of the induced draft fan. There is increasing use being made of heat recovery equipment, air heaters, economizers, etc. in a continuing endeavour to produce more and more efficient steam generating units.

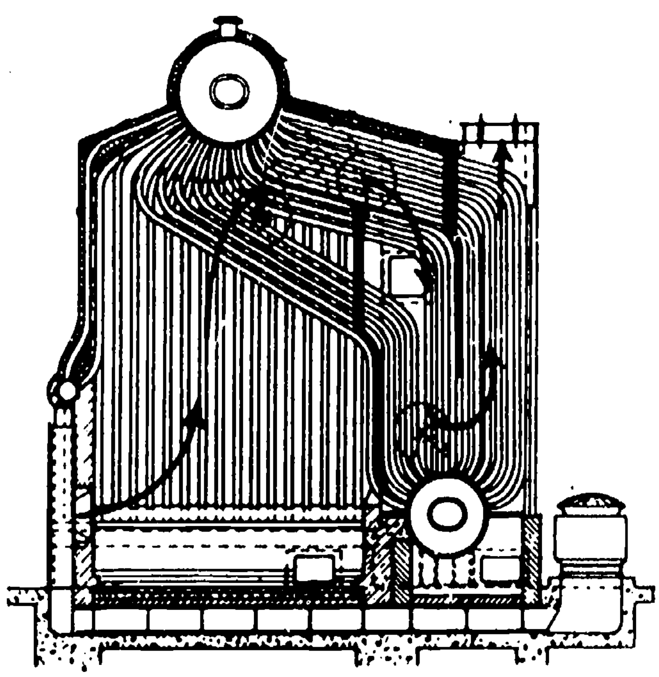
Fig. 5 shows a watertube boiler design by Babcock and Wilcox. Maximum continuous steam capacity 454 000 kg/h at 10 700 kPa and 538°C. This steam generator is fired by a cyclone furnace and designed for pressurized firing.

Lecture 3 will discuss the separate sections such as furnace firing equipment, superheaters, etc. in boilers of this type.



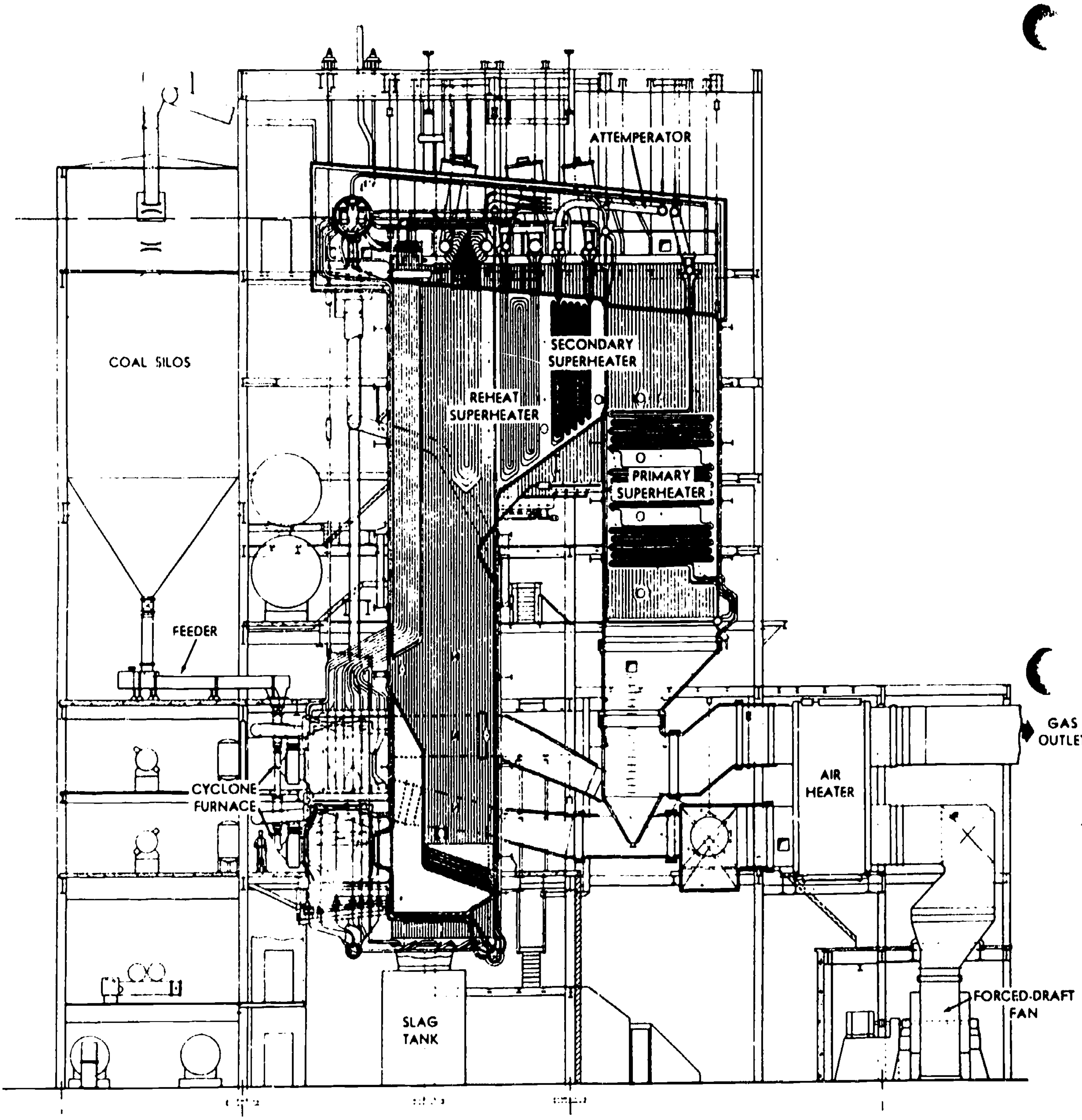
Bent-tube Boiler
Fig. 3

This bent-tube type, using all-steel construction, first became popular around the turn of the century. By moving the relative position of their two, three and sometimes four drums, they are quite flexible and are readily adapted to a variety of space limitations.



Two-drum Boiler
Fig. 4

Water-cooled furnace walls were developed because of the increasing rate of heat release in the furnace proper. Water from the drum is supplied to lower header. Steam, actively generated in the walls, rises to upper drum where it separates from boiler water. (PE 2-2-2-5)



Watertube Steam Generator - pressurized Cyclone-furnace fired. <u>Fig. 5</u>

Maximum continuous steam capacity, kg/h	454 500
Design pressure, kPa	12 070
Pressure at superheater outlet, kPa	10 700
Final total steam temperature, °C	540
Reheat steam temperature, °C	540
Feedwater temperature to boiler, °C	238

(PE2-2-2-6)

Packaged Watertube Boilers

Packaged boilers began to appear on the market in the late 1940's and have grown in popularity at an extraordinary rate. By definition this is

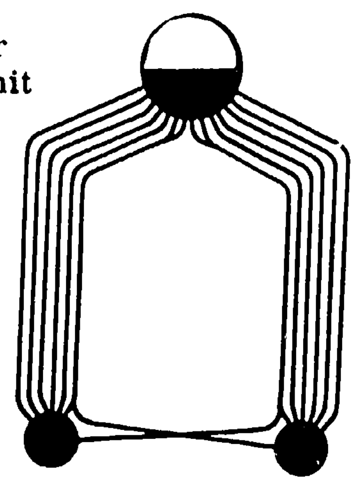
A BOILER EQUIPPED AND SHIPPED COMPLETE WITH FUEL BURNING EQUIPMENT, MECHANICAL-DRAFT EQUIPMENT, AUTOMATIC CONTROLS AND ACCESSORIES

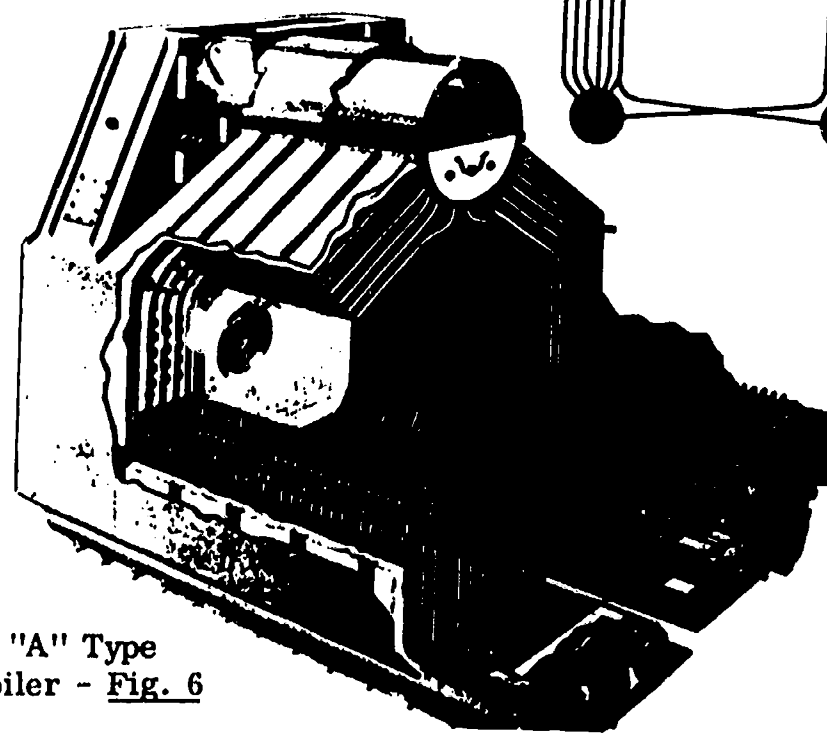
It has many inherent advantages particularly when it is to be installed in a remote location. The boiler is completely erected on its bedplate and tested, together with all auxiliaries before being dispatched from the manufacturer's plant. The on-site work is thus reduced to a minimum and consists only of positioning and making steam, water, drain, electrical and stack connections.

Packaged watertube boilers are available in ratings up to 45 000 kg/h and 5000 kPa. The great bulk of these units however are in the ratings 7000 to 36 000 kg/h.

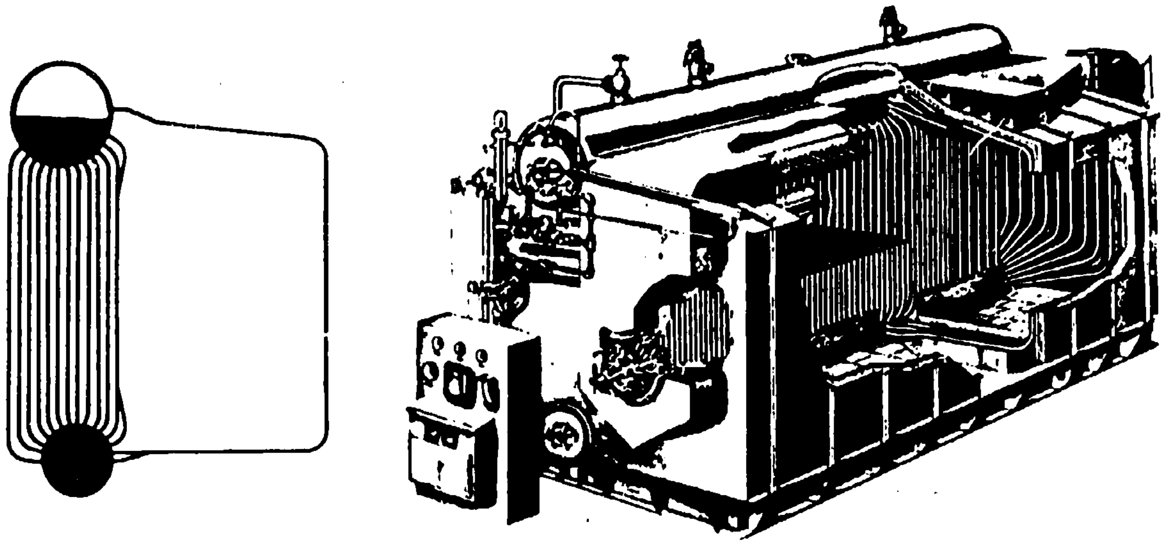
Most of these boilers follow one of the structural configurations shown in Figs. 6, 7 and 8.

The "A" type has two small lower drums or headers. The upper drum is larger to permit separation of water and steam. Most steam production occurs in center furnace-wall tubes entering the drum.



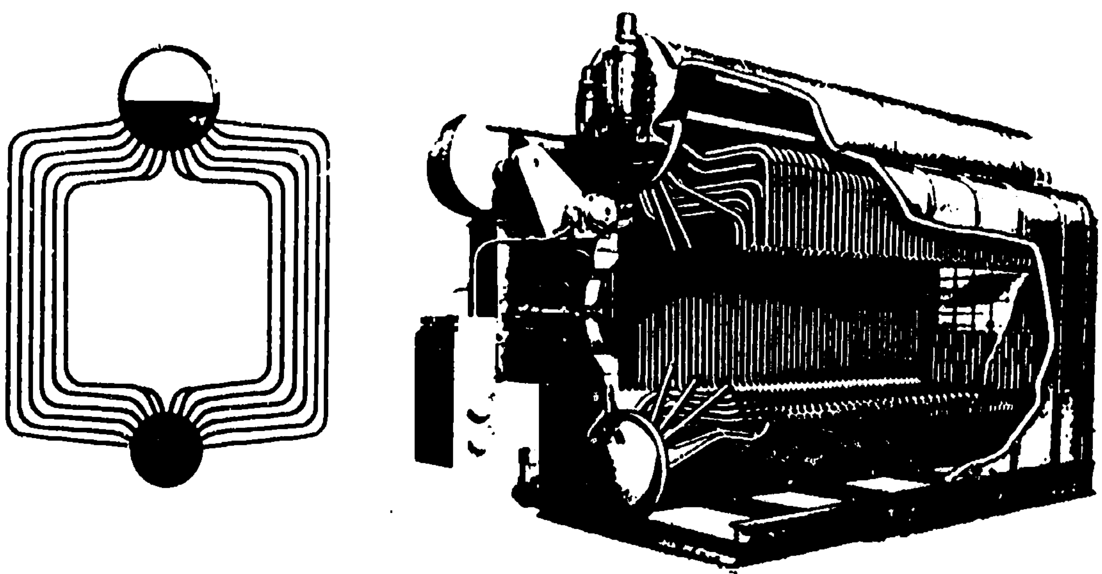


"A" Type
Boiler - Fig. 6



"D" Type Boiler
Fig. 7

The "D" type allows much flexibility. Here the more-active steaming risers enter the drum near the water line. Burners may be located in the end walls or between tubes in the buckle of the "D", at right angles to the drum.



"O" Type Boiler
Fig. 8

The "O" type is also a compact steamer. Transportation limits the height of the furnace, so for equal capacity, a longer boiler is often required. Floors of "D" and "O" types are generally tile-covered.

(PE2-2-2-8)

The "A" type, Fig. 6, has two small lower drums or headers. The upper drum is made large to permit separation of water and steam. Most of the steam production occurs in the centre furnace wall tubes.

The "D" type, Fig. 7, allows much flexibility of design since the combustion chamber volume can be easily varied. The more active steaming tubes become risers and enter the drum near the water line. The boiler is fired between the outer "D" tubes either at the end or at the side, the tubes being bent to allow the burner entry. Superheaters and economizers can be added to the "D" type radiant or convection zone with relative ease.

The "O" type, Fig. 8, has a symmetrical design but exposes the least tube surface to radiant heat.

Manufacturers tend to standardize package boiler designs with regard to the outside dimensions of width and height and to vary the length according to the required boiler output rating. This is largely dictated by the size limitations imposed on rail or road transportation.

Shop-assembled Boilers

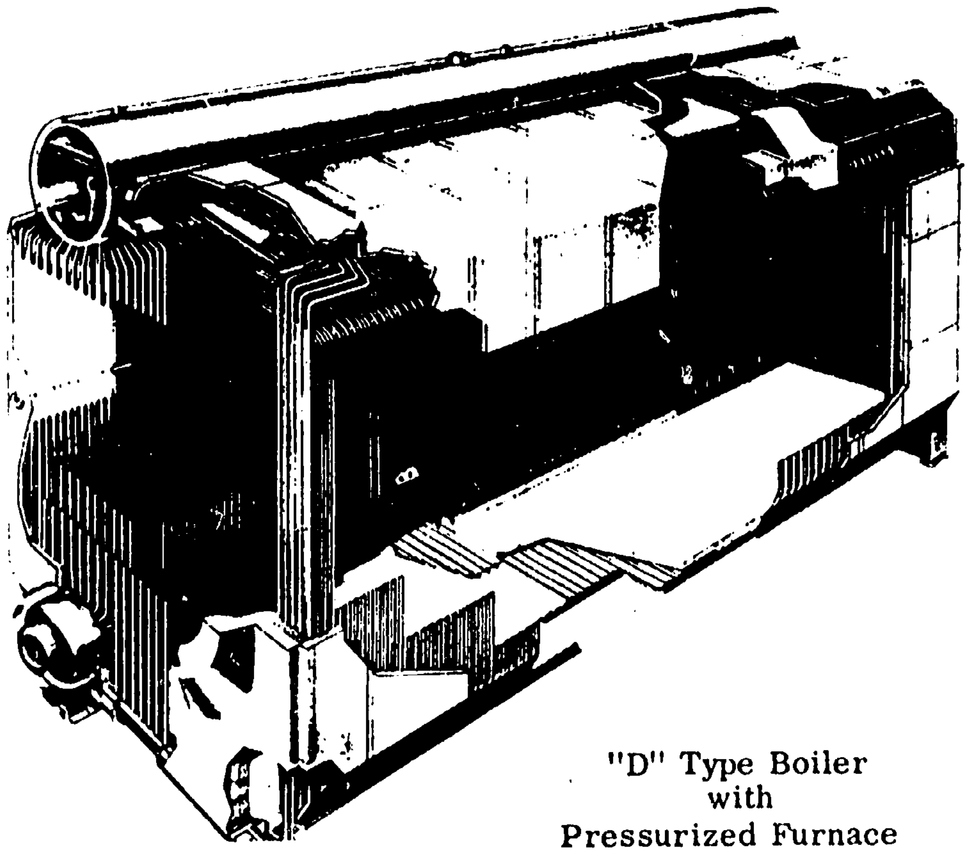
These are technically the same as packaged units since they are completely assembled at the manufacturer's plant together with all of their auxiliaries and controls. The name is customarily applied to the biggest of the packaged boilers where each one is built to a customer specification as regards required output, types of fans, burners, pumps and controls etc.

All of the packaged and shop-assembled boilers have the advantage of lower cost compared with field-erected boilers of equivalent rating, some engineers estimating that the field-erected boilers' cost is double that of the packaged unit.

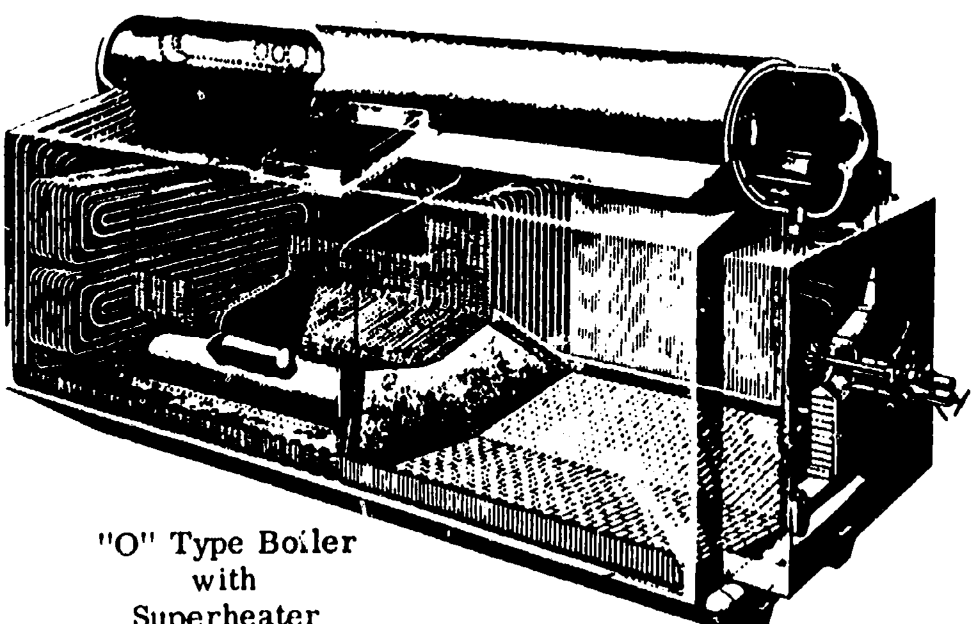
Figs. 9 and 10 are further examples of "D" and "O" type packaged boilers respectively.

Fig. 9 is pressurized, no induced fan is used. A convection superheater is located in the gas flow and the boiler can be built to give an output of up to 45 000 kg of superheated steam/h at up to 400°C.

Circulation pattern of water, steam and gases may be readily traced on this boiler. From mud drum and lower headers, water and steam rise in finned waterwalls and enter the drum near its water line (note the drum internals). Some of the convection tubes above the mud drum act as downcomers, the rest serve as risers. Gases from the burner at left (not shown) make a 180° turn at the far left end of the furnace, enter the convection zone of the boiler between nontangent, nonfinned tubes. They leave the boiler at the front left.



"D" Type Boiler
with
Pressurized Furnace
Fig. 9



"O" Type Boiler
with
Superheater
Fig. 10

(PE2-2-2-10)

As an alternate in some designs, gases turn into an additional pass toward the rear. This rerouting is accomplished by a baffle made of refractory or simply tangent tubes. Superheater and economizer can be easily installed in the convection portion of this unit. The furnace floor is tiled.

The compact "O" type unit shown in Fig. 10 is skid-mounted. This packaged boiler may generate over 45 000 kg/h of superheated steam/h at a maximum of 5350 kPa and 400°C.

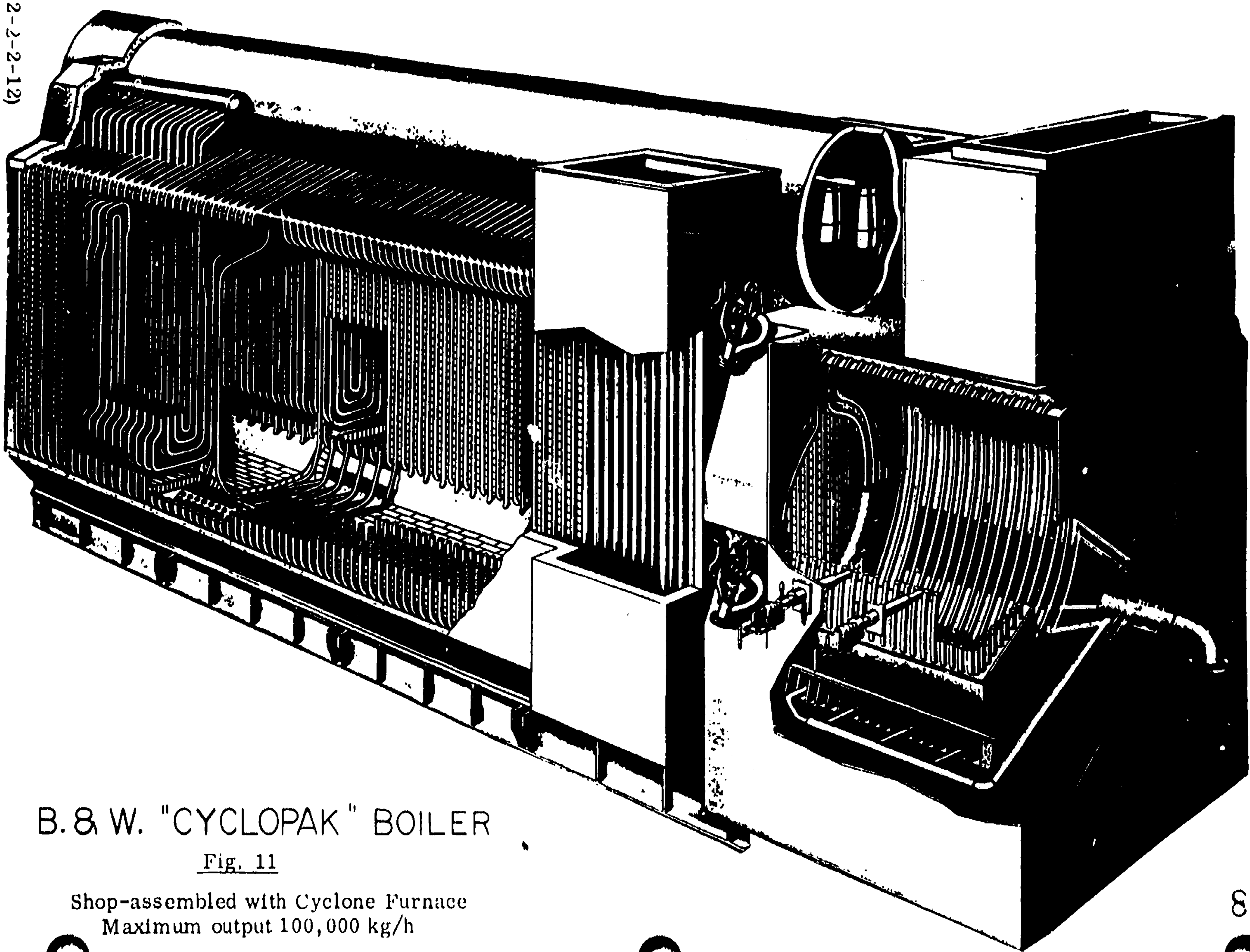
Note the double-steel casing and cyclone-type drum internals to assure drier steam. Convection superheater is located at a point where the flow of gases, directed by finned-tube water walls, splits into two parts. Each turning point of 180° directs the flow toward a flue-gas exit located on either side of the upper drum.

A forced-draft fan (not shown) may be located at any convenient place. The furnace is pressurized and no induced fan is required. Four soot blowers, two per bank, serve to keep convection banks clean. The symmetrically-arranged surface is designed for balanced heat absorption. Tubes are arranged in rows with alternate wide and narrow spacing.

The design trend in packaged or shop-assembled boilers is towards greater outputs, using higher heat-release rates, bigger drums and headers to facilitate steam separation and inspection, and the addition of superheaters and economizers.

One BABCOCK and WILCOX design incorporates a cyclone burner for oil or gas. The burner is a fully water-cooled cylinder and is claimed to give stable combustion over a 10 : 1 load range. Steam purity is attained through the use of cyclone separators and steam scrubbers. Output ratings up to 90 000 kg/h at 61 200 kPa and 442°C final steam conditions are achieved.

Fig. 11 shows the Babcock and Wilcox "CYCLOPAK" Boiler.



B.& W. "CYCLOPAK" BOILER

Fig. 11

Shop-assembled with Cyclone Furnace
Maximum output 100,000 kg/h

Field-erected Watertube Boilers

Recent developments in boiler design and construction have promoted the sale of packaged boilers to supply the demands of industry, for steam rates up to about 45 000 kg/h or even higher in some special cases.

Boilers with steam rates above this figure generally become too large for transport to site in one piece, and as a result have to be field-erected. The principle of shop assembly or prefabrication of parts is not abandoned altogether however, and it is found that large sections of water wall, superheaters and economizers are being completed in the manufacturer's plant and then shipped to the site for erection.

The great majority of field-erected boilers at the present day are of large output though there still remain a few applications where because of difficulty of access or some other special reason a small field-erected boiler is the best solution.

Boiler outputs seem almost to have no limit particularly in the field of electricity generation. The biggest on record to date is that built for Consolidated Edison Company to supply steam to a 1000 MW turbo-generator in that Company's Ravenswood Station. Steam rate is 2 900 000 kg/h with stop-valve conditions of 19 000 kPa and 538°C. This exemplifies the trend which has been followed in post-war years of matching boiler output to turbo-generator demand and producing "unit" electricity generating sets. Boiler outputs are in fact commonly referred to by the MW rating of the turbine set with which they will be "unitized". This gives a truer picture of the boiler size than a rating quoted in kg/h of steam leaving the stop valve because of the large reheat sections included in these boilers.

Boilers designed for use in thermal generating plants have necessarily followed the preferred standard sizes of steam turbine generators issued by the A.S.M.E. and A.I.E.E. These standards were adopted in post-war years with the object of allowing manufacturers to concentrate on a few standard designs and so reduce the cost of production and speed-up delivery dates. The following are some of these standard ratings:

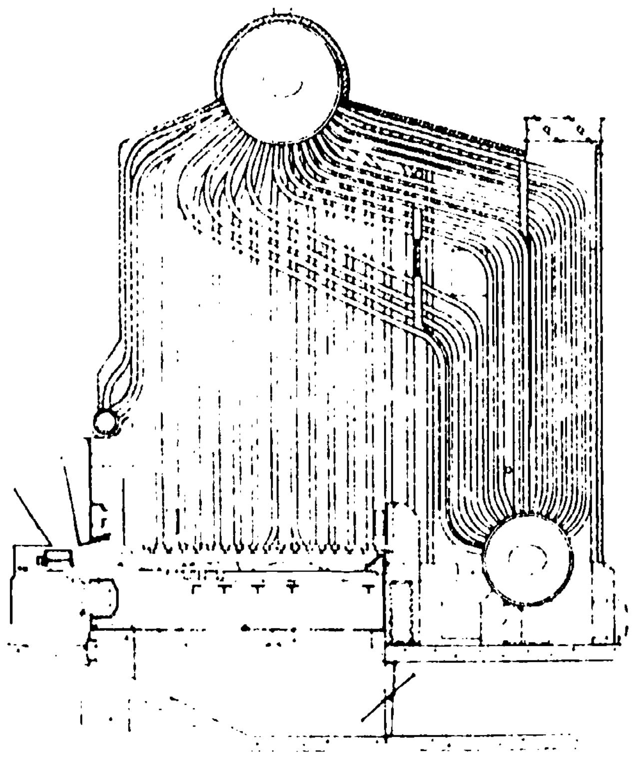
22 MW	at	5860 kPa	and	482°C
44 MW	at	5860 kPa	and	482°C
66 MW	at	8600 kPa	and	510°C
100 MW	at	10 000 kPa	and	538°C with one reheat to 538°C
150 MW	at	12 400 kPa	and	538°C with one reheat to 538°C

Industrial boilers for use in individual plants are of course designed to meet the needs of that particular plant and consequently do not follow any standard size pattern. The design of these boilers however follows similar lines to the thermal generating plant boilers in the tendency towards higher pressure steam, pressurized furnaces, increasing use of radiant heat and decreasing convection surfaces and maximum use of heat recovery devices.

There are many boilers designed for special purposes such as the recovery of waste heat in pulp and paper plants or sulphur recovery plants and these boilers have each to be designed for its particular service.

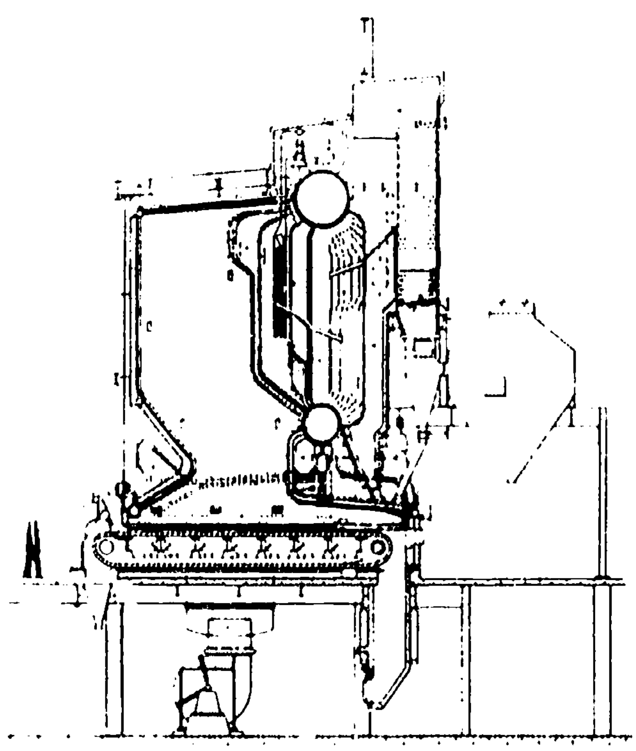
(PE2-2-2-13)

The following pages, Figs. 12 to 24, show a series of watertube boiler designs, typical of those used in the quoted boiler output range. (Figs. 12 to 17 are Combustion Engineering (C-E) Design.)



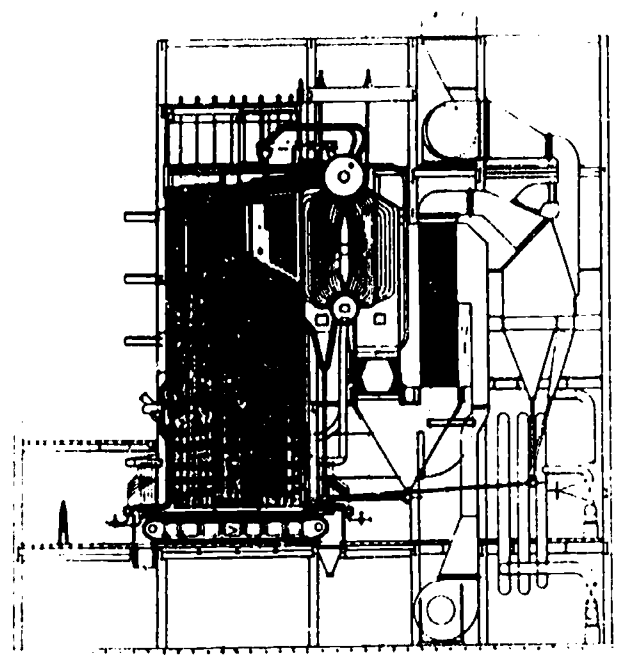
C-E Steam Generating Unit
Fig. 12

Type VU-10 fired by Type E Stoker (steam piston drive). Approximate capability range, 4500 kg/h to 18 000 kg/h of steam.

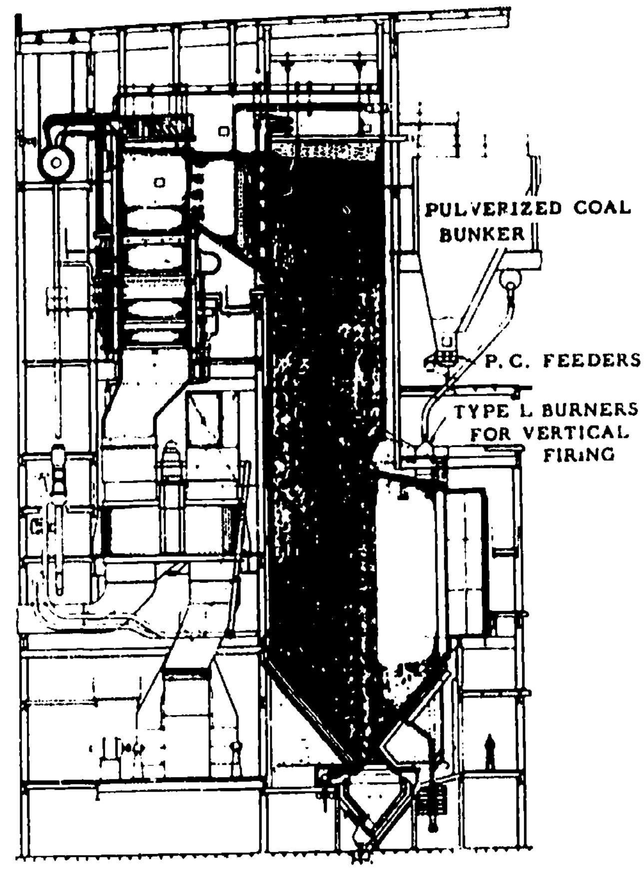


C-E Type VO-50 Boiler
Fig. 13

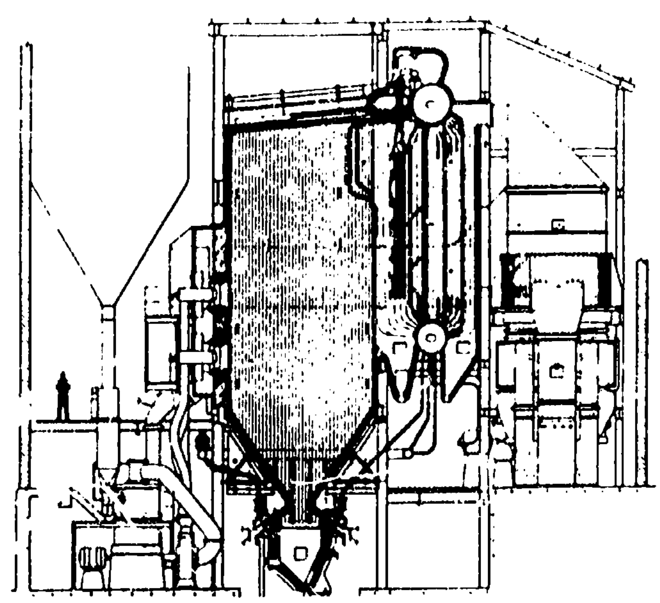
Fired by C-E travelling grate stoker burning bituminous coal. Capability 45 000 kg/h steam at 5860 kPa and 307°C.



C-E Type VU-40 Boiler
Fig. 14
with high-set spreader stoker, designed to burn bark, oil, natural gas and coal. Note baffle-less boiler (to avoid cinder erosion), cinder return to furnace, economizer and tubular air heater.

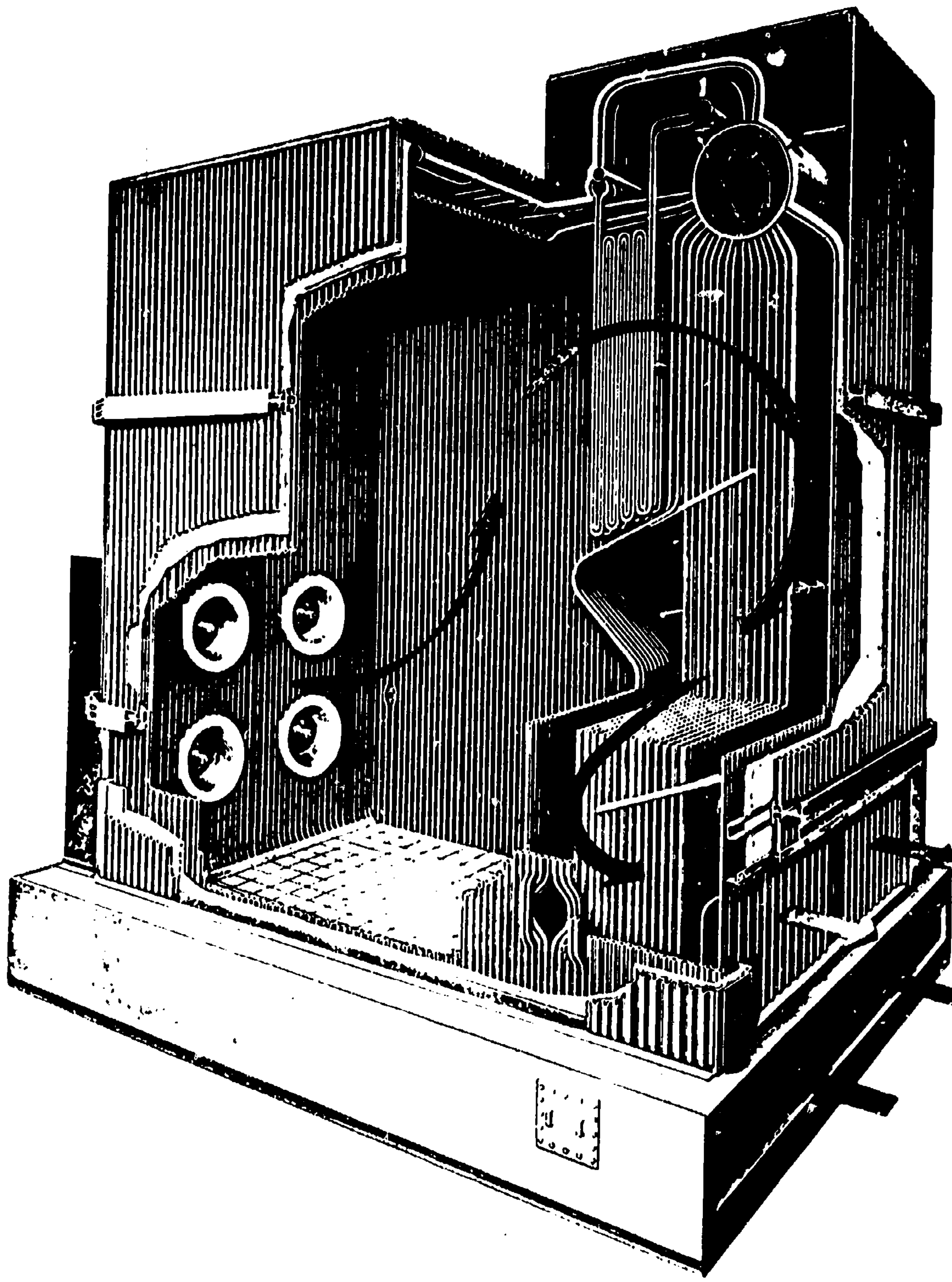


Indirect (Storage) System
Fig. 15
For burning Pulverized Coal



Direct Fired System
Fig. 16
For burning pulverized coal; C-E Raymond Bowl Mills and Type R (horizontal) Burners firing VU-50 Boiler, 79 000 kg/h steam at 5930 kPa and 440°C.

(PE2-2-2-15)

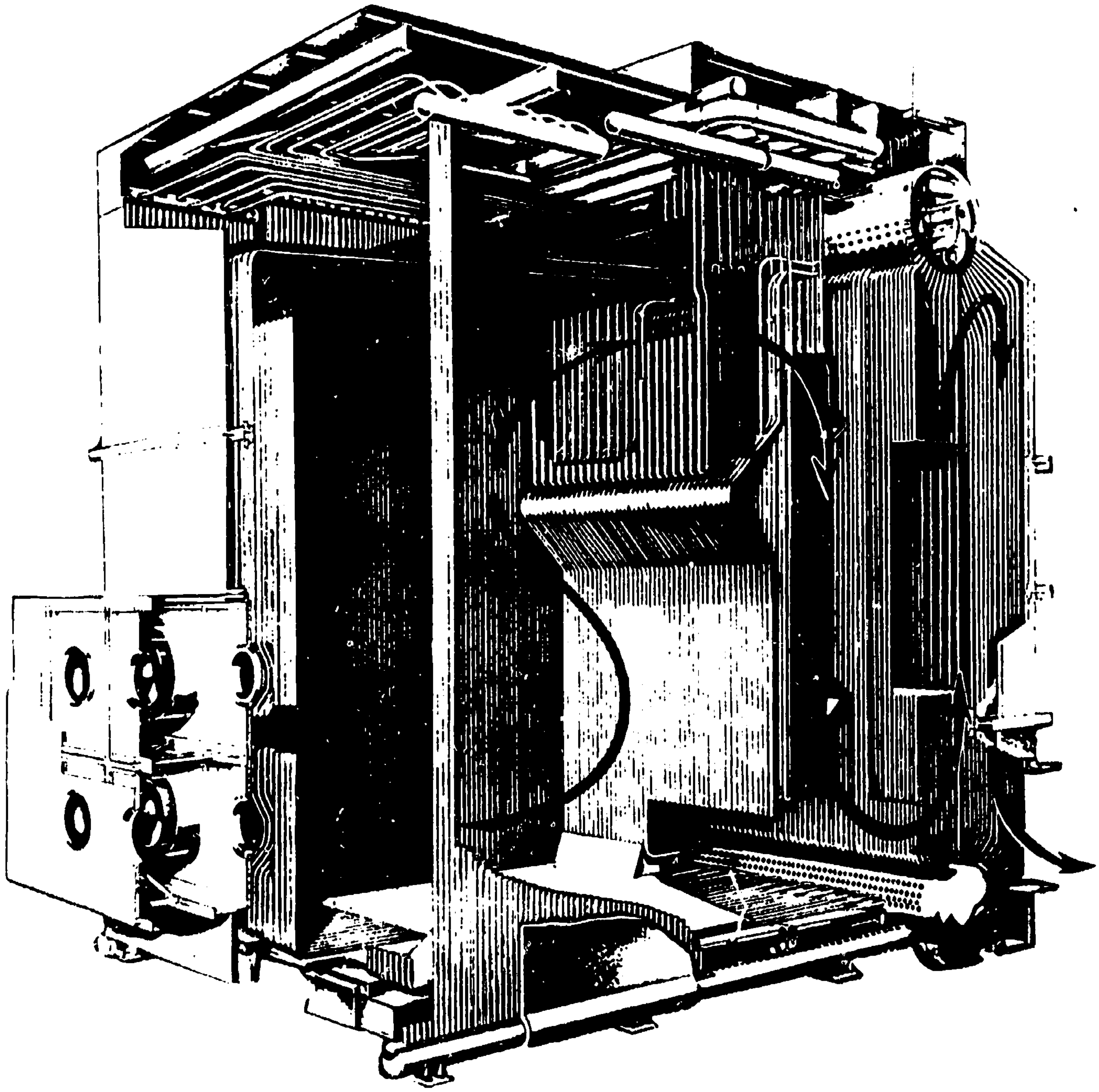


C-E VU-60 BOILER

fired by C-E Type R Horizontal Burners Fig. 17

Arrows on the main body of the sketch show the gas path through the unit. The crossflow design provides maximum heat absorption and virtual uniformity of temperature and flow of combustion gas across the width of the heating surface. Arrows to bottom right show air inlet to duct under the furnace floor tubes. This construction permits less overall unit height than is attainable in units using overhead air ducts. Up to 163 000 kg/h steam at 6550 kPa and 480^{o}C. Fuel-natural gas or oil.

(PE2-2-2-16)



FOSTER-WHEELER SERIES SD

Fig. 18

Single Furnace
Continuous capacity 227 000 kg/h at 10 350 kPa and 515^{o}C
Fuel - oil, gas or low-heat-value waste fuel

(PE2-2-2-17)

LEGEND
(referring to Fig. 19)

(1) MEMBRANE WALL FURNACE - gas-tight for high efficiency pressure firing. Membrane construction prevents gas-side corrosion. Completely water-cooled Integral Furnace gives balanced heat absorption, eliminates refractory maintenance.

(2) GENERATING TUBE BANK gains optimum heat transfer from horizontal cross-flow gas pattern. Arrangement of tubes makes possible effective soot-blower cleaning while the unit is in service.

(3) CYCLONE STEAM SEPARATORS deliver pure, dry steam for high turbine and process equipment efficiency. Steam-free water returned to boiler provides maximum circulating head. gives better control of drum water level during rapid load swings.

(4) SUPERHEATER combines radiant and convection surfaces to hold steam temperature virtually constant over wide load range. Inverted-loop design makes superheater drainable for quick. safe start-ups.

(5) OIL AND GAS BURNERS are centrally located for operator convenience. Versatile burner design permits single-fuel or combination firing. Easy fuel change-over permits operators to take advantage of favorable prices.

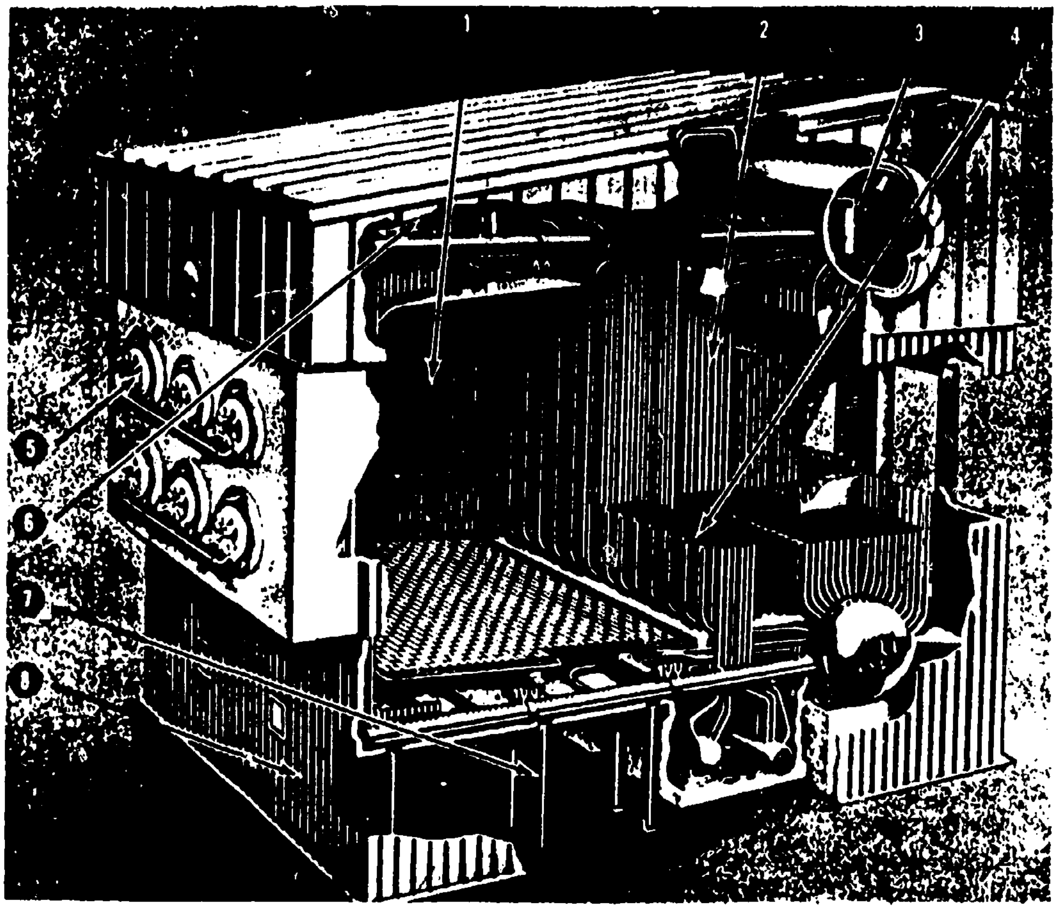
(6) INTEGRAL AIR DUCT cuts required boiler space and headroom, minimizes connecting ducts and flues. Full-width "plenum chamber" distributes combustion air uniformly to all burners.

(7) SIMPLE FOUNDATION SUPPORTS eliminates external steelwork.

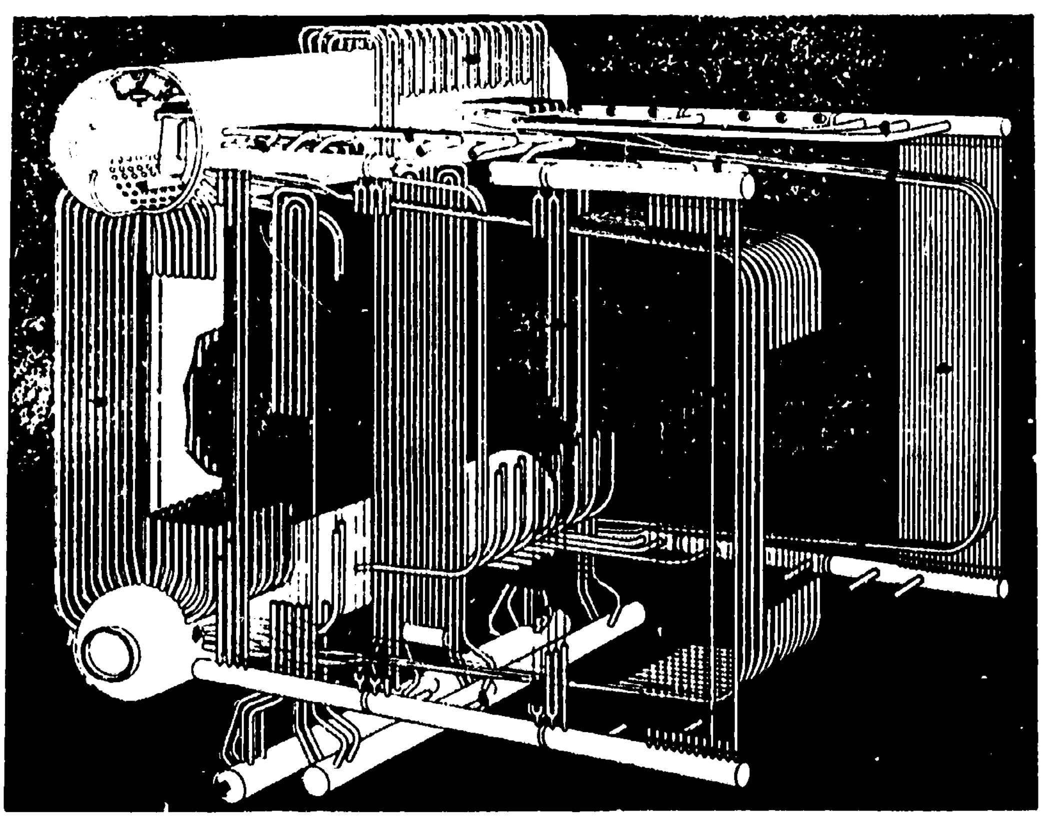
(8) STEEL CASING AND LAGGING covers the entire boiler and auxiliary equipment, making this boiler equally suitable for indoor or outdoor installation. Aluminum lagging is also available when desired.

Fig. 20 shows the circulation system in the "Power for Industry" boiler of Fig. 19. Note the superheater headers below the furnace floor.

(PE2-2-2-18)



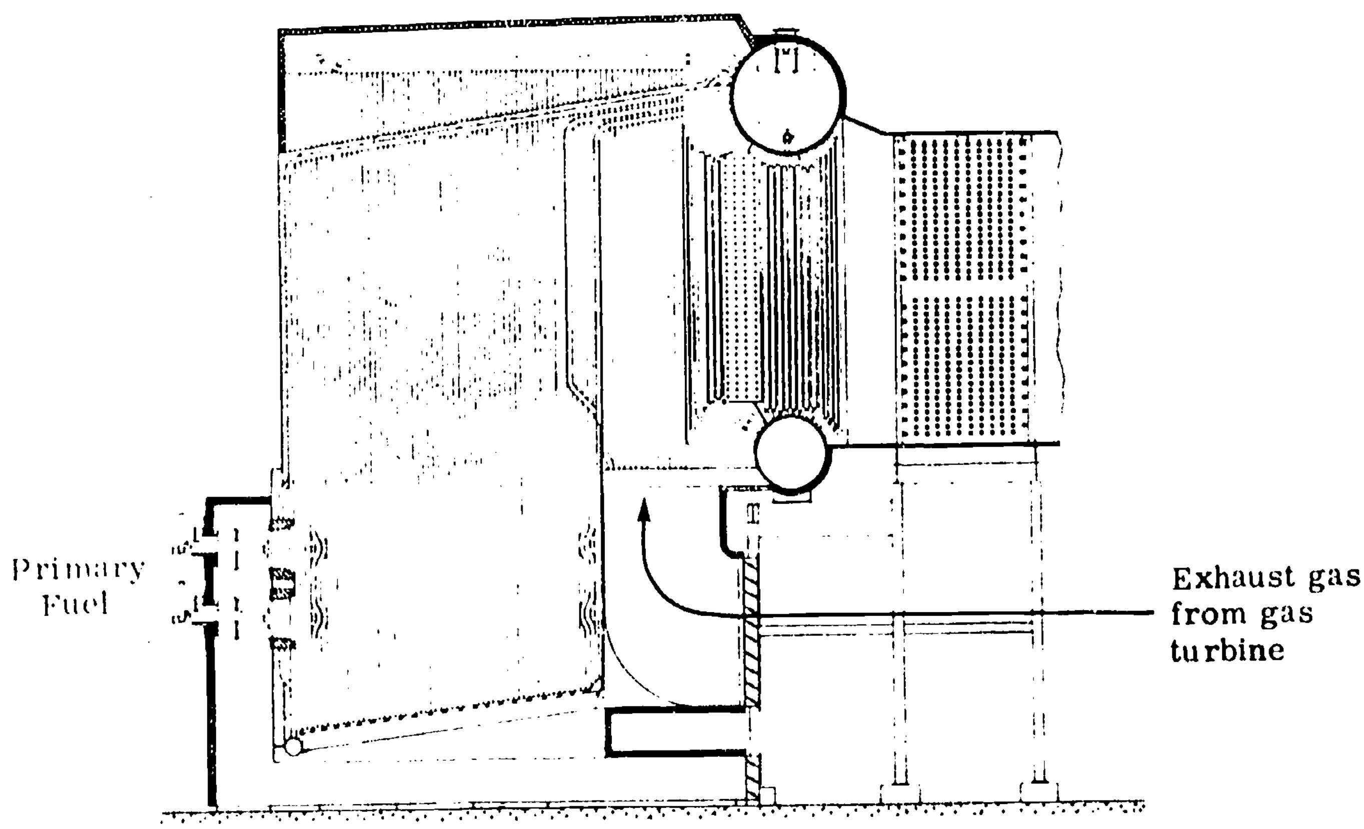
B and W "POWER FOR INDUSTRY" Boiler (Field Erected)
Fig. 19



Circulation System for above
(Up to 204 000 kg/h) Fig. 20 (PE2-2-2-19)

WASTE HEAT BOILERS

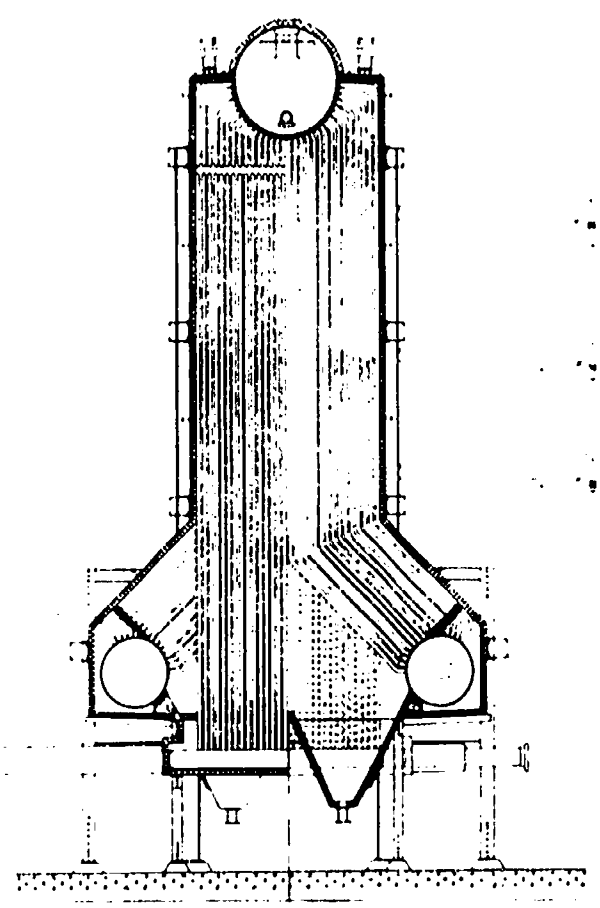
The following three figures show examples of waste heat boilers manufactured by Messrs. Foster-Wheeler Co.



Steam Generator
Fig. 21
designed to produce full load with either waste heat or direct firing

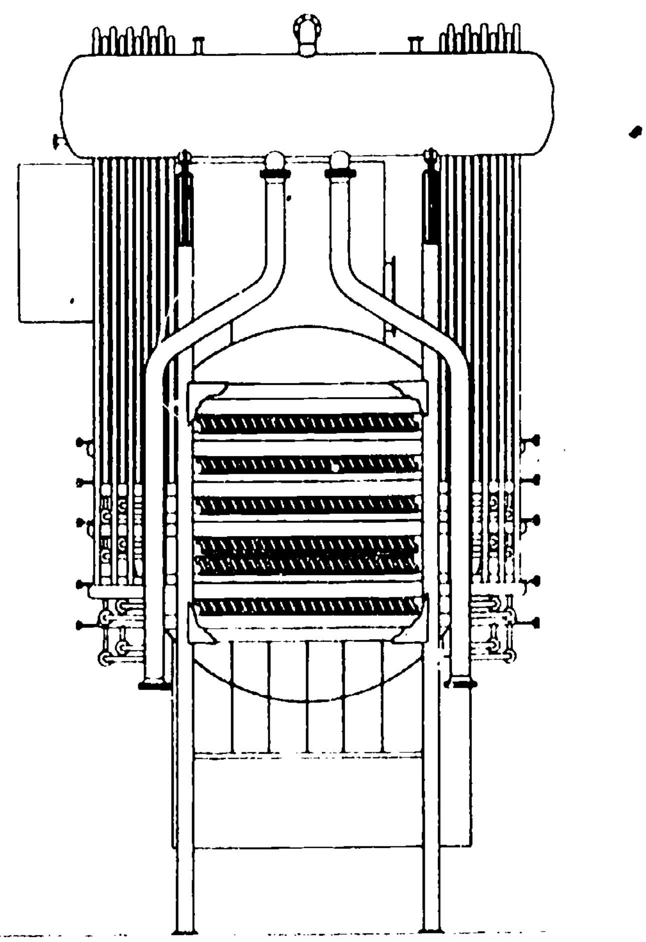
The design of this natural circulation boiler allows the use of waste heat from gas turbines. It meets immediate steam load by direct firing, and will provide waste heat recovery by utilizing exhaust gas as this energy source becomes available.

(PE 2-2-2-20)



Sulphur Recovery Plant
Installation
Fig. 22

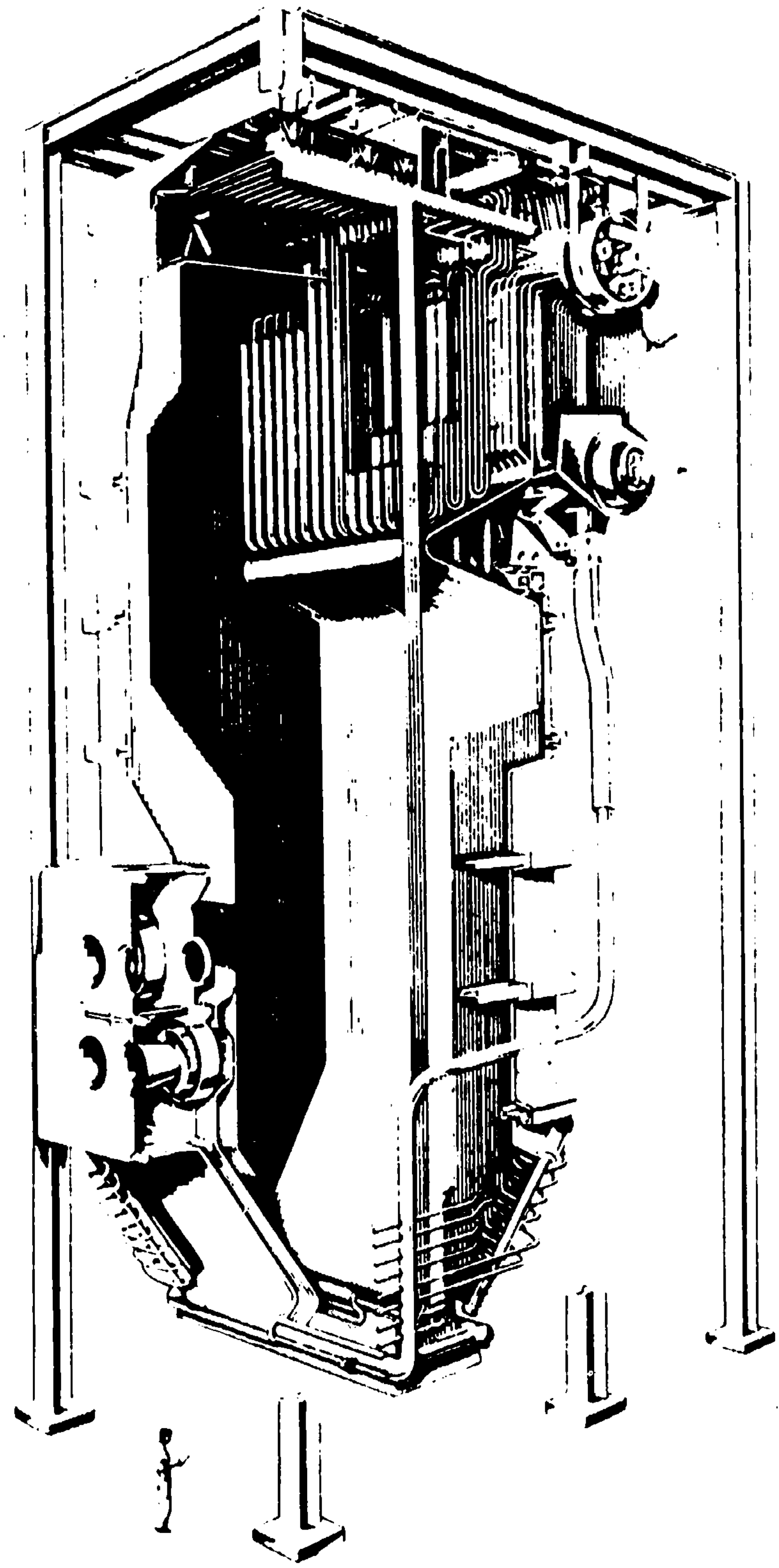
Natural circulation waste heat boiler installed in Alberta; has protected watertube design for maximum reliability. The highly corrosive character of the flue gases required special attention to this feature.



Steel Plant Installation
Fig. 23

This design produces superheated steam for process, or turbine drives, from heavily dust-laden gases (i.e. open hearth furnaces, cement plants, etc.) Construction permits thorough water washing in short time period. In service with an open hearth furnace in a large Ontario steel plant.

(PE 2-2-2-21)



363 000 kg/h

at 10 350 kPa

and 515°C.

Balanced draft

or pressurized.

Fuel -

pulverized coal,

oil or gas.

FOSTER-WHEELER SERIES SF

Fig. 24

(PE2-2-2-22)

Forced Circulation Boilers

Natural circulation in a boiler depends upon the difference in densities between water and steam to produce the circulation head. It was pointed out in Lecture 1 of Section 2 that this difference in density becomes progressively less with increased pressure and disappears altogether at critical pressure 22 106 kPa.

Boilers designed to operate at high pressures, particularly those with intricate tube paths must be designed with great care in order to ensure good natural circulation, or alternatively they can employ a pump in the boiler water systems to give forced circulation.

Forced circulation in a boiler has the advantage of giving a positive flow in all tubes; further by fitting orifices or nozzles of varying sizes at tube inlets the flow in the tubes can be regulated.

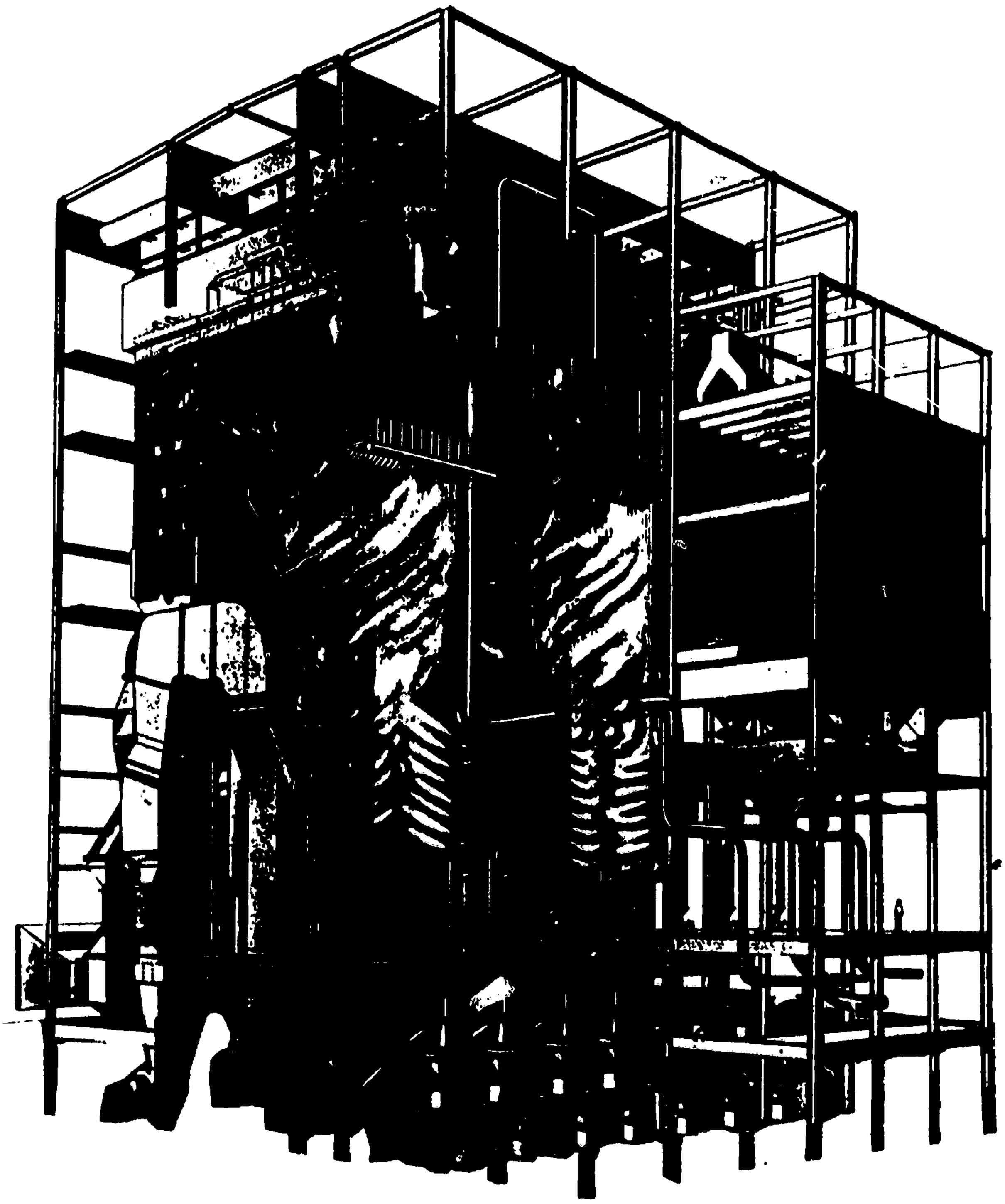
The disadvantages are the increased cost of equipment, pumps, piping, etc. and the increases in maintenance and running costs. One particular difficulty lies in effectively sealing the glands of the circulating pump against a pressure breakdown to atmosphere.

Forced circulation becomes advantageous at pressures of about 12 500 to 13 800 kPa upwards, and essential for supercritical steam.

Once-through boilers are a development of forced circulation; in this case the feedwater is forced through the circuits of the boiler and the change of state (water to steam) takes place in its course along the full length of the tube.

Fig. 25 shows a C.E. forced circulation dual-furnace boiler rated at 454 500 kg/h with final steam conditions of 14 500 kPa and 565^{o}C. The unit is fired with tilting tangential burners to give superheat temperature control.

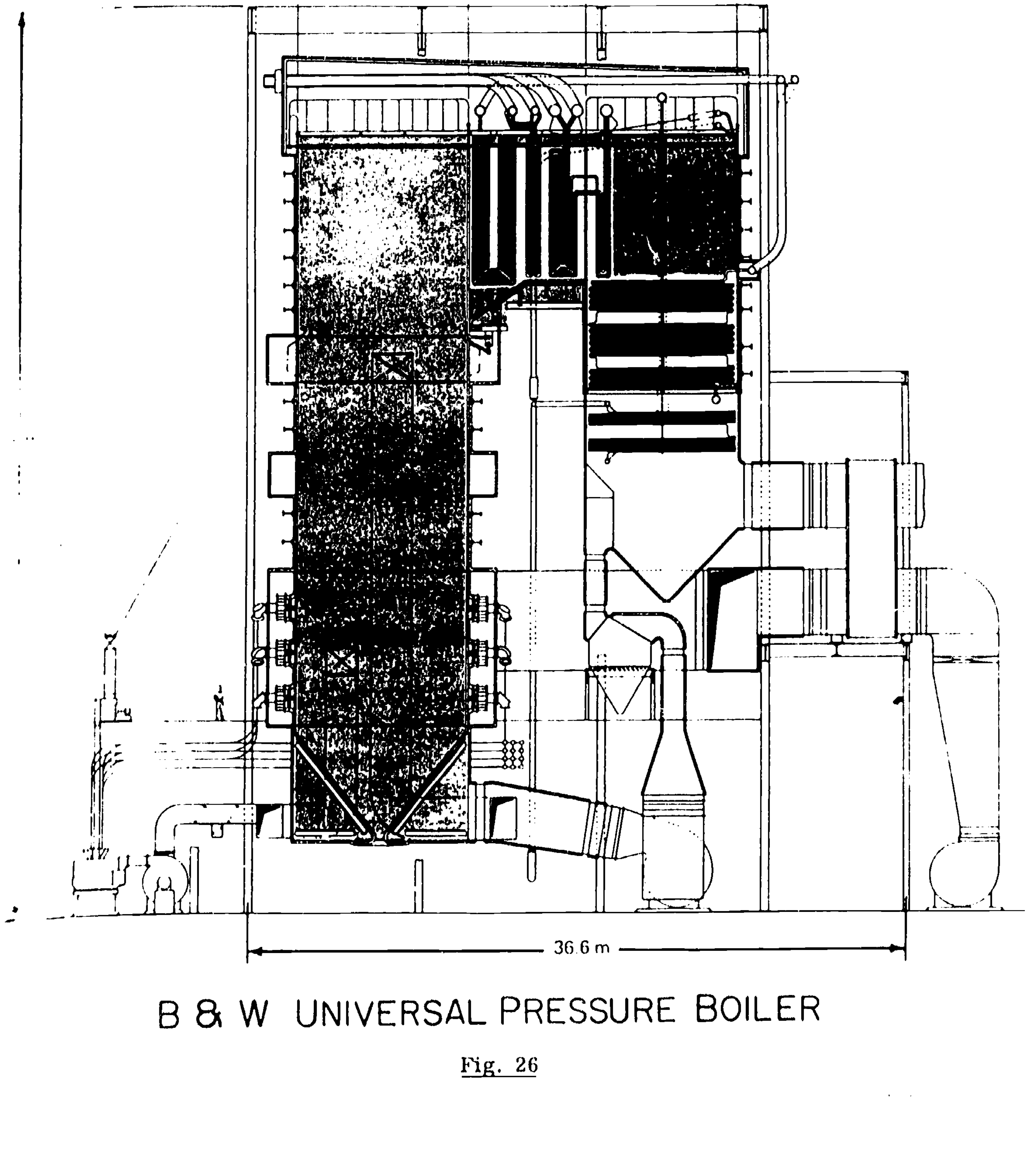
Fig. 26 shows a Babcock and Wilcox universal pressure boiler (once-through) designed for both pulverized coal and oil firing, steam conditions are 16 500 kPa at 538^{o}C with one reheat to 538^{o}C. The capacity of the unit is 1 197 000 kg/h at which the maximum capability of the unit approaches 400 MW. The single furnace is 14.63 metres wide with firing through both front and rear walls.



C-E CONTROLLED CIRCULATION DUAL-FURNACE BOILER Fig. 25

With Tilting Tangential Burners and Raymond Bowl Mills. Capacity - 454 500 kg/h at 14 500 kPa and 565°C primary and secondary steam temperature.

(PE2-2-2-24)



B & W UNIVERSAL PRESSURE BOILER

Fig. 26

(PE2-2-2-25)

Steam Flooding Boilers

A particular application of the once-through boiler design which has come into use in recent years is the steam flooding boiler. This is a boiler used for flooding oil wells with steam in order to increase their recovery or for supplying sulphur-mines with the heat required for sulphur recovery by the Frasch process.

Fig. 27 shows a Struthers Thermo-Flood Corp. boiler (external view).

Fig. 28 shows a similar boiler trailer-mounted.

These boilers are more correctly described as oilfield heaters; they are specifically designed for use in steam and/or hot water secondary oil recovery operations. They are basically forced circulation steam generators with a single pass or once-through coil. They are designed to produce steam of 75 to 80% quality depending upon the solids concentration in the feedwater. The effluent steam, consisting of a steam water mixture is generally injected into the well without any prior phase separation. The boiler has no steam drum, which simplifies controls. Outputs from these boilers range from 5 million kJ/h to 50 million kJ/h in standard sizes and up to 125 million kJ/h in special cases with working pressures up to 17 250 kPa.

High-pressure steam injection has quite recently gained status as an accepted successful procedure for increasing the recovery of oil from wells which have been partially depleted. The operation is particularly suited to the recovery of high viscosity crude oils.

Oil might be recovered by other means such as water-flooding, or solvent flooding. Steam injection is more expensive than water-flooding but has proved to be much more effective; solvent flooding is in experimental stages only.

The reason for the use of steam at such high pressures is to allow the maximum quantity of heat to be put into the well with the minimum quantity of injected fluid. This also keeps to a minimum the amount of fluid which must be pumped out later. Quantity, in the sense used here, means not only mass of steam (water, after condensation) but also volume of injected steam.

For example steam at 15 000 kPa has specific volume of 10.337 cm^3/g and contains 2610.5 J/g. Steam at 1500 kPa has specific volume of 131.77 cm^3/g and contains 2792.2 J/g.

Their comparative energy contents then, are:

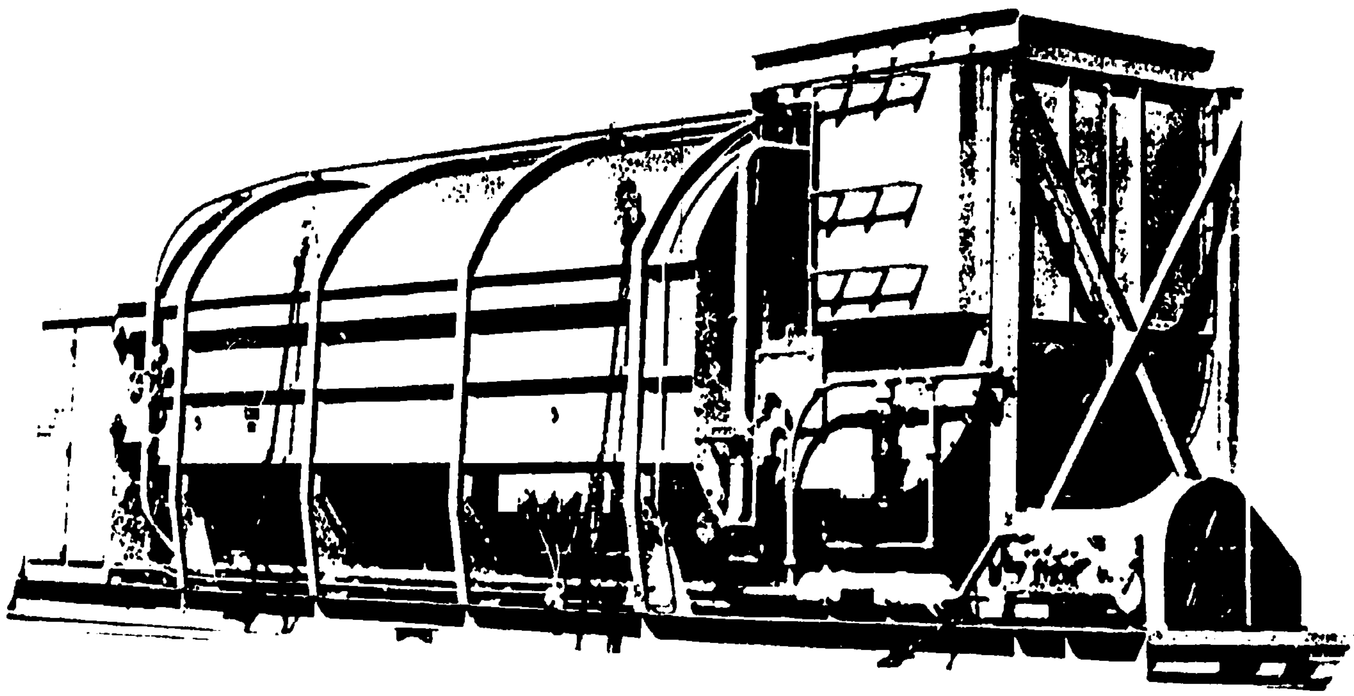
$$\text{15 000 kPa steam} \quad \frac{2610.5}{10.337} = 252.5\ J/cm^3$$

$$\text{1500 kPa steam} \quad \frac{2792.2}{131.77} = 21.19\ J/cm^3$$

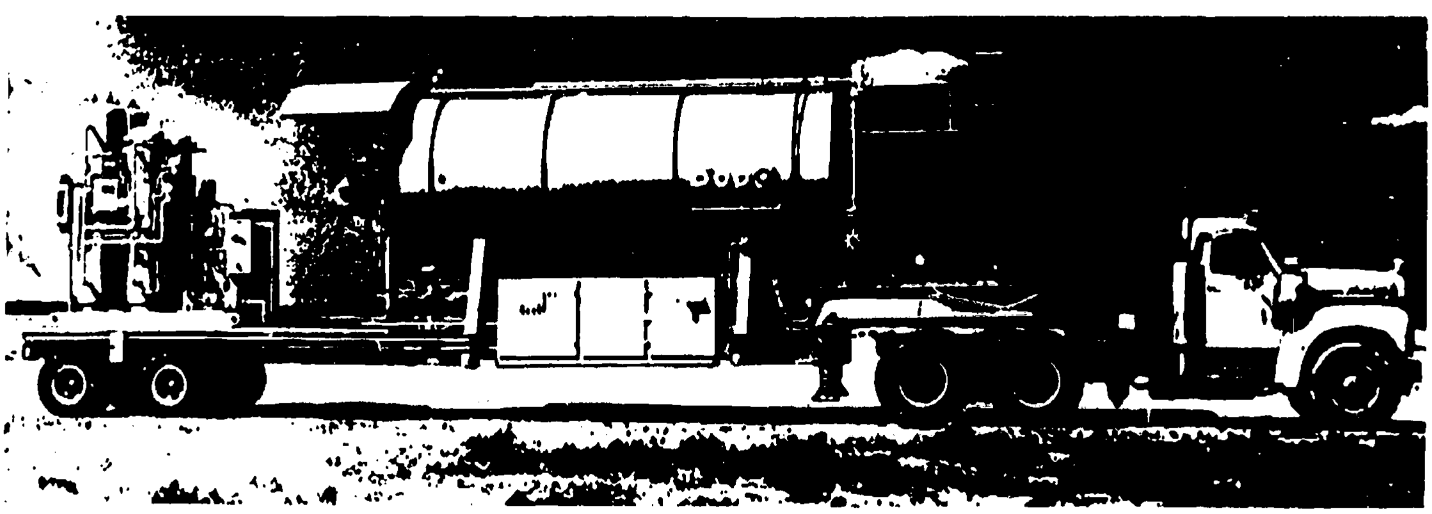
The high pressure steam contains $\frac{252.5}{21.19} = 11.19$

times the energy quantity per unit volume.

(PE2-2-2-26)



Struthers Thermo-Flood Corp. Boiler
(External View)
Fig. 27



Thermo-Flood Packaged Boiler
complete with water-treating equipment (Trailer Mounted)
Fig. 28

Further, the recovery of oil is proportional to the temperature reached at the bottom of the well, the optimum being 178°C (which is saturation temperature for 950 kPa steam) and this high temperature will be more easily reached with a supply of high-temperature steam.

The boiler units incorporate feedwater treatment since water must be treated for hardness and the oxygen removed to ensure trouble free operation. Feedwater with a relatively high percentage of solids can be handled provided that the solids have been converted to soluble form.

(PE2-2-2-27)

QUESTION SHEET

POWER ENGINEERING

Second Class
Sect. 2, Lect. 2

1. Compare watertube and firetube boilers and state the advantages of the watertube boiler.

2. (a) Sketch and describe a straight-tube boiler.
   (b) What are the advantages of a bent-tube boiler compared with a straight-tube boiler?

3. (a) Discuss the advantages of the packaged boiler compared to a field erected boiler.
   (b) With the aid of simple sketches describe 'A', 'O' and 'D' type packaged boilers.

4. (a) Explain the difference between shop-assembled boilers and packaged boilers.
   (b) Explain the difference between field-erected and shop-assembled boilers.

5. Where are 'Waste Heat Boilers' used and how are these boilers heated or fired?

6. Describe forced-water circulation and discuss the advantages and disadvantages.

7. (a) What is the purpose of a "Steam Flooding Boiler"?
   (b) Describe a Steam Flooding boiler.

8. What preparations must be carried out to make a steam generator ready for external and internal inspections.

9. Make a sectional elevation through a watertube boiler of your choice showing the positions of the drum, the water walls, economizer, superheaters, and reheaters (if any). Show also the firing arrangement, dust collection, fans, and the supporting steelwork. Use single-line sketch method.

INSTRUCTIONAL LEARNING SYSTEMS

7.3

BOILERS -- CONSTRUCTION

Goal:

The apprentice will be able to describe boiler construction.

Performance Indicators:

1. Describe materials used in boiler construction.
2. Describe processes used in boiler construction.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Capped
* Carbon steel
* Casings
* Extrusion process
* Ductwork
* Fin tubes
* Flat stud tube
* High alloy steel
* Hydrastatic testing
* Killed
* Low alloy steel
* Mandrel
* Piercing and rolling
* Rimmed
* Sectionally supported settings
* Semi-killed
* Solid wall settings
* Stays and braces
* Tangent tube
* Tube and brick
* Watercooled settings
* Welded tube

Introduction

Modern boilers are expected to operate at high pressures with a life expectancy of 20 years. Good materials must be used in construction of the steam plant and the fabrication methods must be of high quality.

Since most parts will be subjected to high pressure, ferrous materials are rather standard in boiler construction.

This package will discuss the materials used and fabrication methods for boiler construction.

Information

Types of Steel

Steel is the most common metal used in the manufacture of boilers. Many grades and types of steel are available:

- Carbon steel (.2 to .3% carbon)
- Low alloy steel (up to 5% alloy)
- High alloy steel (over 10% alloy)

Steel is often classified according to its manufacturing process and the amounts of carbon monoxide produced as the steel solidified. These classes are:

1. Rimmed--has a rim of pure iron and a core of carbon steel.
2. Capped--has a thinner rim and less carbon in the core than rimmed.
3. Semi-killed--has silicon and aluminum added to prevent excess gas bubbles.
4. Killed--has all oxygen removed by adding oxygen and aluminum as deoxydizing agent. Process used in making both carbon steel and alloy steel.

Materials for Boiler Construction

The following chart shows the materials used in boiler construction.

Boiler Parts	Type of Material
Drum and Shell	Carbon steel or low alloy steel. Rolled while hot and welded seams.
Tubes	Carbon steel or alloy steel.
Pipe fittings, valves, water columns for pressures under 2400 kPa and temperatures less than 232 C.	Malleable iron and cast nodular iron.
- Up to 1700 kPa	Cast iron

Information

Boiler Parts	Type of Material
Blow-off connections and other connections that fit directly into the boiler.	Carbon steel or alloy steel.

Processes of Boiler Construction

Foundations

Foundations must be constructed to eliminate movement from settling or other shifting. The foundation size depends upon the weight of the boiler to be supported. Boiler manufacturers will supply the specifications for each boiler sold. Large boilers require overhead support from structural steel hangers. Small boilers may be grouted into the cement floor of the power plant.

Settings

A setting is a wall that encloses the furnace and pressure parts of a boiler. Usually a setting is made with firebrick or plastic fireclay. Solid wall settings are independent of the boiler. Sectionally supported settings are anchored and supported in sections by external steelwork. Watercooled settings are used in internally fired, firetube boilers and water tube boilers. A tube and brick setting offers both refractory and water cooled furnace walls. A common type of tube and brick wall is constructed with fin tubes. Metal fin bars are welded to tubes to give a continuous wall surface and bricks are laid against the fin tubes.

Information

Other types of wall settings include:

- Tangent tube
- Flat stud tube

Baffles

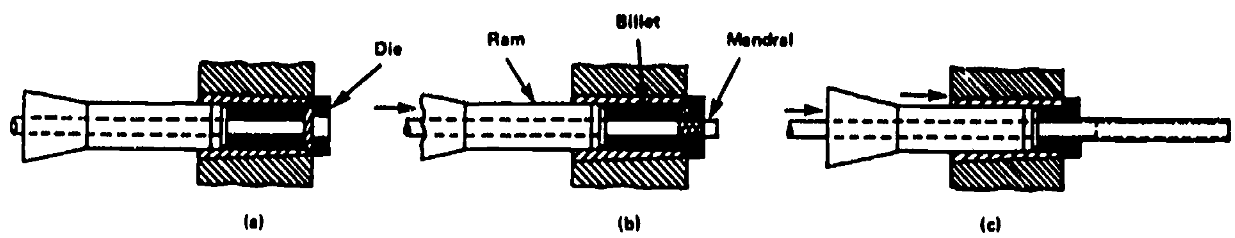
Brick or other refractory material is used to construct baffles. Individual bricks are fitted around the tubes in a way that the flow of gases is directed to the tubes. Gases must be redirected so that a continuous pattern of heat is directed to the tubes. Some baffles are manufactured as one piece. Others are formed as curves to reduce friction.

Casings

Air tight casings are used to protect wall insulation and to keep air away from the furnace. Casings are made of welded steel. Often a layer of insulation is placed between the casings and wall tubes.

Tubes

Tubes are formed by the extrusion process or by piercing and rolling. The extrusion process squeezes hot steel through a die that has a mandrel to punch out the opening in the tube.

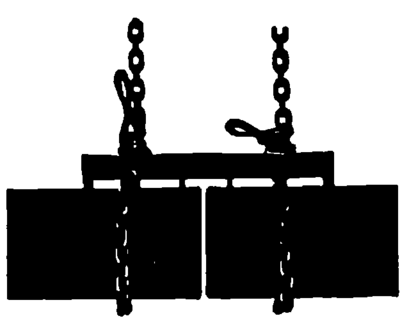


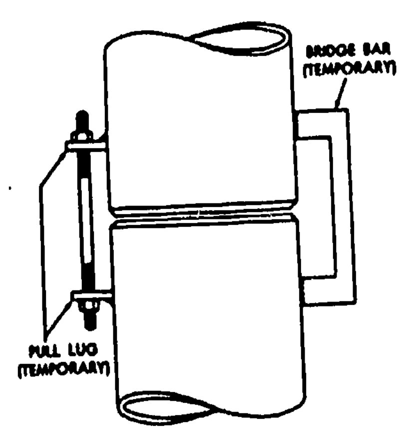
Information

In piercing and rolling, hot carbon or alloy steel bar is forced through a piercing point with rollers. The bar is then reheated and rolled to reduce its wall thickness. Then it is burnished and rolled to finished size. Welded tubes are made from flat strips of steel by rolling and then butt welding the seams.

Tube Installation

The tubes are joined to drums and headers by expanding or welding to tube stubs. An expander tool presses the tube wall into the tube hole and expands it. In welded installations, the tube is connected to the tube stub of the drum and welded in place. Alignment jigs are used to align the parts for welding.





Stays and Braces

Firetube boilers require stays and braces to hold their shape under pressure. All flat surfaces must be braced. Tube sheets must be stayed to the shell. In firebox type boilers, the water-legs must be supported by stays.

Hydrastatic Testing

Manufacturers test boilers by filling them with water and applying 1.5 times the pressure for which they were designed. Leakage from welds allow the tester to spot defects in the weld or other metal parts.

Information

Ductwork

Metal ducts are required to move combustion air and gases to and from the furnace. The common ducts required are:

- Main air duct from fan to heater to burner.
- Main gas duct from the economizer outlet to heater to fan to stack.
- Air circulating duct from heater outlet to fan inlet.

Assignment

* Read pages 1 - 29 of supplementary reference.

* Complete job sheet.

* Complete self-assessment and check answers.

* Complete post-assessment and have instructor check answers.

Job Sheet

INSPECT CONSTRUCTION OF A BOILER

* Obtain permission to inspect a boiler.

* Observe materials used in construction of:

  - Shell or drum
  - Casing
  - Blow-off valves
  - Other valves and fittings
  - Tubes
  - Wall setting
  - Ductwork

* Observe construction features

  - Which parts are riveted or bolted?
  - Which parts are welded?

* Ask questions needed to understand the materials used in boiler construction and processes for construction.

Self Assessment

1. Low alloy steel has ________ percent or less of alloy.

2. ________________ steel has all of the oxygen removed by adding deoxidizing agent.

3. Drums are made from _____________ steel and low alloy steel.

4. ____________________ wall settings are independent of the boiler.

5. A setting is a wall that encloses the __________________ and pressure parts of a boiler.

6. Metal bars welded to tubes for construction of a setting are called __________ _________________.

7. A setting that uses both brick and tubes is called a ______________ and ______________________________.

8. _________________ or other refractory material is used to construct baffles.

9. Casings are made of __________________ steel.

10. An ________________ tool is used to press tubes into the tube holes of a drum and lock them in place.

Self Assessment Answers

1. 5%
2. Killed
3. Carbon
4. Solid
5. Furnace
6. Fin tube
7. Tube and brick
8. Brick
9. Welded
10. Expander

Post Assessment

Match the following terms with their descriptive phrase.

____ 1 Hydrastatic testing	A. Used to align tubes for welding.
____ 2 Stays and braces	B. Made of carbon steel or alloy steel.
____ 3 Ductwork	C. Pressure applied at 1.5 times designed levels.
____ 4 Alignment Jigs	D. Has less than .2 to .3 percent carbon.
____ 5 Baffles	E. Helps firetube boilers hold their shape under pressure.
____ 6 Foundation	F. Required to move combustion air and gases to and from furnace.
____ 7 Setting	G. Squeezes hot steel through die to make tube.
____ 8 Tubes	H. Constructed from a refractory material.
____ 9 Carbon steel	I. Wall that encloses furnace and pressure parts.
____10 Extrusion process	J. Must be free of settling and shifting.

Instructor Post Assessment Answers

C 1.

E 2.

F 3.

A 4.

H 5.

J 6.

I 7.

B 8.

D 9.

G 10.

Supplementary References

* Correspondence Course. Lecture 2, Section 2, First Class. Steam Generation. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATION

First Class
Lecture 2

BOILER CONSTRUCTION AND ERECTION

Although modern boilers operate at pressures as high as 35 000 kPa and at temperatures in excess of 550°C they have a life expectancy of 20 years or more. In order to achieve this 20 year service period, the proper materials and the proper methods must be used during the fabrication of the boiler. In addition, the proper procedure must be followed during the erection of the boiler whether it is a field erected or a shop assembled unit.

The selection of the type of material used for the boiler components is governed by the ASME Boiler and Pressure Vessel Code. Paragraph PG-6.1 lists the specifications of materials to be used for boiler plates, while paragraph PG-9 lists materials for boiler tubes and piping.

In addition to governing the choice of materials used, the ASME Code contains rules and regulations regarding the design, fabrication, installation, testing and inspection of boilers and related equipment.

In each province, a department of the provincial government makes rules pertaining to the design, fabrication, installation, inspection and operation of boilers and pressure vessels. These provincial authorities are guided by and follow, in general, the ASME Codes.

In regard to the materials selected for boiler construction, their strength and ductility at the various temperatures encountered in service and during fabrication must be considered as well as their corrosion resistance under operating conditions. Other important factors are: the behavior of the material under mechanical and thermal shock, thermal stresses due to temperature changes, and stresses present in the material due to fabrication processes.

Ferrous materials are used for the pressure parts of the boiler such as drums, headers and tubes. This is also true for most of the other parts of the boiler and its related equipment including pulverizers, fuel carrying systems, soot blowers, structural supports, economizers, air heaters, casings, ducts, piping and fittings.

Nonferrous materials are used only to a minor extent in boiler construction, therefore any discussion of materials in this lecture will be confined mainly to ferrous materials, in particular the various steels used.

MATERIALS USED

Steel

Steel is the most commonly used material of construction in the boiler and pressure vessel industry. It is basically an alloy of iron and carbon but, depending upon the proportion of other alloying elements used in its production, it can be classed into three groups: plain carbon steel which contains from 0.20 to 0.30 percent carbon; low alloy steel which contains other alloying elements in addition to carbon up to a total of usually not more than 5.0 percent alloy content; high alloy steel in which the amount of the alloying elements chromium, nickel or manganese is 10 percent or higher.

Steel is also classified according to its method of manufacture. In most steel making processes the molten metal is saturated with oxygen which tends to combine with carbon in the metal to form carbon monoxide gas. The amount of this gas produced during the solidification of the metal will determine whether the steel is classed as rimmed, capped, semikilled or killed.

Rimmed Steel

In this method, the oxygen-rich molten metal is poured into a mold and begins to solidify by forming a layer of almost pure iron on the walls and bottom of the mold. This tends to concentrate the carbon content in the remaining liquid metal and this carbon reacts with the oxygen to form carbon monoxide gas. This gas, in the form of bubbles, attempts to rise and escape from the metal. Much does escape but some is trapped in the rest of the metal as it solidifies.

Rimmed steel therefore features a rim of nearly pure iron around its periphery and a central core of steel which contains carbon and other elements such as phosphorus and sulphur.

Rimmed steel is cheaper to manufacture than other types and has a defect-free surface due to the pure iron rim. It is seldom used for pressure vessel construction however, due to its lack of homogeneity and also due to its porosity caused by the gas trapped in the metal during its manufacture.

Capped Steel

In the making of capped steel, the molten metal poured into the mold is allowed to rim for a short period of time until a thin skin of pure iron is formed. Then a heavy metal cap or chill plate is locked on top of the mold. The molten metal rises due to the formation of gas bubbles and upon reaching the cap this molten metal chills and solidifies, forming a solid crust of metal which prevents further formation of gas bubbles. Sometimes a deoxidizer may be added to the molten metal to give a controlled rimming action.

The difference between capped steel and rimmed steel is that capped steel has a thinner rim and a somewhat more homogenous core than has rimmed steel. However, like rimmed steel, it has considerable porosity in the ingot.

Semikilled Steel

In the production of semikilled steel a small amount of a deoxidizing agent (silicon, aluminum) is added to the molten metal. This deoxidizing agent combines with some of the oxygen and prevents the excess production of gas bubbles which would otherwise cause rimming. The remaining oxygen does evolve some gas which prevents the shrinkage which would otherwise occur solidification of the metal in the mold. This also causes some porosity in the ingot.

Semikilled steel is often used for thin-walled light duty pressure vessels as it is the cheapest type of steel suitable for this work.

Killed Steel

Killed steel is made by completely removing the oxygen in the molten metal before solidification takes place. This means that there is no evolution of gas and the metal solidifies quietly without effervescence or rimming action. Consequently there is a shrinkage cavity or "pipe" formed in the upper end of the ingot. This piped end is discarded leaving a homogenous and non-porous metal ingot.

The removal of the oxygen is carried out by adding sufficient amounts of a deoxidizing agent such as silicon or aluminum. This method of steel production is used for nearly all alloy steels and for carbon steels containing more than 0.25 percent carbon. It is used in all thicknesses for pressure vessels intended for severe duty and for most seamless piping and boiler tubes.

Steel Types

As mentioned, the three classes of steel according to ingredients used during manufacture are plain carbon steel, low alloy steel, and high alloy steel.

1. Plain Carbon Steel

Plain carbon steels contain on an average of from 0.20 to 0.30 percent carbon and the amount of carbon present has a great effect on certain mechanical properties of the steel such as hardness, strength, ductility, and toughness. Generally speaking, the greater the carbon content the greater will be the strength and the hardness and the lower will be the ductility and toughness of the steel.

In addition to carbon, plain carbon steel contains varying amounts of impurities such as manganese, silicon, sulphur and phosphorus. These impurities may also have an effect on the properties of the steel although this will be much less than the effect caused by carbon. However, in the selection of a plain carbon steel both the carbon content and the amount of impurities present must be considered.

A plain carbon steel listed in ASME PG-6 is SA-285. Grade C of this steel contains a maximum carbon content of 0.30 percent, a maximum manganese content of 0.80 percent, a maximum phosphorus content of 0.04 percent and a maximum sulphur content of 0.04 percent.

2. Low Alloy Steel

A low alloy steel can be considered as a carbon steel to which certain alloying elements are added in order to improve the properties and characteristics of the steel. In a low alloy steel the total percentage of alloying elements does not usually exceed 5.0 percent.

In general, low alloy steels are superior to plain carbon steel in regard to one or more of the following characteristics: Strength at room temperature, strength at high temperature, impact strength at low temperature, corrosion resistance, oxidation resistance at high temperature, creep resistance and machinability.

Alloying elements which may be found in low alloy steel, in addition to the carbon, include manganese, phosphorus, sulphur, silicon, chromium, molybdenum, nickel, aluminum, copper, lead, and vanadium. The purposes of adding these elements are discussed briefly as follows:

Manganese

Manganese is an efficient deoxidizer and its addition improves the mechanical properties of the steel such as strength and hardness. It also has a beneficial effect on the creep properties of the steel. On the other hand, it makes the steel more difficult to weld properly. The manganese content of low alloy steel is usually in the range 0.30 to 1.30 percent.

Phosphorus

Phosphorus is found in all steels and in high percentages is considered an impurity as it has an embrittling effect on the steel and increases welding difficulties. When present in small amounts, however, it improves the machinability of the steel. The phosphorus content is normally kept below 0.04 percent.

Sulphur

This element is present in all steels and is generally considered an impurity as it reduces the weldability of the steel. For most steels the sulphur content, like the phosphorus content, is kept below 0.04 percent.

Silicon

Silicon is added, in the case of semikilled and killed steel, to deoxidize the molten metal. It also has the effect of increasing the strength of the steel although amounts in excess of 2.5 percent cause brittleness. A typical low alloy steel may have a silicon content of from 0.15 to 0.30 percent.

Chromium

Chromium is one of the most common alloying elements and, in low alloy steel, is present in amounts below 10 percent. It increases the strength, hardness and toughness of the steel and gives higher resistance to wear or abrasion.

Molybdenum

The addition of molybdenum in low alloy steel increases its strength, hardness and creep resistance. Low alloy steels usually contain from 0.50 to 1.0 percent molybdenum.

Nickel

Nickel increases the toughness, strength and hardness of steel and is often used to provide toughness in steel at low temperatures. Some low alloy steels have nickel contents of from 0.50 to 3.50 percent.

Aluminum

Aluminum is a minor constituent of low alloy steel and is used primarily as a deoxidizing agent in the production of killed steel.

Copper

Copper is added to steel to increase resistance to atmospheric corrosion and to act as a strengthening agent. The copper content may range from 0.20 to 0.50 percent.

Lead

Lead added in the 0.15 to 0.35 range improves the machinability of steel but does not alter the mechanical properties.

Vanadium

Vanadium is not only a powerful deoxidizer but also increases the strength and toughness of the steel. Its content in a low alloy steel may range from 0.09 to 0.14 percent.

An example of a low alloy steel which is listed in ASME PG-6 is SA-203. This is a plate steel which has, depending upon the thickness and the grade, a carbon content of from 0.17 to 0.25 percent, a manganese content of 0.70 to 0.80 percent, a phosphorus content of 0.035 percent, a sulphur content of 0.04 percent, a nickel content of 2.13 to 3.82 percent and a silicon content of 0.13 to 0.32 percent.

An example of a low alloy steel used for steam piping is SA-335 P22. Its alloy content in percentages is as follows:

Carbon -	0.15 max.
Manganese -	0.30 to 0.60
Phosphorus -	0.030 max.
Sulphur -	0.030 max.
Chromium -	1.90 to 2.60
Silicon -	0.50 max.
Molybdenum -	0.87 to 1.13

3. High Alloy Steels

A steel is considered to be a high alloy steel if the amount of chromium, nickel or manganese is 10 percent or higher. These steels are used primarily because of their corrosion resistance and creep strength at very high temperatures.

They can be divided into two general types: straight chromium steels which have a chromium content ranging from 12 to 27 percent and chromium-nickel austenitic steels where the chromium content may range from 18 to 25 percent and the nickel content from 8 to 20 percent. Special types of chromium-nickel steels have additional alloying elements such as columbium, titanium, molybdenum and copper.

High alloy steels differ from other steels in the following ways:

1. Their thermal conductivity is much lower therefore they are more susceptible to local overheating and to distortion when they are welded.

2. Their thermal expansion is higher which tends to increase welding distortion and to produce higher stresses in the welds during cooling.

3. They are more corrosion resistant and have higher strength and oxidation resistance at high temperatures.

An example of a chromium - nickel austenitic steel which is listed in ASME PG-9 is SA-376. This is used in the production of seamless piping and its alloy content for Grade TP 304 is listed as follows in percentages:

Carbon -	0.08 max.
Manganese -	2.00 max.
Phosphorus -	0.03 max.
Sulphur -	0.03 max.
Silicon -	0.75 max.
Nickel -	8.0 to 11.0
Chromium -	18.0 to 20.0

An example of a straight chromium steel which is listed in PG-9 is SA-268. This is used for both seamless and welded general service tubes. The alloy content in percentages for Grade TP 430 is as follows:

Carbon -	0.12 max.
Manganese -	1.00 max.
Phosphorus -	0.04 max.
Sulphur -	0.03 max.
Silicon -	0.75 max.
Nickel -	0.50 max.
Chromium -	14.0 to 18.0

Maximum allowable stress values for various temperatures for the materials listed in PG-6 and PG-9 are contained in the ASME Table PG-23.1.

For example, the chromium - nickel austenitic steel SA-376 Grade TP 304 for seamless piping has an allowable stress value of 84.116 MPa for temperatures from 204° to 260°C. The allowable stress value drops to 76.532 MPa for temperatures from 343° to 371°C and to 70.326 MPa for temperatures from 454° to 482°C. On the other hand, the straight chromium steel SA-268 Grade TP 430 for seamless tubing has an allowable stress value of 88.492 MPa for temperatures from 204° to 260°C. The allowable stress value drops to 83.427 MPa for temperatures from 343° to 371°C and use of this material for temperatures above 371°C is not current practice.

Nonferrous Materials

The ASME Code allows the use of nonferrous pipe or tubes not over 76 mm in diameter for steam lines, feed lines, and drains. The types allowed are listed in PG-9.5 and it is also specified in PG-9.5 that nonferrous pipe or tubes shall not be used for blow-off piping or any other service where the temperature exceeds 208°C.

Maximum allowable stress values for various temperatures for nonferrous materials are contained in ASME Table PG-23.2. Referring to this table, it can be seen that nonferrous pipe or tube SB-42 and SB-75 have an allowable stress value of only 20 680 kPa at temperatures between 175° and 205°C.

Cast Iron

Cast iron may be used for boiler connections such as pipe fittings, water columns, and valves, for pressures up to 1700 kPa providing the steam temperature does not exceed 232°C. The type of cast iron to be used in specified in PG-8.2.2.

For blow-off valves, however, the limit for which cast iron can be used is 1400 kPa and this is discussed in PG-58.1.4 together with the requirements for the cast iron to be used.

Cast iron shall not be used for nozzles or flanges attached directly to the boiler for any pressure or temperature.

Malleable Iron and Cast Nodular Iron

These materials must not be used for blow-off connections but can be used for other boiler connections such as pipe fittings, water columns, and valves, for pressures not to exceed 2400 kPa provided the steam temperature does not exceed 232°C. Specification numbers for these materials are given in PG-8.3.

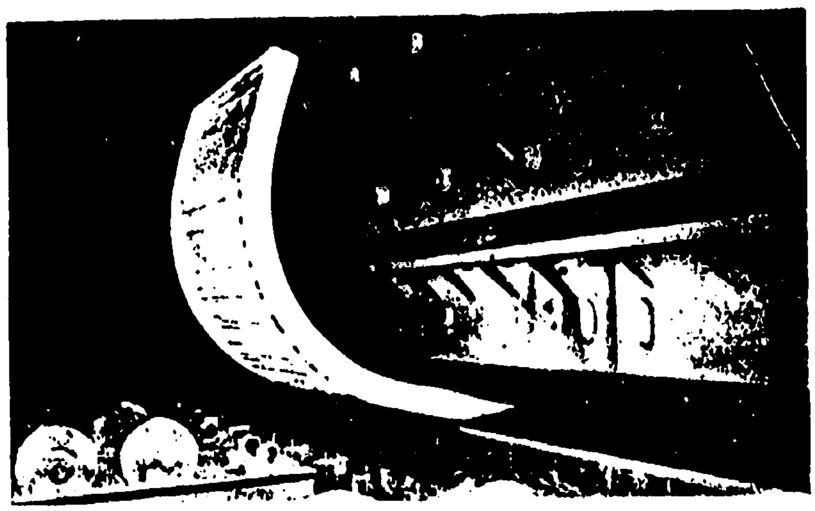
Material Selection

The selection of the material used in the pressure parts of the boiler depends upon the actual metal temperature to be sustained during operation. The steam generation tubes are primarily of carbon steel. Superheater and reheater tubes may also be carbon steel in low temperature areas but as the temperature increases the chrome-molybdenum steels are used and for the highest temperature areas the material is chrome-nickel austenitic steel such as Grade 304, 316, 321 or 347.

SHELL AND DRUM FABRICATION

The boiler drum is fabricated from plate of the desired material, usually some type of carbon steel or low alloy steel. Depending upon the desired service conditions and the drum diameter these plates may be up to ten inches thick.

Usually the plate is bent to the required shape while hot but in some cases while cold, the method depending upon the plate material and thickness and the desired radius to which it is to be bent. The plate may be bent or rolled to the full circumference or it may be formed into half cylindrical sections which are subsequently welded together.



Hot - Bending Boiler Plate (Foster Wheeler)

Fig. 1 (a)

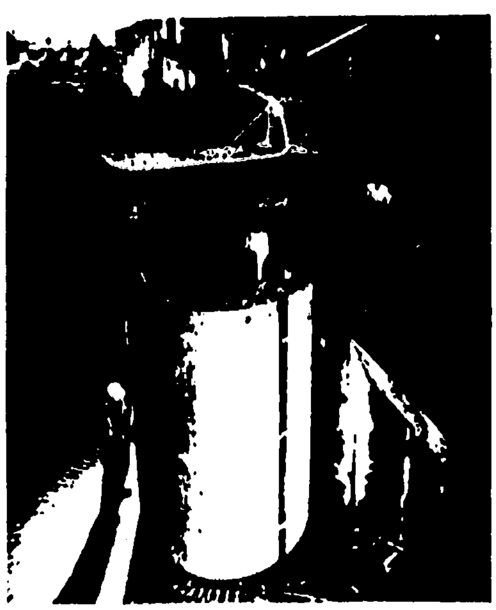


Fig. 3. Checking the contour of a cylindrical section

Contour Checking
(Babcock and Wilcox)

Fig. 1 (b)

Fig. 1 (a) shows a section of 180 mm thick boiler plate being bent to the required shape while hot and Fig. 1 (b) shows contour checking of a heavy plate cylindrical section.

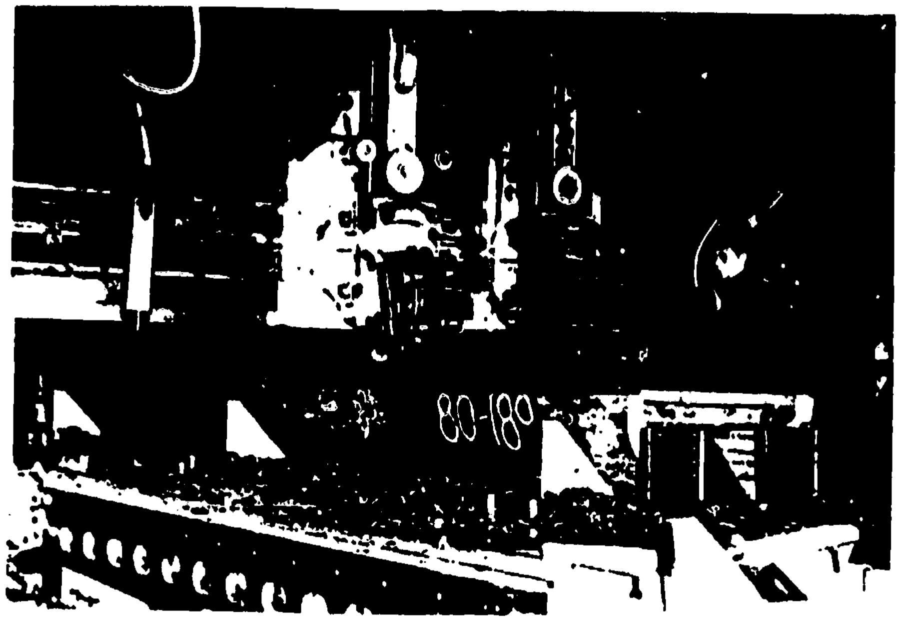
(PE1-2-2-9)

Cold - Bending Boiler Plate
(Foster Wheeler)

Fig. 2

Fig. 2 illustrates the cold - bending process applied to a slightly thinner plate.

After forming of the plate into full or half shell sections, the plate edges are machined to form the longitudinal weld grooves.

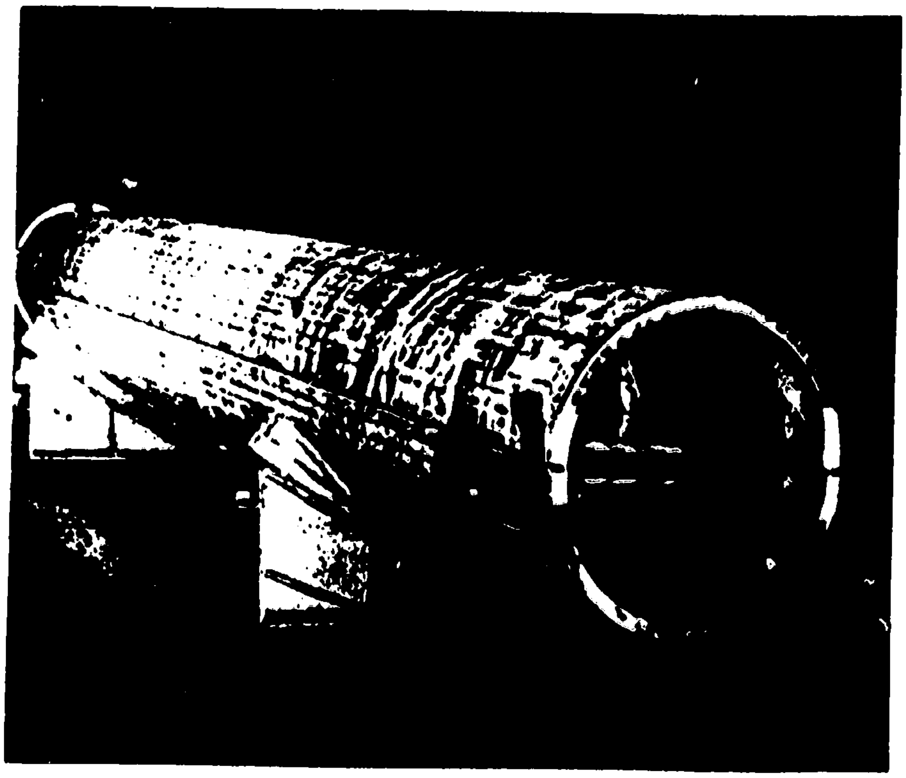


Machining Welding Grooves
(Foster Wheeler)

Fig. 3

In Fig. 3 the edges of a small diameter half shell section are being machined to form the required welding grooves.

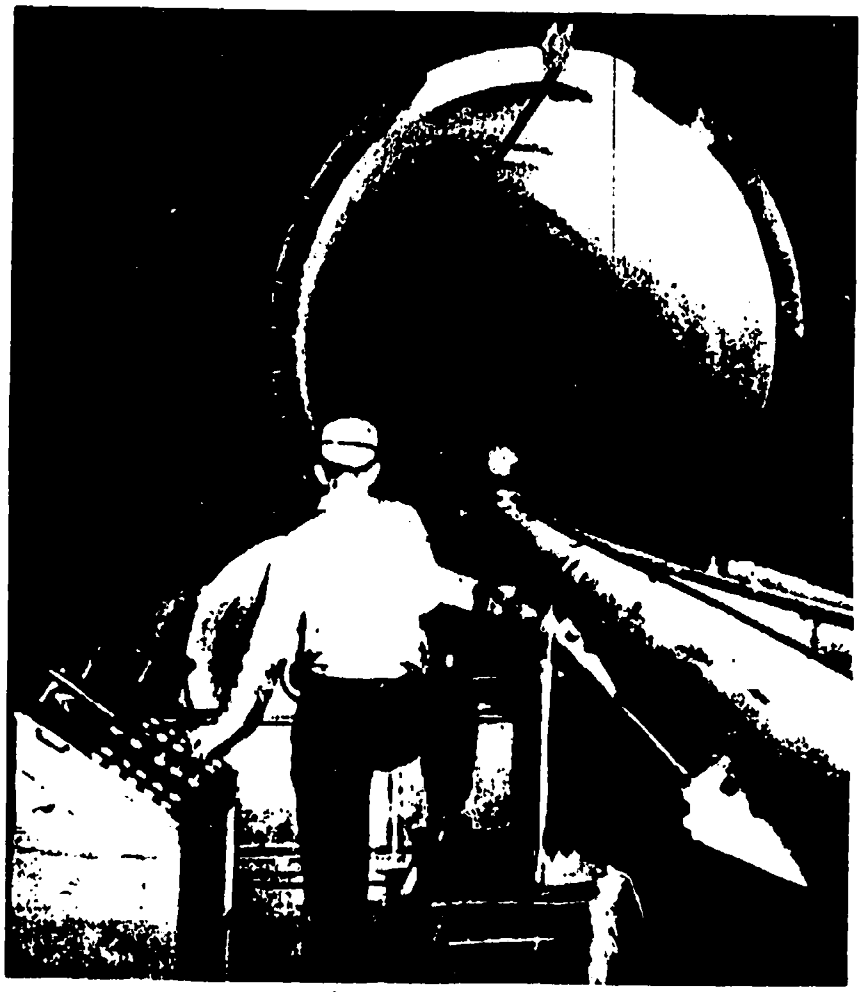
The shell sections are then set up for welding and the outside and inside seams are automatically welded.



Shell Half - Sections
(Foster Wheeler)

Fig. 4

Fig. 4 shows the shell sections set up for welding and Fig. 5 illustrates the welding of an inside seam.



Inside Seam Welding
(Foster Wheeler)

Fig. 5

The drum heads are fabricated by hot-pressing in dies of the proper shape and dimensions and then they are machined for the circumferential weld grooves. Circumferential welds are used to join the heads to the drum or shell and also to join cylindrical drum sections together to form a longer drum.

After welding of the longitudinal and circumferential seams, the nozzle openings are cut in the drum and the nozzles welded into place. These nozzles include those for the safety valves, steam outlets, water column connections, downcomers, etc.

Upon completion of all welding, the drum is heat treated in order to stress relieve the welds. This stress relieving is done in a furnace which is large enough to accomodate the entire drum and in which heat is maintained under controlled conditions.

(PE1-2-2-12)

The conditions for the stress relieving or postweld heat treating are specified in the ASME Code PW-39. The Code states that the drum assembly shall be heated slowly to a specified temperature, held at that temperature for a specified time and then allowed to cool slowly in a still atmosphere to a temperature not exceeding 427°C.

The specified holding time is based on a minimum of one hour per 25 mm of thickness of the material. The specified temperature varies according to the type of material and Table PW-39 lists the temperatures used for materials according to the P-number group they come under. For example, materials in group P-1 are held at a temperature of 593°C, materials in group P-5 are held at 677°C and so on.

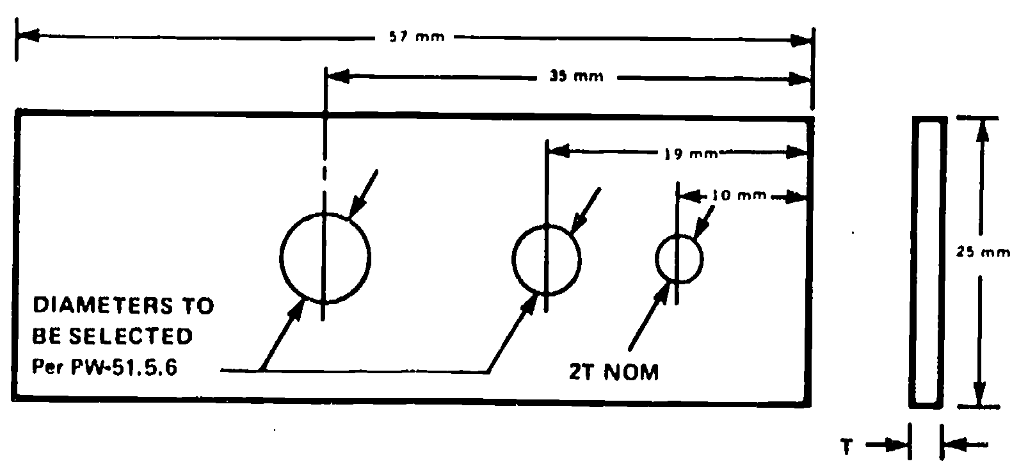
The specification numbers of materials in each P-number group are listed in Table Q-11.1 in the ASME Code Section IX.

After completion of the postweld heat treatment, the weld surfaces are ground off and the welds are radiographed.

Radiographic testing consists of exposing the weld to radiation in the form of X-rays or gamma rays. A photographic film is placed on the opposite side of the weld from the source of radiation and any defects in the weld will be indicated on the film.

The X-ray radiation is produced by an electronic X-ray tube while gamma ray radiation is produced by a radioactive material such as cobalt or radium.

During the radiographic inspection of a weld, strips of metal called penetrameters are used. (See Fig. 6) These are made of the same material as the welded parts and have a thickness equal to a definite percentage of the thickness of the welded parts. Usually several small holes are drilled in the penetrameter and it is placed adjacent to the weld. When the radiographic "picture" of the weld is taken, the outline of the penetrameter will be visible on the film and this will give an indication of the sensitivity and clarity of the radiograph and the holes will give an indication of the size of any defects present.



Penetrameter

Fig. 6

(PE1-2-2-13)

Weld defects which may be discovered by radiography include the following: porosity, slag inclusions, inadequate penetration, incomplete fusion, undercutting and cracking.

Porosity refers to voids within the weld which are caused by gases released during the welding process and trapped in the molten metal.

Slag inclusions are formations of oxides and other nonmetallic solids entrapped in the weld metal or between the weld metal and the base metal.

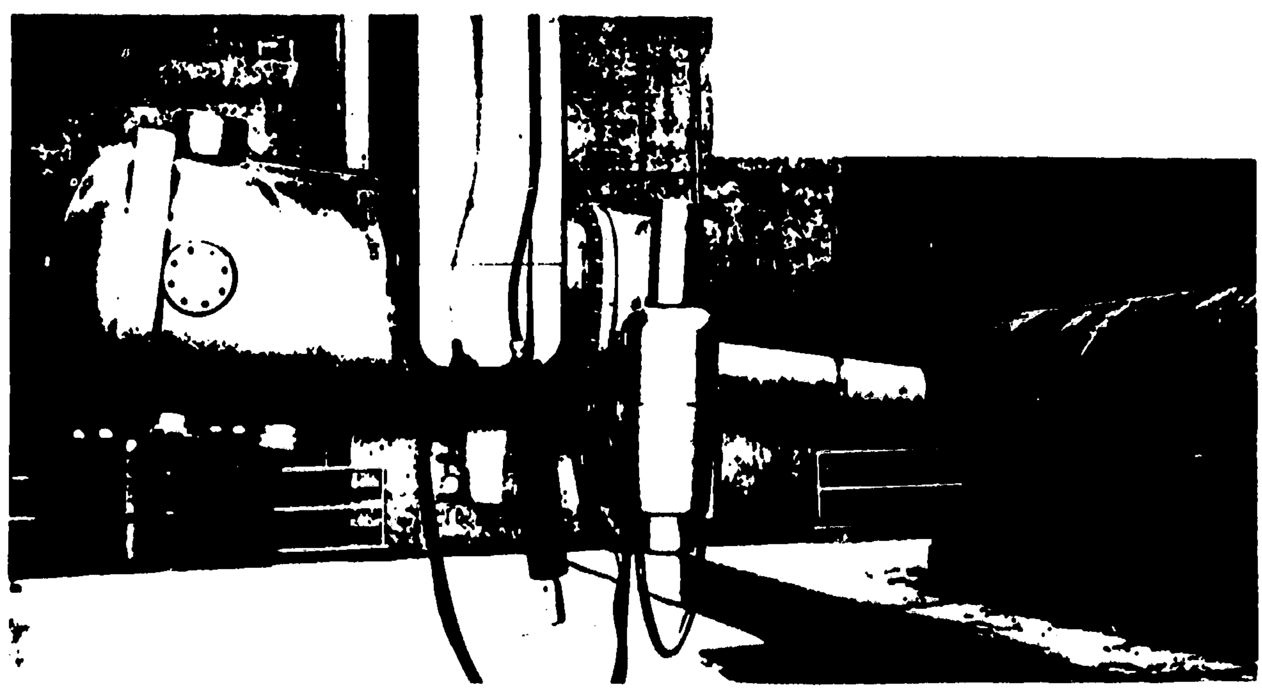
Inadequate penetration refers to the incomplete filling of the bottom of the weld groove with weld metal.

Incomplete fusion refers to the lack of bonding between beads or between the weld metal and the base metal.

Undercutting refers to a groove melted into the base metal adjacent to the toe of the weld and left unfilled by weld metal.

Cracking of the welded joint results from the presence of localized stress and may occur in the weld metal or the base metal.

Radiographic procedures are covered in PW-51 ASME which discusses weld joint preparation, penetrameter specifications and use, identification, and unacceptable defects.



Weld Radiography (Foster Wheeler)

Fig. 7

Fig. 7 shows the main seam of a boiler drum in the process of being radiographed by the X-ray method.

(PE1-2-2-14)

As well as radiographic inspection, test plates or coupons containing metal deposited during the welding operation are removed from the drum and submitted to strength tests, chemical analysis and microscopic examination.

A final test which is carried out in the manufacturer's shop is a hydraulic or hydrostatic test which is carried out to Code requirements (see PW-54) at a pressure of at least 1.5 times the design working pressure. The drum is then ready to be shipped.

TUBE FABRICATION

Boiler tubes may be fabricated in a seamless form or they may be welded.

1. Seamless Tubes

One method of producing seamless tubes is by piercing and rolling. A hot solid round billet of carbon steel or alloy steel is forced over a piercing point bar by means of conical shaped rolls. Then the piercing bar is withdrawn from the inside of the roughly formed tube which is then reheated for rolling.

In the rolling mill the tube is lengthened and its wall thickness is reduced to the approximate desired dimensions. It is then smoothed off and burnished while still hot in a reeling machine and then finally rolled to the finished size in a sizing mill.

In cases where the tubing is required to have a more smooth and even finish and more accurate dimensions, it is subjected to a further process of cold drawing. In this process the cold tube is drawn through dies until the desired finish and dimensions are achieved.

Another method of producing seamless tubes is by the extrusion process. With this method a hot hollow billet of steel is forced through a die by means of a ram. A mandrel attached to the end of the ram extends through the hollow billet and through the die. As the ram moves forward, the metal is squeezed out between the die and the mandrel. A special glass lubricant is used to lubricate the mandrel, billet, and die during the operation.

Fig. 8 illustrates the extrusion process.

In Fig. 8 (a) the hot billet is pushed into a container to which is attached the die. In Fig. 8 (b) the ram and mandrel are pushing the billet toward the die and in Fig. 8 (c) the hot metal is being pushed through the die and around the mandrel to form the tube.

After being formed by the extrusion process the tubes are cold drawn to the desired finished size.

2. Welded Tubes

Welded tubes are formed from a flat strip or skelp which is rolled into tubular form and the edges then butt welded together. Either of two welding methods may be used; the furnace butt weld or the electric resistance weld.

To make furnace butt welded tubes, the hot skelp is taken from the furnace and formed by a series of rolls into a circular tube shape. The hot tube then passes through welding rolls which squeeze the edges together and so fuses them. The welded tube then passes to reducing and sizing rolls for final finishing and dimensioning.

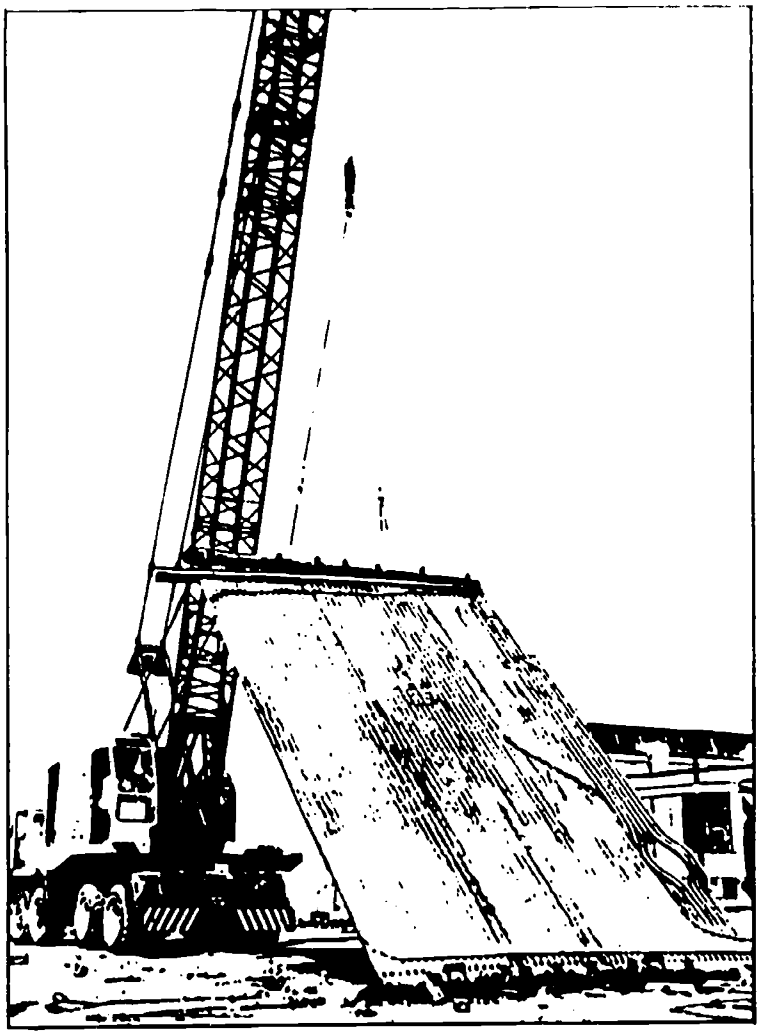
To make electric resistance welded tubes, the flat strip is rolled into tube form by forming rolls. The tube is then welded by a welding roll having two electrode halves which straddle the tube joint. The welding current passes between the electrodes through the tube joint thus producing enough heat to fuse the edges together.

After welding, the excess metal is trimmed off on the outside and the inside of the weld seam. The tube then is rolled to the correct size.

BOILER ERECTION

In the case of small-sized boiler units, the entire unit is fabricated and assembled in the manufacturer's shop and then shipped as a single package to the customer. On arrival at the customer's plant the unit is mounted on a suitable foundation and the necessary piping, ductwork and electrical connections are supplied thus completing the erection.

In the case of larger sized units the usual procedure is to fabricate and



Furnace Wall Panel

Fig. 9

In addition to the furnace wall tubes, other parts which may be shipped in panel or module form are superheater, reheater and economizer tubes. If shipping is done by rail then 100 or more rail cars may be required to handle all the components of a large central station boiler. Besides the tubes already mentioned, these components include the drum, air heaters, soot blowers, dust collectors, burners, valves, wall casings, pulverizers, structural steel, walkways, stairways, gratings, ducts etc.

Foundations and Structural Steel

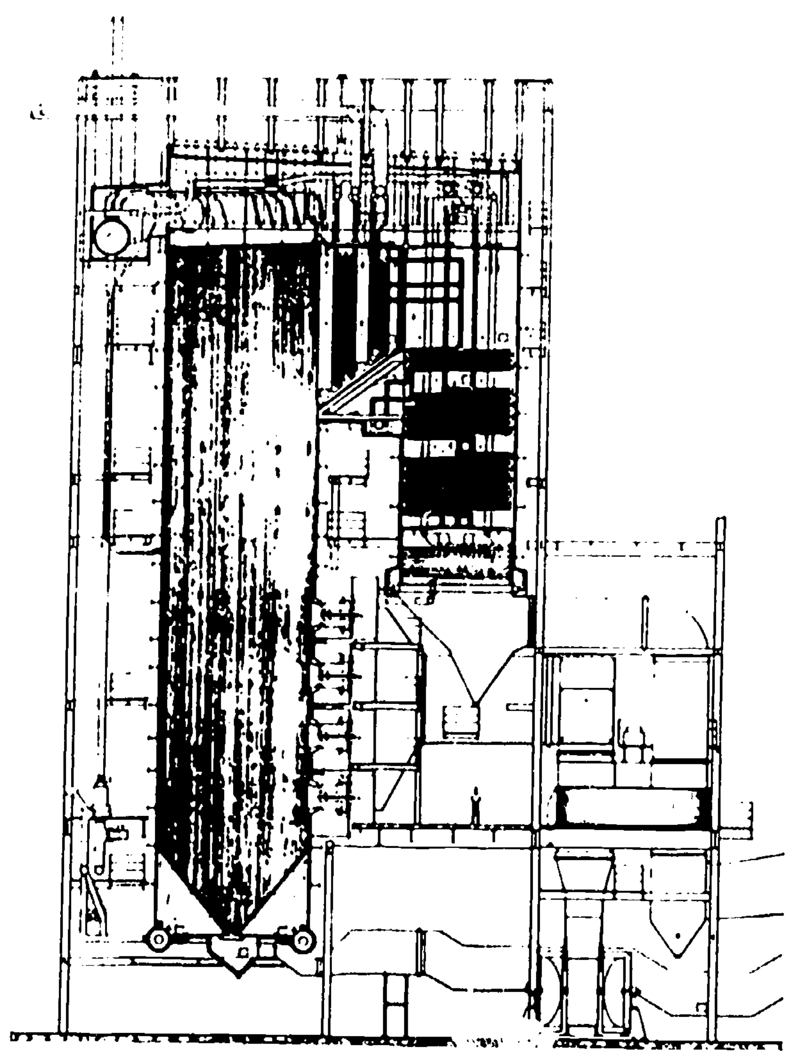
An adequate foundation is necessary for the boiler in order that there will not be any settling or movement of the unit which could cause strain on piping or cracking of refractory.

For small packaged boilers the boiler room floor is usually sufficiently strong with the unit being grouted into place. Medium-sized boilers which are bottom supported require proper footings and piers. The large boilers are top-supported by means of steel columns which require massive foundation piers.

The boiler foundations are usually designed and installed to specifications by the building contractor from plans supplied by the boiler manufacturer.

The large high central station boilers require extensive supporting steelwork. This supporting structure must be able to withstand the mass of the boiler and other related equipment, plus wind loads and earthquake forces where the plant location makes this necessary. In addition, the structure must support the boiler in such a way as to allow for free expansion of all parts. These large boilers are top-supported by means of hangers which extend from the structural steel to the various component parts of the boiler. In this way the boiler is allowed to expand downward from the main supports at the top.

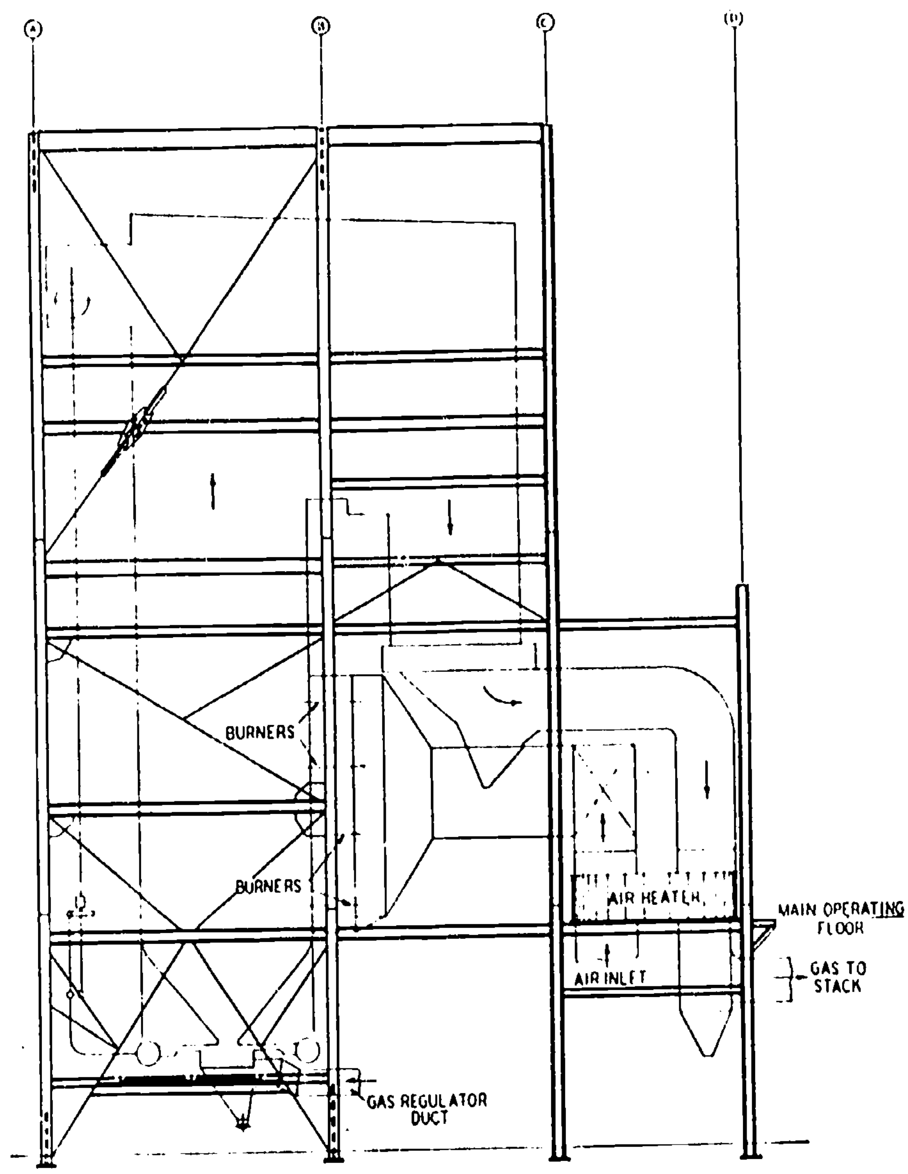
Fig. 10 shows a cross section of a boiler showing the supporting steel framework with hangers extending to the main drum and to channel-type beams known as the pressure parts support level. From the pressure parts support level more hangers extend to the waterwalls, superheater, reheater and economizer.



Reheat Boiler
(Combustion Engineering)

Fig. 10

(PE1-2-2-18)



Boiler Structural Steel
(Combustion Engineering)

Fig. 11

Fig. 11 shows the arrangement of the structural steel for the boiler in Fig. 10 before the drum hangers and the pressure parts support level are in place.

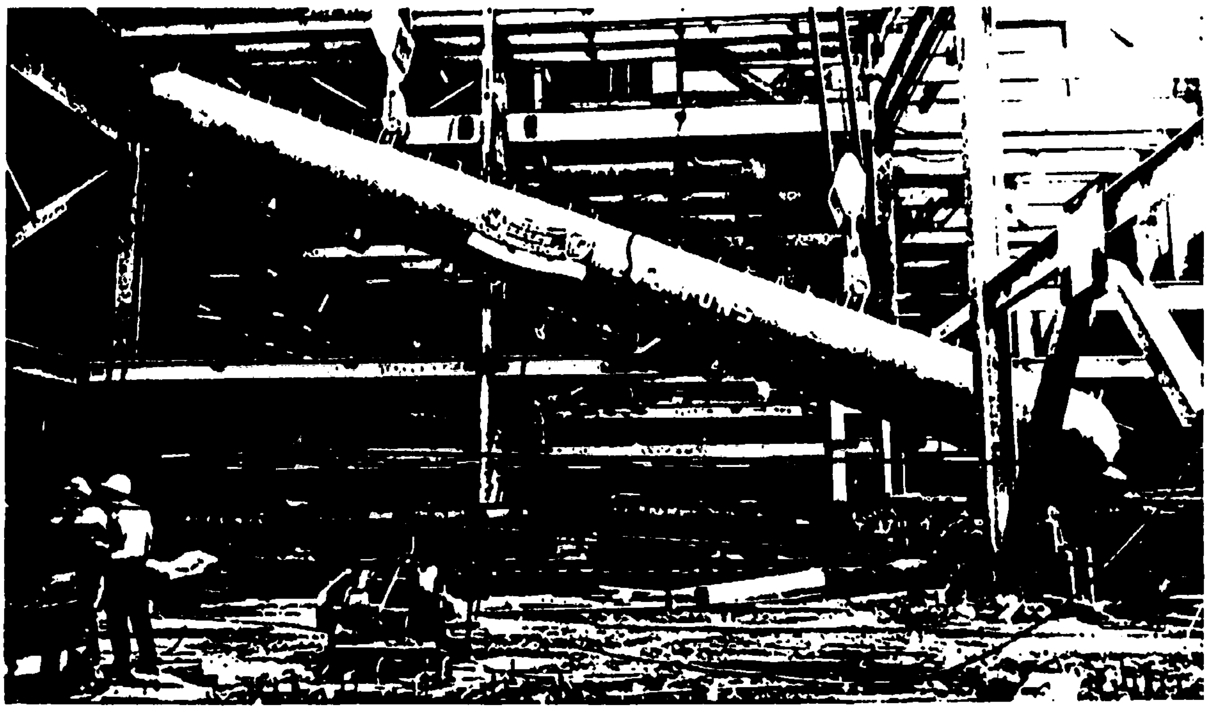
As well as supporting the boiler drum and other pressure parts, the structural steel must also support air heaters and ductwork. In addition, the structure must provide for platforms and walkways which are necessary for operation and maintenance of the unit.

The boiler structural steelwork is normally integrated with the steelwork of the building which houses the boiler, with the platforms and walkways arranged for access from the various floors in the plant.

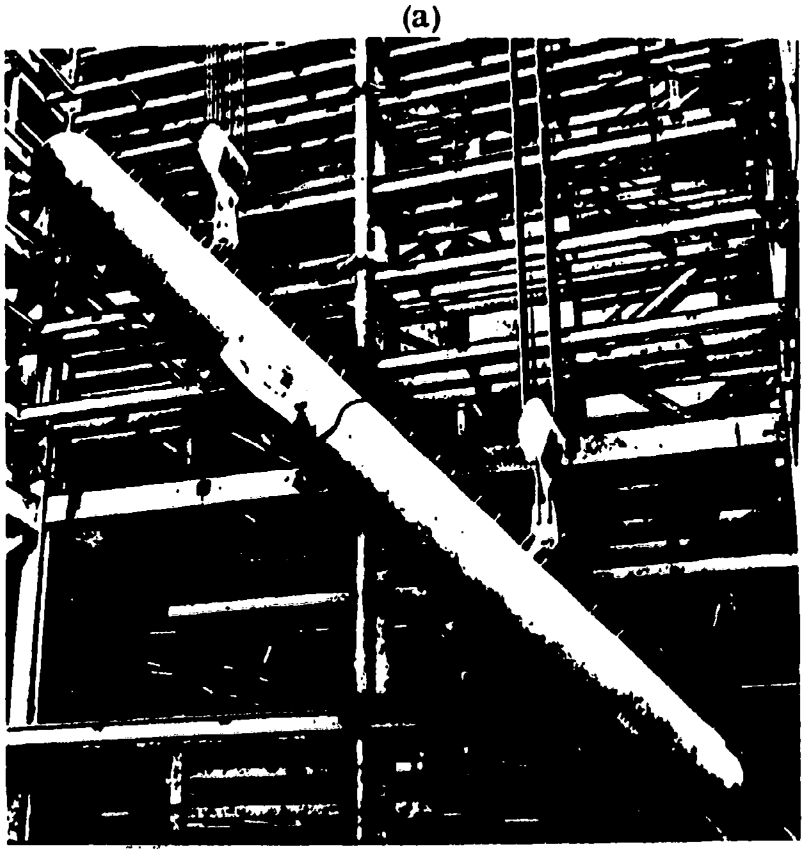
(PE1-2-2-19)

Boiler Drums

After the structural steelwork has been erected, accurately aligned, and bolted or rivetted together, then the boiler drum is raised into position.



(a)



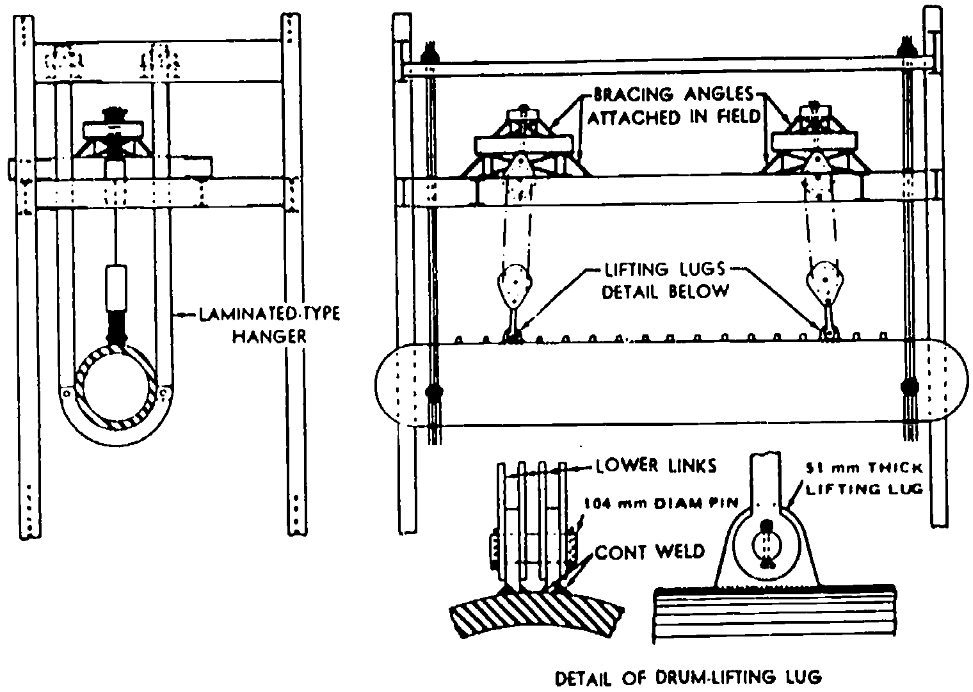
(b)

Lifting Boiler Drum (Foster Wheeler)

Fig. 12

(PE1-2-2-20)

Fig. 12 (a) shows a 250 tonne drum being raised from its railroad flatbed car and Fig. 12 (b) shows the angled lift necessary to clear steelwork obstacles as the drum rises to its final position.



Lifting Gear
(Babcock and Wilcox)

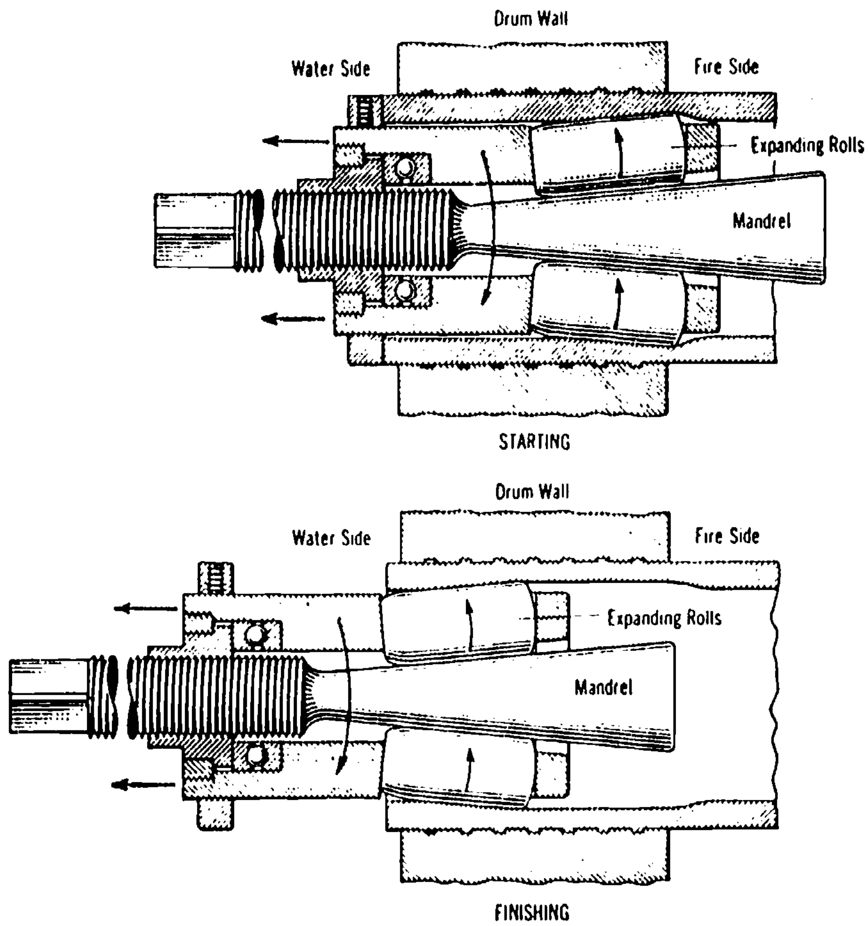
Fig. 13

Details of lifting gear and the drum hangers are shown in Fig. 13. Note that with this arrangement the lifting lugs are secured to the drum by shop-welding.

Tube Installation

Once the drum is in place it is braced or blocked to make sure no movement will take place during the installation of the tubes. The tubes are attached to drums and headers by rolling (expanding) or more usually, for large high pressure units, they are welded to tube stubs which have already been welded to drums and headers in the manufacturer's shop.

In the rolling or expanding method, a tool called an expander is used to press the tube wall against the metal of the tube hole which is usually grooved. A method known as retractive expanding is illustrated in Fig. 14.



Retractive Expanding
(Babcock and Wilcox)

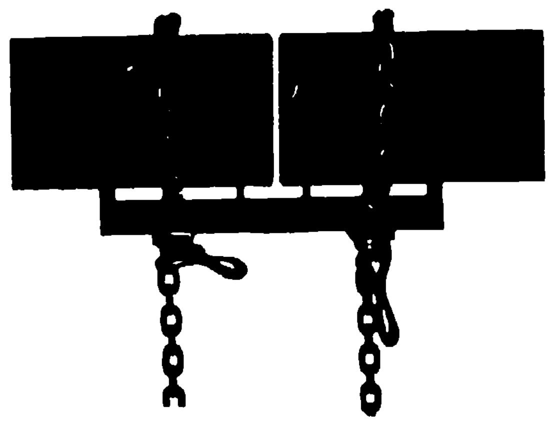
Fig. 14

The expanded connection has great strength and is widely used. Under some conditions, however, it is not suitable due to inaccessibility of the connection or due to high requirements due to high temperatures and pressures. In these cases welded connections are preferred.

During the boiler erection a large number of butt welds must be made in the field. These include butt welding of tube sections together and butt welding of tubes to tube stubs in drums and headers.

Tube ends are usually prepared for welding in the manufacturer's shop and only cleaning and buffing are required in the field.

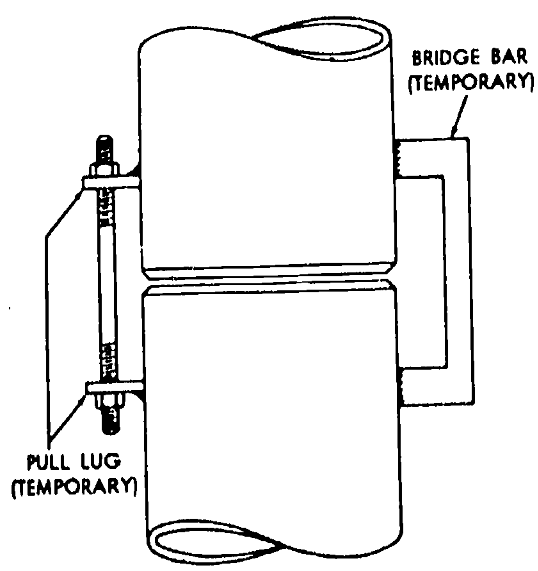
In fitting the joint together for welding, care must be taken to assure proper alignment of the tube ends. Fig. 15 shows a simple form of jig used to align the tube ends for smaller sizes of tubes and pipes.



Alignment Jig

Fig. 15

An arrangement of a bridge bar and pull lugs such as shown in Fig. 16 can be used to align larger sizes of tubing and piping.



Alignment Arrangement

Fig. 16

(PE1-2-2-23)

Weld Inspection

Inspection of welding of pressure parts is required to assure the manufacturer that all workmanship meets his standards and to assure the authorized inspectors that all welding complies with the ASME Code.

The inspection involves the following considerations:

1. Determining that each operator is qualified, in accordance with the Code, for the welds he makes.
2. That the welding procedure specifications are followed in every respect.
3. Examination of the joint for proper fit-up and alignment before the weld is started.
4. Routine checks during the welding procedure of preheat and welding current, technique of operator in regard to cleaning of slag from each bead, and keeping the weld free from slag, porosity and undercutting.
5. Visual examination of the finished weld for undercutting, general appearance and proper weld reinforcement.

Field welded joints must be radiographed unless they conform to the conditions laid down in PW-41.1. Capsules containing radium sulphate or a radioactive isotope are used as the source of radiation and these are placed within the pipe or tube with the film on the outside.

Unless specifically exempted by the ASME Code (see PFT-24, PG-39.7, PG-42.1 and Table PW-39 notes) all welded pressure parts of power boilers shall be given a postweld heat treatment. This heat treatment can be carried out in the field by flame heating, electrical resistance heating, or electrical induction heating.

During the boiler erection, a method frequently used is the welding together of tubes and headers into panels at ground level. The panels are then hoisted into place in the unit.

Fig. 17 shows a lower section panel of a waterwall being raised into position for welding to the upper section which is already in place.

After all tubes, headers and other pressure parts have been erected and connected, the external attachments such as tie bars, buckstays, and brickwork and insulation supports are installed and welded. Then a hydrostatic test of $1\frac{1}{2}$ times the maximum allowable working pressure is applied.

Erecting Waterwall Panel

Fig. 17

Hydrostatic Test

Before the boiler is filled with water for the hydrostatic test, the tubes are probed to ascertain that they are not plugged and drums and headers are cleaned out and closed up. The drum internals are usually not installed until after completion of the hydrostatic test and water gage glasses are removed prior to the test.

To perform the test the boiler is filled with water at ambient temperature but not less than 21°C. The pressure is then applied gradually until it is $1\frac{1}{2}$ times the maximum allowable working pressure. Then the test pressure is reduced to the maximum allowable working pressure and maintained at this pressure while the boiler is carefully examined.

After completion of the hydrostatic test, the gage glasses are installed and checked to see if they read correctly. To do this the water is drained down to just below the level of the manhole in the drum head and measurements are taken to see if the gage glass level corresponds. The boiler is then drained completely and the drum internals and safety valves are next installed.

Also, after the hydrostatic test is completed and the unit has been proved leakproof, the refractory and insulation is applied.

Casing and Insulation

Plastic chrome ore is often used as the refractory around insp ction and burner openings. Plastic insulation is applied to the outside of the waterwall tubes and block insulation is frequently applied over the plastic insulation. The cracks between the insulation blocks are pointed up with asbestos cement. A finish coat of plastic insulation may then be applied and finally a complete metal casing is installed over the installation.

The plastic insulation is made up of mineral wool fibres processed into nodules and then dry-mixed with clay. Before application it is mixed with the correct amount of water and then it is applied by throwing against the surface and then finishing off to the correct thickness with a trowel.

Block insulation may be produced from diatomaceous earth, mineral wool, magnesia, and kaolin clay. The blocks are held in place by galvanized wire criss-crossed from the welded insulation supports.

Expanded metal lath may be used to reinforce the insulation and wire mesh is used to reinforce the finish coat.

The metal casing may be supported by the wall structure itself or it may be supported by external steelwork. The casing may be classified as airtight, nontight or pressure.

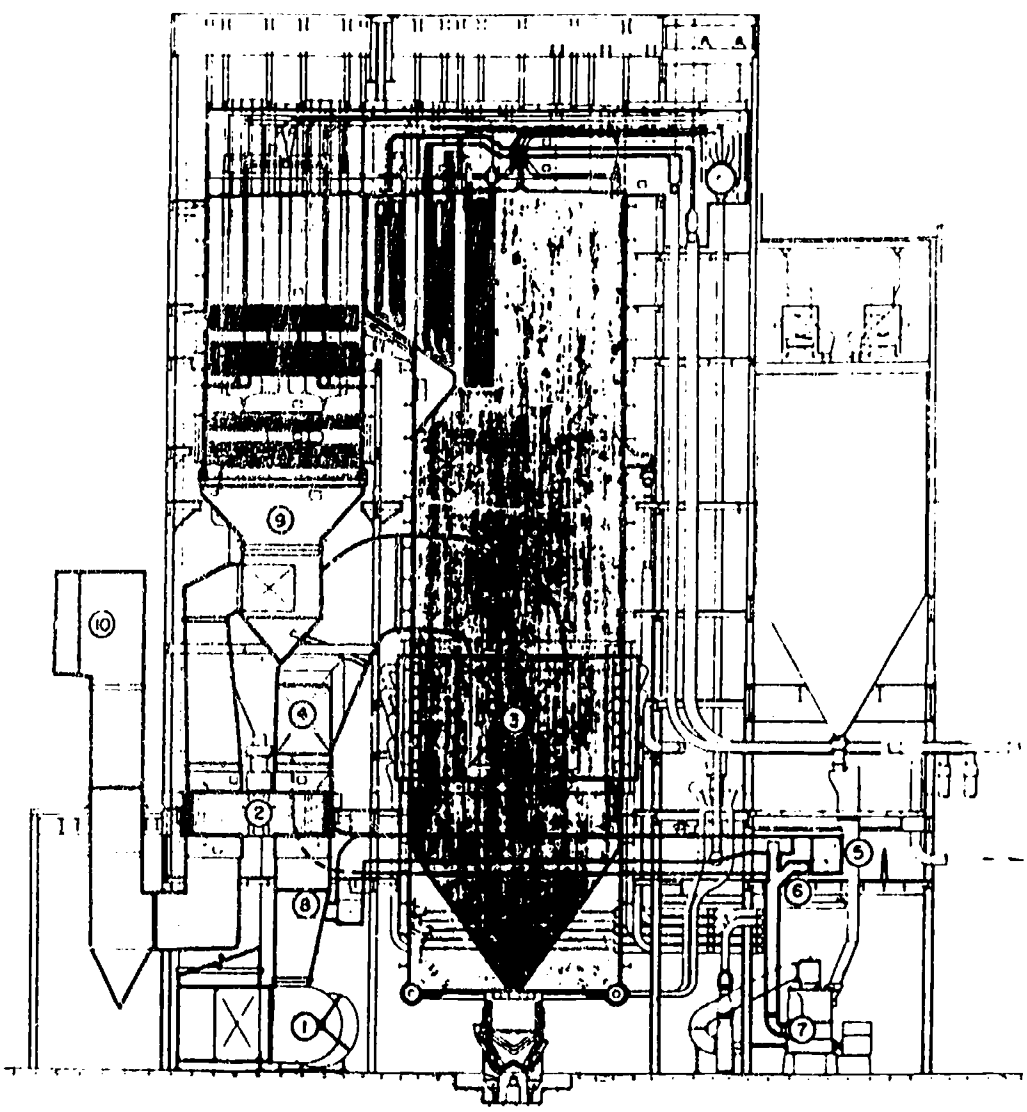
The airtight casing has to be reasonably tight to keep air leakage to a minimum. It is usually constructed of flanged panels which are bolted or welded together.

The nontight casing only serves to protect the insulation and to improve the appearance of the boiler. Air leakage is prevented by the insulation which must be arranged and installed to be quite airtight.

The pressure casing is used for pressurized furnaces and must be completely airtight against the pressure carried within the furnace. This type of casing is therefore completely welded.

Boiler Ductwork

A system of metal ducts is necessary for conveying the combustion air to the furnace and for conveying the combustion gas from the furnace to the stack. These ducts are supported by the structural steelwork and consist essentially of: a main air duct from the forced draft fan to the air heater and then to the burners, a main gas duct from the economizer outlet to the air heater and then to the induced draft fan and to the stack. If the boiler is fired with pulverized coai there will also be a primary air duct from the main air duct to the pulverizers. This primary air duct is taken off the main duct just after the air heater as the air it carries to the pulverizer must be heated. In addition, an air recirculating duct may be used to recirculate air from the air heater outlet to the forced draft fan inlet in order to control the temperature of the air entering the air heater.



Ductwork Arrangement
(Combustion Engineering)

Fig. 18

(PE1-2-2-27)

Fig. 18 shows the arrangement of the ductwork in a central station boiler. The circled numbers in the sketch refer to the following items.

1. forced draft fan
2. air heater
3. burner windbox
4. primary air take-off
5. pulverizer manifold
6. pulverizer tempering air
7. pulverizers
8. forced draft fan discharge
9. economizer gas outlet
10. ductwork to stack

Pre-Operation Inspection

After the boiler has been completely erected, a thorough inspection of all parts must be carried out before the boiler can be filled with water and fired.

All trash and debris must be removed from the drum, and tubes should be closely checked for obstructions. The drum internals must be checked for correct position and tightness of fastenings. In the case of the chemical feed line, the continuous blowdown line, and the feedline itself, those portions which are located within the drum must be inspected to make sure they are clear. In addition, all drum connections must be checked for clearness.

An internal inspection of the furnace must be carefully carried out and all timbers, scaffolding parts, cardboard and other debris removed. Flue gas baffles are examined for proper location and installation as are the furnace openings for inspection, flue gas sampling, and pressure and temperature instruments. Movement of soot blowers are checked to make sure of proper clearance and to avoid the possibility of direct steam impingement on tubes or baffles.

All breeching and duct work must be cleared of dirt and other obstructions. Dampers should be operated to ascertain their freedom of movement and the open and closed positions are marked on the operating mechanism. Pressure and temperature measuring connections, such as those before and after the air preheater, are checked for location and installation. The air preheater is checked for cleanliness and freedom of movement in the case of the rotary type. If soot blowers are installed for the air heater they must also be checked for proper location and installation. Induced draft and forced draft fans must be lined up, lubricated, checked for direction of rotation and operation of control mechanisms.

Dust collectors are usually installed before induced-draft fans in order to reduce wear on fan blades and liners as well as to reduce the amount of dust sent to the atmosphere. Collectors may be of the mechanical or electrical type or a combination of the two. Before they are placed in operation, a complete final check for internal cleanliness, casing tightness, proper positioning of elements, proper insulation of electrical elements, provisions for expansion, means for dust removal, and location of draft and test sampling points should be made. Shutoff and bypass dampers if provided should be checked for tightness of closing, provision for expansion under heat, and completeness of travel. Open and closed positions of dampers should be plainly marked and adequate means for operating and positioning dampers should be provided.

If a fan is incorporated in the dust-collector assembly, the usual precautionary checks for alignment, lubrication, and cleanliness should be made. If the collector utilizes electrostatic equipment, a final check of transformers, rectifiers, and auxiliary and control apparatus should be made before the collector is placed in service.

All boiler piping must be carefully examined to make sure it is complete. Smaller lines such as drains and blow-off piping are sometimes accidently left disconnected. Safety valve discharge piping must be adequately supported with the proper clearance allowed so that no weight is carried by the safety valve under any conditions. This piping must also be carefully examined to make sure it is clear and free from obstructions. Chemical feed lines, water sampling lines, and water column and gage glass drains are checked for completeness. Valves in main steam piping and in feedwater piping are checked for proper operation.

Piping to burners is checked for completeness and burner damper vanes and louvres operated to assure freedom of movement.

Upon completion of the overall inspection of the above components the boiler is ready for dry-out and boil-out and these proceedings will be described in a subsequent lecture.

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 2

1. Discuss the following terms as applied to steel manufacture:

    (a) rimmed steel
    (b) capped steel
    (c) semikilled steel
    (d) killed steel

2. Describe the inspection that should be carried out after a boiler has been erected and before it is put into operation.

3. (a) List the advantages of low alloy steel compared to plain carbon steel.

    (b) Give an example of a typical low alloy steel and list its alloy content in percentages.

4. Sketch the basic outline of a large boiler showing the arrangement of the ductwork.

5. List a suitable material for the following boiler parts:

    (a) steam drum
    (b) waterwall headers
    (c) waterwall tubes
    (d) radiant superheater tubes

6. Describe the various checks which should be carried out in relation to the welding of a pressure joint.

7. Discuss the weld defects which could be revealed by radiography.

8. Describe the method and the gear used to raise a large boiler drum into position during erection.

9. Sketch a typical arrangement of the structural steel for a large boiler including the drum hangers.

10. Describe briefly how the following types of tubes are fabricated:

    (a) seamless tubes
    (b) electric resistance welded tubes
    (c) furnace butt welded tubes

INSTRUCTIONAL LEARNING SYSTEMS

7.4

BOILERS -- FITTINGS

Goal:

The apprentice will be able to describe boiler fittings.

Performance Indicators:

1. Describe safety valves.
2. Describe water columns and gage glasses.
3. Describe pressure gages.
4. Describe feedwater connections.
5. Describe blow-off valves and connections.
6. Describe slop and check valves.
7. Describe drum intervals.
8. Describe soot blowers.
9. Describe fusible plugs.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Angle type valve
* Bellows gauge
* Bi-color gauge glasses
* Bottom blow-off
* Bourdon, spring gauge
* Combination blow-off valve
* Continuous blow-off
* Fireside fusible plug
* Flat gauge glasses
* Gauge glasses
* Gate type valve
* Globe type valve
* Helix Bourdon gauge
* High pressure gauge glass
* Huddling chamber type valves
* Jet flow type valves
* Long retractable nozzle soot blower
* Main dial gauge
* Metallic diaphragm gauge
* Non-return stop valve
* Nozzle reaction type valve
* Outside screw-and-yoke type valve
* Pointer mechanism
* Power operated relief valves
* Pressure gauge siphons
* Pressure gauges
* Remote gauge glass indicators
* Safety valves
* Seat and disc blow-off valves
* Seatless sliding plunger and blow-off valve
* Single nozzle retractable soot blower
* Sliding disc blow-off valve
* Solenoid
* Spiral Bourdon gauge
* Surface blow-off
* Torsion bar safety valve
* Tubular gauge glasses
* Water column
* Waterside fusible plug

Introduction

Boiler fittings are those items that are directly attached to the boiler. The fittings are necessary for safe and efficient operation of the boiler.

The apprentices should be concerned with this unit of instruction. Future safety may depend on the ability to identify each fitting, its function and how it operates. Steam plant operators must know about fittings and gain experience in their operation.

Beyond the safety aspects, fittings are part of efficiency. The goal of all good operators is to run safe and efficient plants.

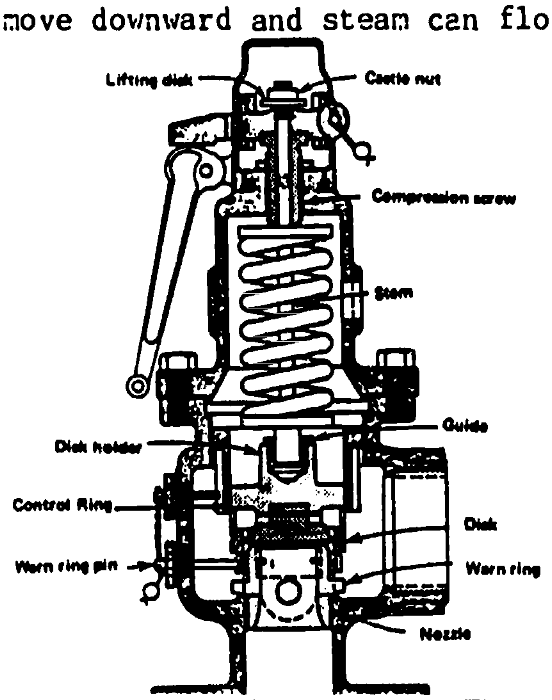
Information

Safety Valves

Safety valves prevent excess pressures in the boiler. When the pressure exceeds safe levels, the safety valve will trip. There are several types of safety valves. Some are held shut by steel springs or torsion bars and open by steam when the pressure exceeds the setting of the valve. The valve may be opened by nozzle reaction, jet flow or huddling chamber.

Nozzle Reaction Valve

When the valve opens, a baffle and disc are raised upward by the steam. This closes off the baffle ports and reverses the direction of the steam. Pressure drops allow the baffle to move downward and steam can flow through the baffle ports.



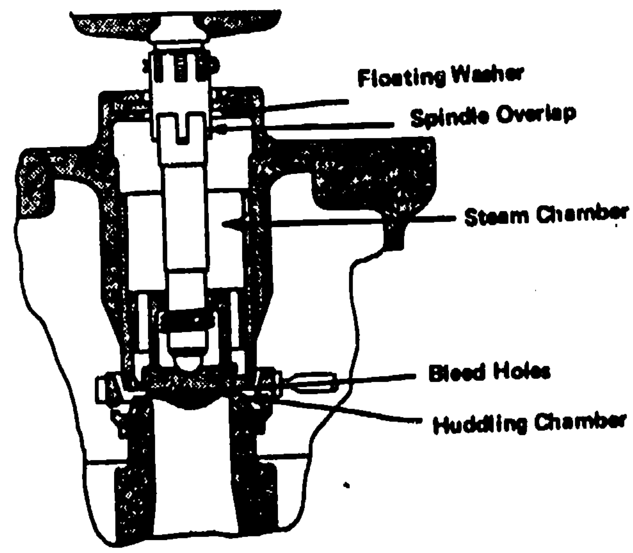
Jet Flow Safety Valves

Steam flows from this valve and strikes the piston. The jet stream is deflected downward to the nozzle ring. This gives more thrust and the valve opens further.

Information

Huddling Chamber Safety Valves

The valve is opened by pressure upon the disc. As it opens the huddling chamber fills with steam and causes a further lift to the disc.



Power Operated Relief Valves

Relief valves can be operated by steam, hydraulics, electricity or remote control. An element is connected with the pressure vessel or header. When pressures exceed the limit, this element activates a soleroid which opens the pilot valve. The excess pressure is relieved from the boiler.

Torsion Bar Safety Valve

On high pressure dry steam such as superheaters or reheaters, torsion bars are used instead of coil springs. Torsion bars are preferred in extreme conditions of high pressure and high temperature.

Water Columns And Gauge Glasses

Gauge glasses are used to read the water levels in a boiler. A water column makes the glass gauge easier to read. The water column allows low and high level alarms to be installed. Gauge cocks are also installed on water columns. Tubular gauge glasses are used with pressures up to 2800 kPa. Higher pressures require a flat glass gauge.

Bi-Color Gauge Glass

One type of gauge glass uses colored glass (green and red) to make easier

Information

reading of the gauge. A light is directed through the colored glass strips. Green light will only shine through when water is in the gauge. Red light shines through when water is absent.

High Pressure Gauge Glass

High pressure gauge glasses are usually built with ports rather than flat glass. Individual port assemblies consist of a flat glass, gaskets, washers, and a cover and screws.

Remote Gauge Glass Indicators

On large boilers it may be difficult to read the gauge glass from floor level. A system of mirrors can be used to transmit the indicator to floor level. Another method of remote indication is achieved by use of a diaphragm. One side of the diaphragm is connected to the water side and the other to the steam side of the boiler. The varying levels of water cause the diaphragm to move. Red and blue light indicators show the water levels.

Pressure Gauges

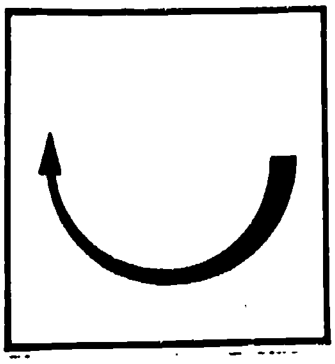
Each boiler has a pressure gauge that shows the pressure within the boiler. The gauge shows a range of 1 1/2 times (or more) the allowable working pressure. Pressure gauges are classified into three basic types.

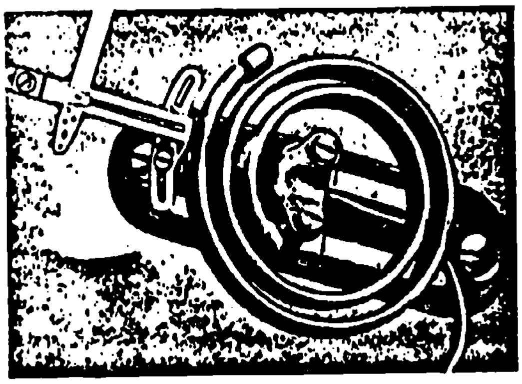
1. Bourdon spring gauge
2. Bellows gauge
3. Metallic diaphragm gauge

Bourdon Spring Gauge

The Bourdon spring is a C-shaped tube that is closed at one end and attached to a pointer mechanism. When pressure is exerted in the tube, the Bourdon spring tends to straighten out. This process operates the pointer that shows the pressure on the dial. Variations of the Bourdon spring gauge are the spiral Bourdon tube and the Helix Bourdon tube. The C-type Bourdon spring gauge is used to measure boiler pressure at the main dial gauge. The Helix and spiral tube gauges are used for recoiling indicators. A spiral Bourdon tube gauge is shown as an example of the Bourdon principle.

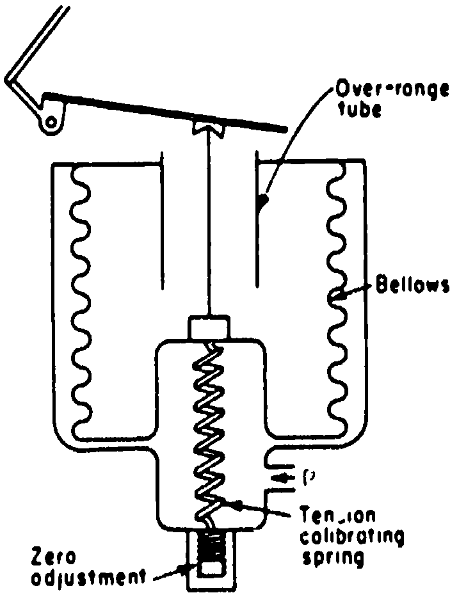
Information





<u>Bellows Gauge</u>

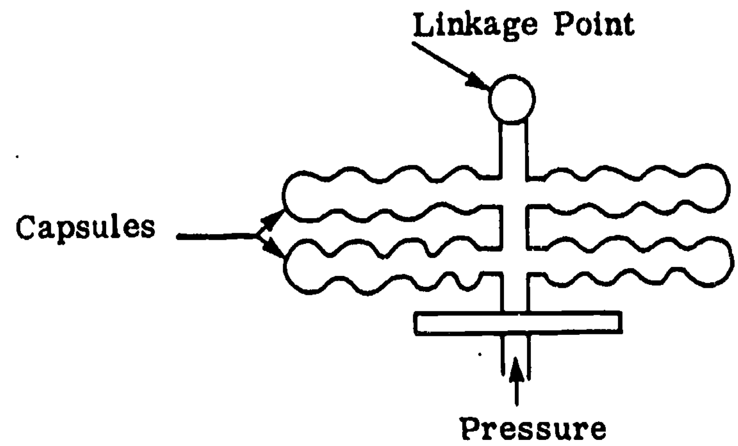
The bellows gauge uses a bellows of elestic metal. When pressure is applied to the bellows, a push-rod moves the dial indicator according to the level of pressure. The bellows is used in pneumatic controls and draft measurement indicators. A bellows type gauge is shown below.



<u>Metallic Diaphragm Gauge</u>

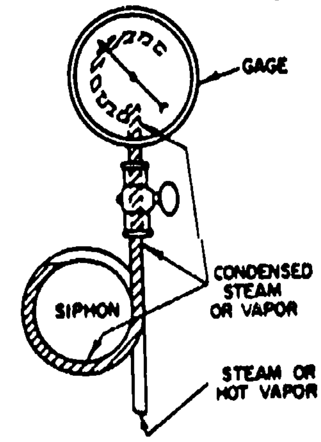
This type of pressure gauge operates with metallic capsules. The metallic capsules are connected together. When pressure is exerted inside the capsules, the capsules expand and move the linkage that operates the indicator. This type is also used in low pressure applications.

Information



Pressure Gauge Siphons

Steam pressure measurement must prevent the hot steam from entering the elements. If steam is allowed to enter the elements, the result will b inaccurate indications of pressure. A siphon is used to trap condensed ste and maintain a seal between the element and the hot steam.



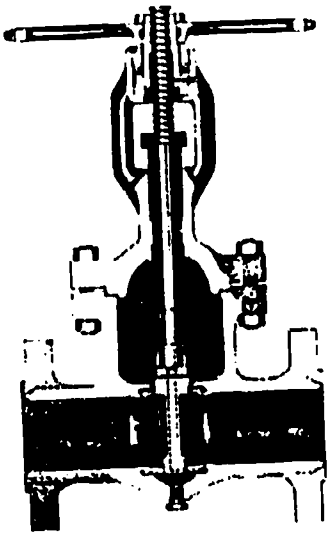
Boiler Stop Valves

A stop valve is used at steam outlets in a boiler. The valve should be an outside screw-and-yoke type. Usually the ouside screw-and-yoke valve is set next to a non-return valve. The two valves should be located close to the boiler with the non-return valve being closest to the boiler. Stop valves are of the following types.

1. Gate type
2. Angle type
3. Globe type

Information

All of these valves are of the outside screw-and-yoke type. One type of screw-and-yoke valve (Gate type) is shown.

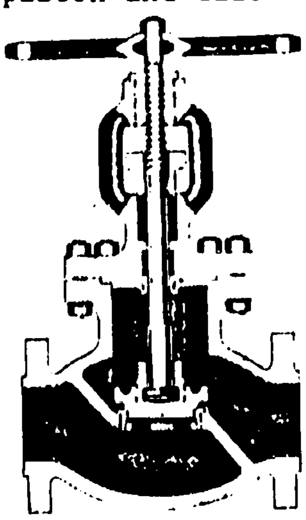


Non-Return Stop Valves

This stop-and check valve prevents a reverse flow of steam back into the boiler. Normally this valve is used when several boilers are pumping into a one common main. It is operated with a piston and disc to open and close the valve. It opens when inlet pressure is greater than oulet pressure. The valve closes when inlet pressure is greater than outlet pressure. Several types of non-return valves are used.

1. Globe non-return valve
2. Y-type non-return valve
3. Angle type non-return valve

All of these valves are operated with a piston and disc arrangement.



Information

Blow-off Connections

Blow-off connections are used for the following purposes:

1. Removal of sludge from boiler.
2. Inject acid cleaning solutions into boiler.
3. Lower excess water level in the boiler.

Types of Blow-off

Three major types of blow-off connections are found on boilers.

1. Bottom blow-off are at the bottom of the boiler and used to remove sludge from the boiler. On firetube boilers, the blow-off connection is to the rear of the boiler. Watertube boilers may have several blow-off connections to clean sludge out of the mud drums and headers.
2. Continuous blow-off connections are located below the water surface. Their purpose is to remove water that is heavy with dirt or sludge. A collecting pipe is located in the heavy water concentrate. A regulating valve controls the amounts of water removed by the continuous blow-off. Most continuous blow-off is part of a heat recovery system that salvages heat from the blow-off.
3. Surface blow-off connections are used to skim off surface sediment from the boiler water. The blow-off line is located at water level. A skimming pan moves up and down with variations in the water level. It scoops off sediment at the water surface.

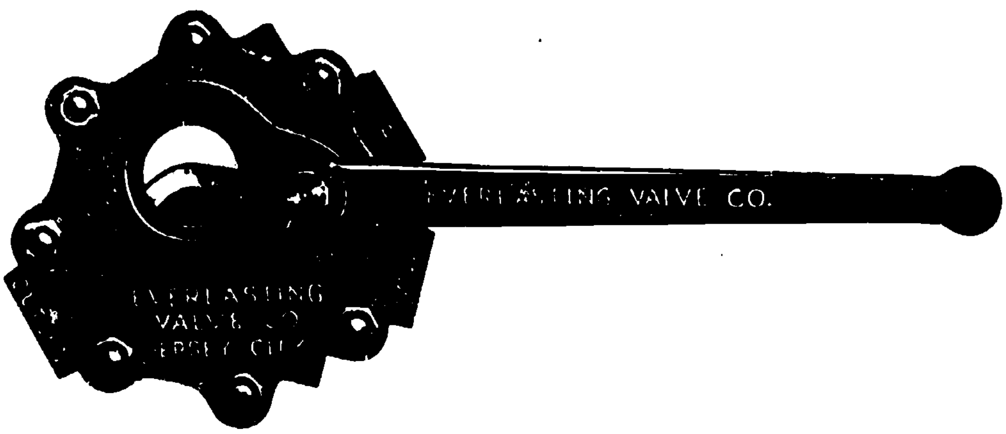
Blow-off Valve Types

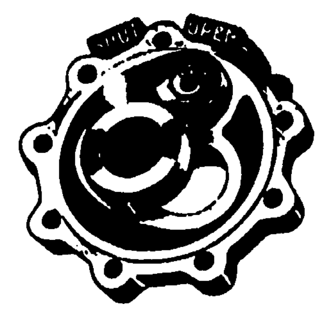
Four types of blow-off valves are used:

1. Sliding disc
2. Seatless sliding plunger type
3. Seat and disc type
4. Combination

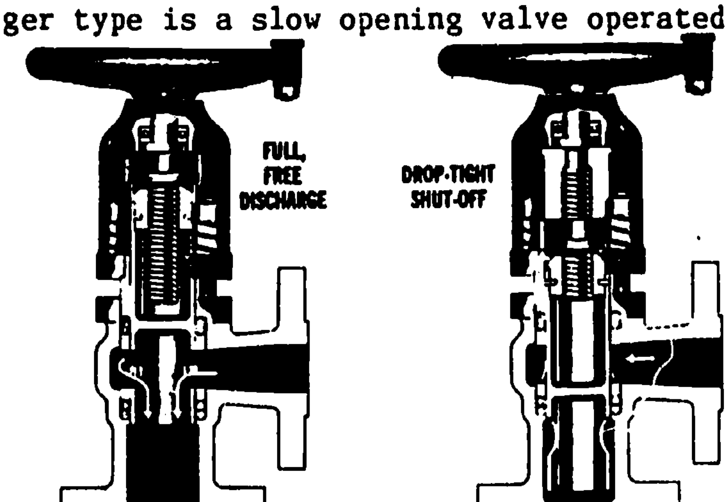
Information

The sliding disc valve is a quick opening valve that operates by lever action.

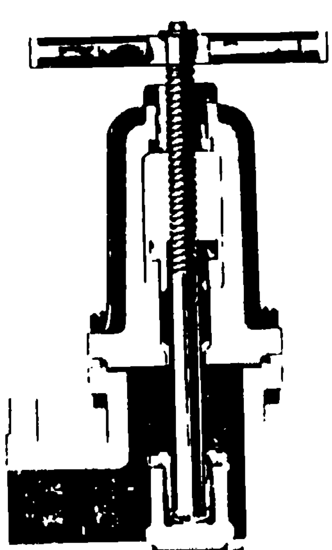


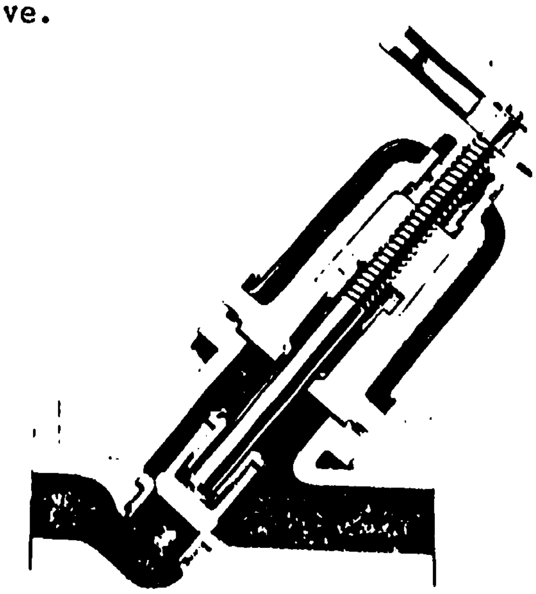


The sliding plunger type is a slow opening valve operated by a handwheel.



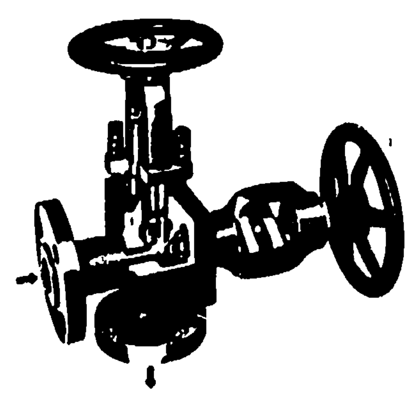
The seat and disc type is also a slow opening vlave with a bottom disc that closes the valve. It is a handwheel operated valve.





Information

Combinations of two types may be housed in one unit. The inlet valve may be of one type and the discharge valve of another type.



Blow-off Connections

Requirements for blow-off connections are summarized below.

1. Flanges shall not be of bronze, brass, flanged or screwed fitting types for use in blow-off lines.
2. Non-ferrous pipe or tubes shall not be used for blow-off piping.
3. All fittings between boiler and blow-off valves shall be of steel for pressures over 900 kPa.
4. Blow-off valves may be of cast iron if pressures do not exceed 1400 kPa. For pressures in excess of 1400 kPa, steel must be used for valves.
5. Minimum size for blow-off pipe is 25mm and the maximum is 64mm for boilers with over 64 square meters of heating surface. For those with less than 64 square meters, the minimum size is 16 mm.

There are many other requirements that are part of boiler safety codes. These requirements should be studied in relation to specific boilers that the apprentice is working with at the time.

Drum Internals

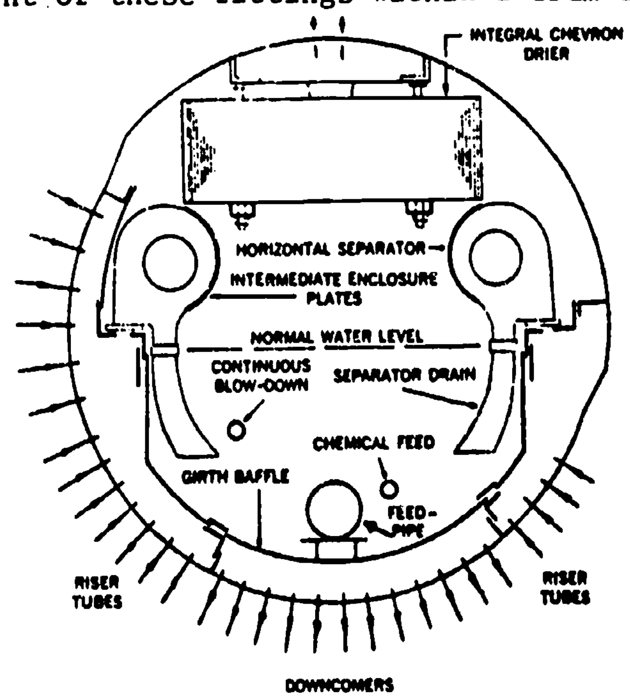
Several types of fittings are attached inside the steam drum. These fittings are devices for separating and washing steam; handling feedwater; handling chemicals and blow-off lines. These devices are given specific treatment in another package. The internals of a steam drum contain the following:

1. Steam separator

Information

2. Steam washer
3. Feedwater lines
4. Chemical lines
5. Blow-off lines

The arrangement of these fittings within a drum are shown below.



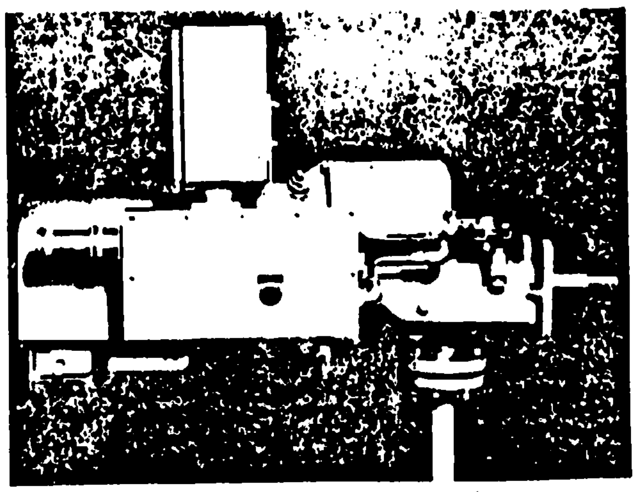
Soot Blowers

Soot blowers are used to remove ash from the furnace walls. An accumulation of ash and slag cuts down the efficiency of steam generation. The type of fuel used in combination determines how much soot removal equipment is needed. Natural gas burns clean and does not require soot blowers. Fuel oil burners do not require soot blowers. On those units that are fired with coal, soot blowers become very important. Soot blowers are of two types:

1. Single nozzle retractable type
2. Long retractable double nozzle type

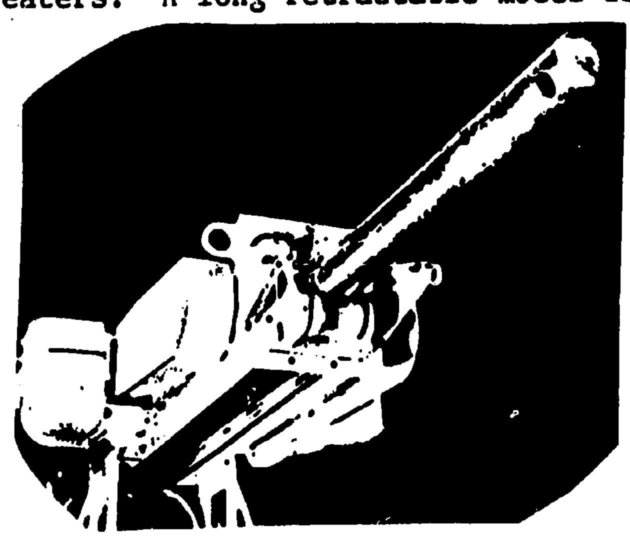
In the single nozzle type, one motor operates the retractable nozzle. The nozzle extends and retracts. Another motor rotates the nozzle a full 360 . Steam, air or water is directed against the sides to dislodge the ash and slag from the heating surfaces. A single nozzle retractable blower is pictured.

Information



Single Nozzle Retractable Wall Blower

A long retractable nozzle blower is used to clean soot from high temperature areas such as superheaters. A long retractable model is shown.



Feedwater Connections

Feedwater connections include valves, fittings and piping for moving feedwater to the boiler. All boilers must have one or more means of feeding water into the system.

Feedwater Valves

Feedwater lines must be fitted with stop valves between the check valve and the boiler. When more than one boiler is supplied by a common feedwater source, a

Information

Regulating valve must be installed on branch lines to the individual boilers.

Feedwater Piping

Piping must meet the requirements of the working pressure of the boiler. The pipe thickness is computed by the following formula:

$$t = \frac{PD}{2\,SE + 2yP} + C$$

where:
t = thickness of pipe
P = maximum allowable workin pressure
S = maximum allowable stress valve at operating temperature (from table)
E = efficiency of longitudinal welded joints (From code)
C = minimum allowance for threading and structural stability in m.m. (From code)
y = a temperature coefficient (From code)

A list of code tables are needed to compute thicknesses needed for feedwater piping on specific boilers.

Fusible Plugs

Fusible plugs give warning of low water levels in the boiler. It is a brass plug with a tin-filled tapered hole drilled through it. It is installed at the lowest permissable water level in the boiler. When water levels drop below the plug, the tin will melt and steam will blow out the plug. The operator is warned so that the boiler can be shut down before damage occurs. Plugs are classified as:

1. Fireside plugs which are tapped into holes from the fire side.
2. Waterside plugs which are tapped from the water side of the boiler.

Assignment

* Read and study illustrations in supplementary references. Read as much of the references as time will allow.

* Complete the job sheet.

* Complete the self-assessment and check answers.

* Complete the post-assessment and ask the instructor to check your answers.

Job Sheet

ANALYZE THE FITTINGS ON A BOILER

* Observe a boiler and closely inspect for the following items. Identify types of each item.

  - Safety valves
  - Water columns and gauge glasses
  - Pressure gauges
  - Feedwater connections
  - Blow-off connections
  - Stop and check valves
  - Drum internals (if possible)
  - Soot blowers (if possible)
  - Fusible plugs (if possible)

* For those items that cannot be readily identified, consult a manufactures diagram or ask the operator to help.

* Learn the identity of every gauge, valve and fitting that is attached to the boiler and its purpose.

Self Assessment

Indicate what type of fitting is listed below by inserting the proper letter in the blank beside the number.

__ 1. Single nozzle retractable type	A. Safety valve
__ 2. Globe type	B. Water column or gauge glass
__ 3. Seatless sliding plunger type valve	C. Pressure gauge
__ 4. Bourdon spring gauge	D. Feedwater connection or valve.
__ 5. Screw and yoke type gauge	E. Blow-off connection or valve.
__ 6. Nozzle reaction type	F. Stop or check valve
__ 7. Steam washer	G. Drum internal
__ 8. Flat glass gauge	H. Soot blower
__ 9. Fireside type	I. Fusible plug
__ 10. Regulating valve	J. Non-return stop valve

Self Assessment Answers

H 1.

J 2.

E 3.

C 4.

F 5.

A 6.

G 7.

B 8.

I 9.

D 10.

Post Assessment

TRUE or FALSE

1. A power operated relief valve is a type of safety valve.

2. Gauge glasses are used to determine the color of boiler water.

3. Tubular gauge glasses are needed on boilers with operating pressures above 2800 kPa.

4. Pressure gauges must show a range of 1 1/2 times the allowable working pressure to meet code.

5. A bellows gauge is a type of pressure gauge.

6. The Bourdon spring gauge operates from pressure on a C-shaped tube that causes it to straighten out and open the valve.

7. The outside screw-and-yoke valve is the most common type of safety valve used on boilers.

8. There are two major kinds of blow-off counnections on boilers.

9. A steam separator is one of the drum internals.

10. Natural gas burners require several soot blowers to free the heating surface of ash.

Instructor Post Assessment Answers

1. True
2. False
3. False
4. True
5. True
6. True
7. False
8. False
9. True
10. False

Supplementary References

* Correspondence Courses. Lectures 4 and 5, Section 2, First Class. Steam Generation. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATION

First Class
Lecture 4

BOILER FITTINGS I

The term "boiler fittings" encompasses all those items directly attached to or within the boiler proper which are necessary for the safe and efficient operation of the boiler. These fittings include safety valves, water columns and gage glasses, pressure gages, feedwater connections, blow-off valves and connections, main steam valves, drum internals, and soot blowers.

The standards governing the design, fabrication, installation, identification, testing and inspection of these various fittings are as set forth in the ASME and CSA Codes. For example, the CSA B51 Code states that drawings and specifications of all fittings to be used on boilers shall be sent to the Provincial Chief Inspector for approval and registration. The ASME Code contains numerous references regarding boiler fittings and these will be discussed in this lecture in conjunction with each individual fitting.

SAFETY VALVES

The safety valve is a positive protection device which prevents the boiler pressure from exceeding that for which the vessel was designed.

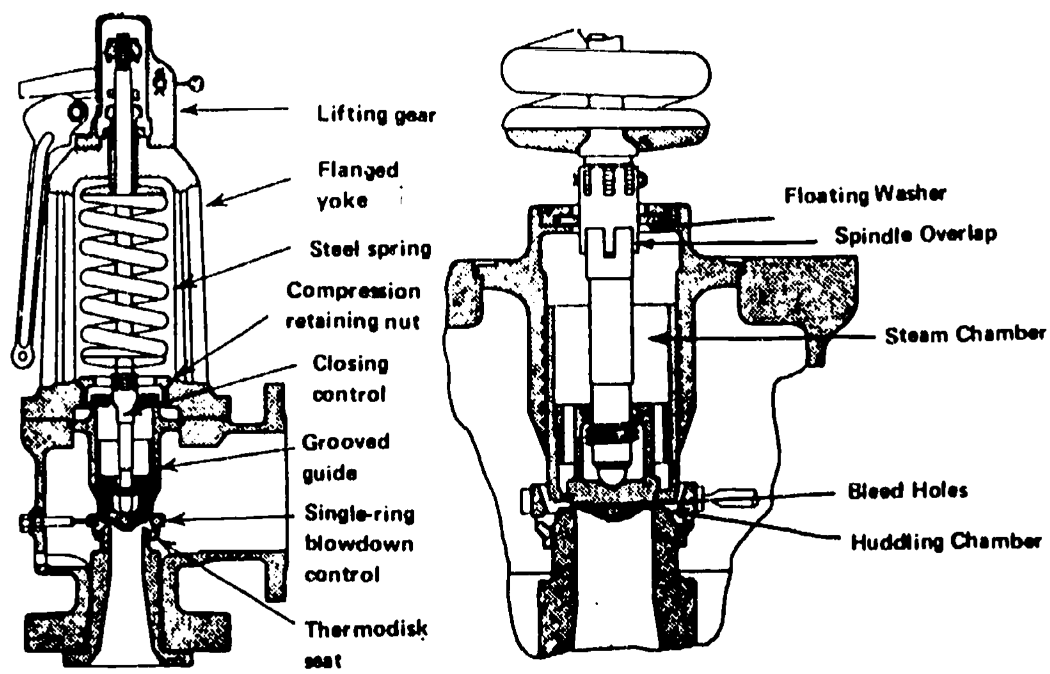
The ASME Power Boilers Code states that each boiler shall have at least one safety valve or safety relief valve and if the boiler has more than 47 m^2 of water heating surface, or if electric it has a power input of more than 500 kW, then it shall have two or more safety valves or safety relief valves. The capacity of the safety valve or valves shall be such as to discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6 percent above the highest pressure at which any valve is set and in no case more than 6 percent above the maximum allowable working pressure of the boiler.

In the case of a low pressure heating boiler, the ASME Heating Boilers Code states that each steam boiler shall have one or more officially rated safety valves of the spring pop type adjusted and sealed to discharge at a pressure not to exceed 103 kPa.

Safety Valve Types

A safety valve is held shut by means of a heavy-steel spring or, in some cases, by steel torsion bars, which hold the safety valve disc tightly against its seat. When boiler pressure reaches the pressure at which the valve is set (popping pressure) the disc will be raised slightly from its seat and steam will begin to escape. The escaping steam provides additional upward force and the valve then pops open. The additional upward force can be produced in different ways according to the design of the safety valve. These ways include; by means of nozzle reaction, by means of jet flow, or by means of a huddling chamber.

Fig. 1 is a cross sectional view of a safety valve featuring a huddling chamber.



Huddling Chamber Safety Valve

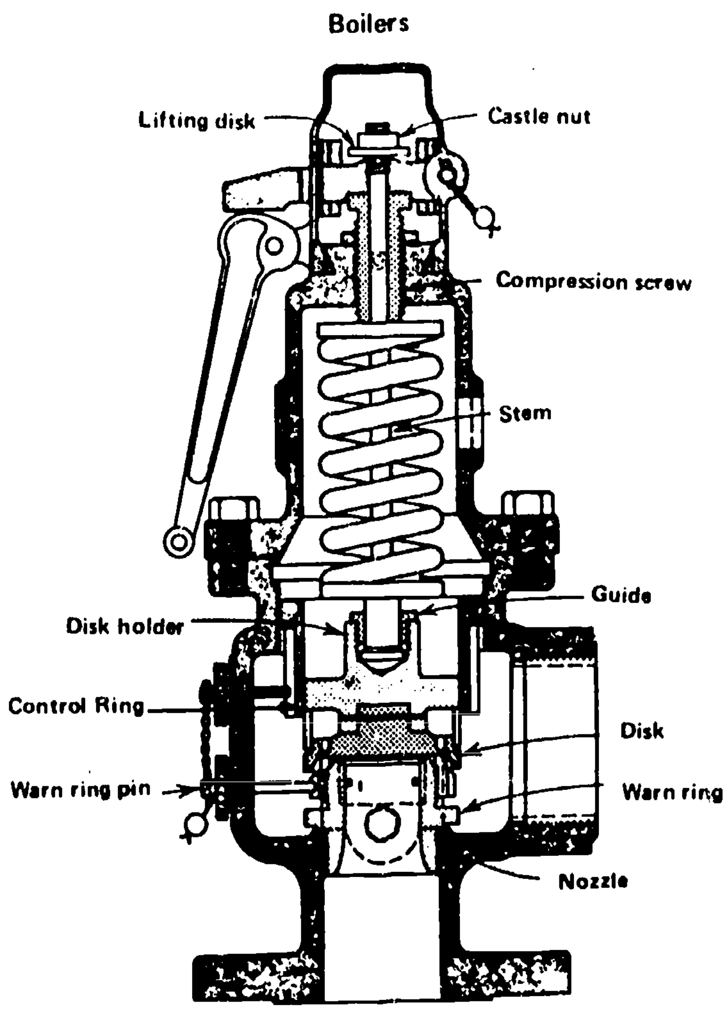
Fig. 1

In the huddling chamber safety valve the pressure acting upon the disc area causes the initial opening of the valve. As the valve opens, the space within the huddling chamber fills with steam and increased pressure is exerted against the disc causing it to lift to full opening. The amount of the blowdown, that is the difference between the opening and closing pressures, can be changed by either raising or lowering the adjusting ring thus changing the amount of steam trapped in the huddling chamber.

When the valve is in the open position, some of the escaping steam is bled into the steam chamber through the bleed holes. At the same time the spindle overlap has risen to a position above the floating washer allowing the bled steam to escape to the atmosphere.

As the valve begins to close the spindle overlap moves down into the floating washer thus cutting off the escape of the bled steam to the atmosphere. This results in a pressure build up in the steam chamber giving a snap closing action to the valve.

A nozzle reaction type of safety valve is shown in Fig. 2. In this type the valve disc has a conical baffle containing ports around its perphery.



Nozzle Reaction Safety Valve

Fig. 2

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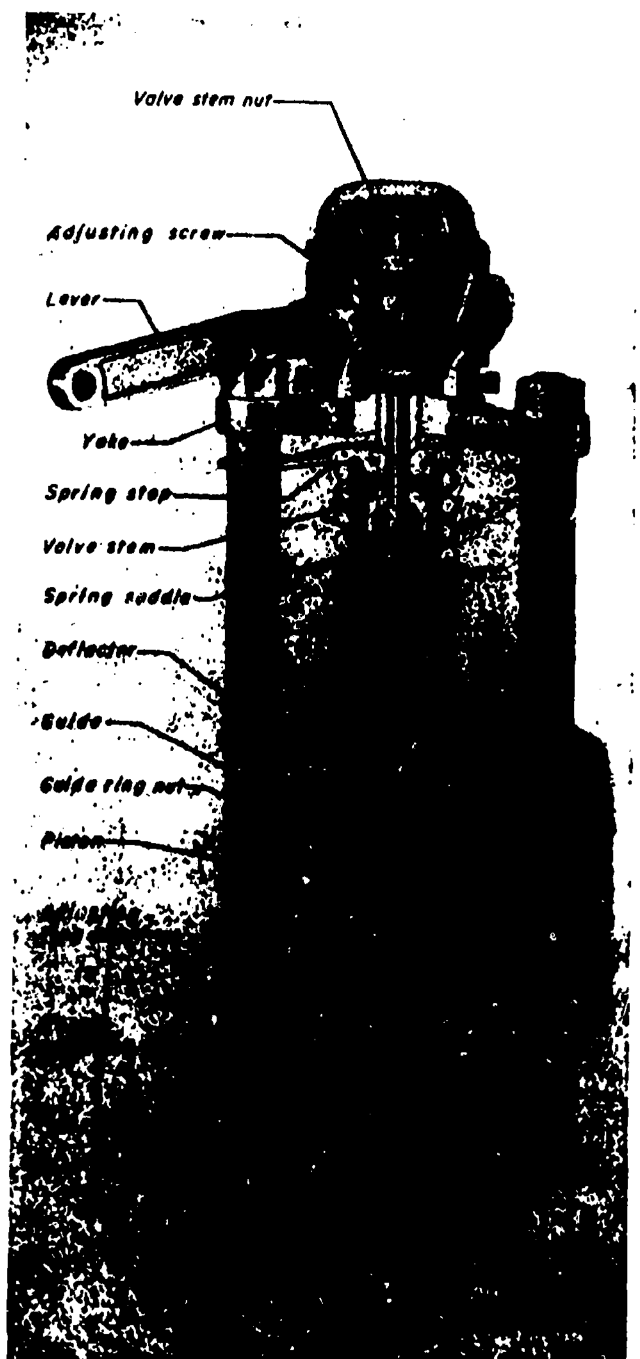
As the valve opens, the escaping steam acts upon the additional area of the conical baffle giving a greater lift force. At the same time there is a dynamic force prod ced by the high velocity steam jet issuing from the nozzle. These forces quickly raise the disc and attached baffle and the baffle ports are closed off producing full reaction force on the disc and baffle as the jet of escaping steam has its direction reversed by the conical baffle.

As the pressure in the boiler drops, the valve disc lowers and the baffle ports are uncovered allowing a portion of the steam to vent through these baffle ports. This reduces the reaction affect of the steam jet upon the disc and the valve closes quickly.

The blowdown of this type of safety valve is adjusted by means of the control ring shown in Fig. 2.

Fig. 3 shows the parts of a jet flow safety valve.



Jet Flow Safety Valve

Fig. 3

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PE1-2-4-4

In the jet flow safety valve, as in the other types, initial opening is produced by static pressure of the steam acting upon the valve disc. As the steam begins to escape through the partially opened valve it strikes against the piston and is deflected downwards against the nozzle ring giving a reaction force which further opens the valve. As steam flow through the valve increases because of this further opening, some steam flows through orifices in the guide assembly. Because of the confining effect of these orifices a further upward lift is produced and the valve opens fully.

The blowdown in this type of safety valve can be increased or decreased by adjusting the position of the nozzle ring.

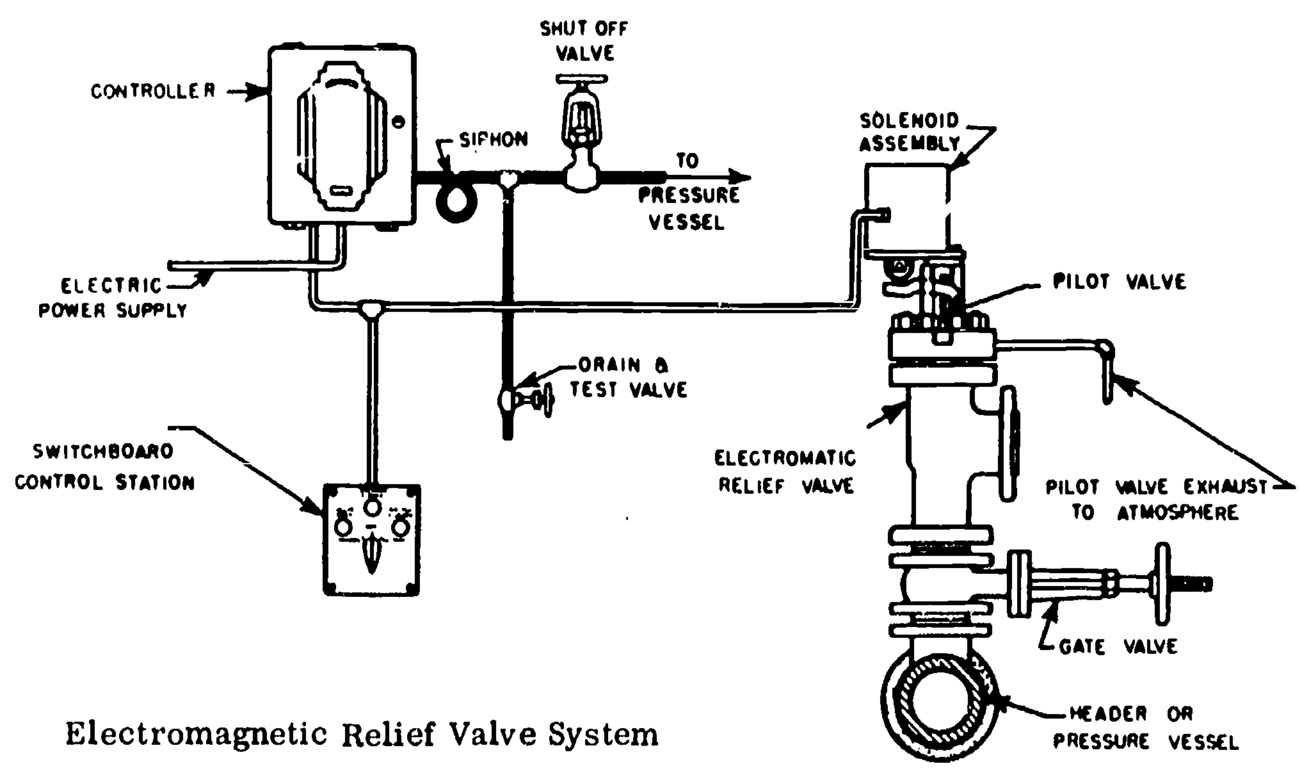
Power-operated Relief Valves

A power-operated relief valve as defined by the ASME, is one whose movements to open or close are fully controlled by a source of power (electricity, air, steam or hydraulic). The valve may be operated manually by remote control or it may be operated by an automatic device.

On a conventional type of boiler the power-operated relief valves can not be used as a substitute for the required safety valves but are often used in conjunction with them.

In the case of a once-through boiler the ASME allows the use of power-actuated relief valves for a certain percentage of the required safety valve capacity and this will be discussed later in this lecture.

Fig. 4 is a schematic diagram of an electromagnetic relief valve system with a separately mounted control station.



Electromagnetic Relief Valve System

Fig. 4

PE1-2-4-5

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The operation of the system is basically as follows:

The controller contains a Bourdon tube element which is connected through a siphon to the pressure vessel or header. When the pressure in the header or vessel reaches a preset value the Bourdon tube element will close a contact switch which energizes the solenoid. The solenoid plunger acts on a lever which opens the pilot valve. With the pilot valve open steam pressure is relieved from above the relief valve disc and the disc is forced open by the steam pressure from the header or pressure vessel.

When the pressure is reduced as a result of the relief valve opening, the Bourdon tube element opens the contact switch and the solenoid is de-energized. The pilot valve spring then closes the pilot valve which traps steam above the relief valve disc and the resulting pressure forces the disc into the closed position.

The control station switch has three positions: manual, off, and automatic.

When the switch is in the automatic position the relief valve will operate when the preset pressure is reached as just described.

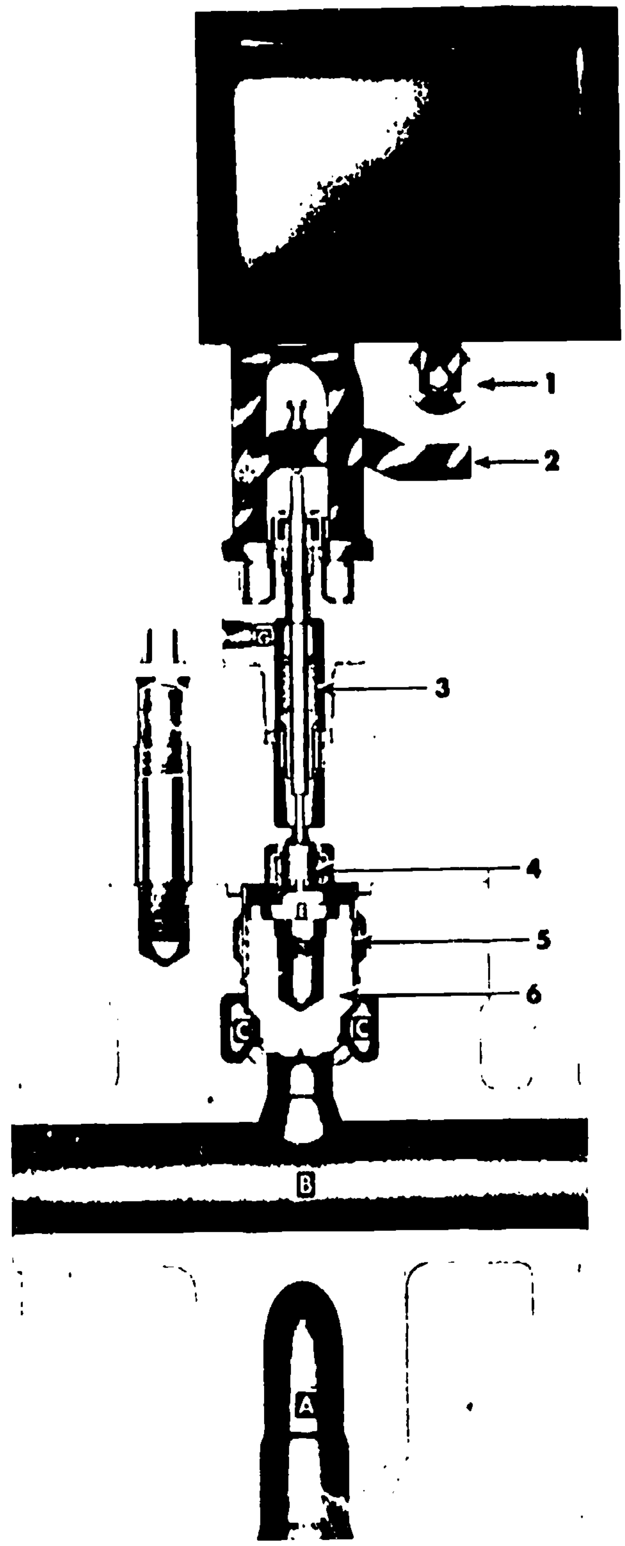
When the switch is placed in the manual position the solenoid is immediately energized and the relief valve opens no matter what the pressure is.

When the switch is in the off position the circuit to the solenoid is broken and the relief valve will remain closed even if the pressure reaches the preset value.

Fig. 5 shows the details of the relief valve. The inlet to the valve A is connected to the space C by means of passages not shown which pass upward around both sides of the exhaust chamber B. Steam passes from C to E through the clearance space 5 around the main valve disc 6. It is the pressure of the steam in E which holds the main valve disc in the closed position.

When the solenoid is energized, either by means of the manual switch or by the Bourdon tube element, the pilot valve 4 which is held closed by the spring 3 is opened by the solenoid plunger head 1 acting upon the lever 2.

Steam is thus released from E through the port G faster than it can enter through 5. The resulting unbalance of pressures in chambers E and C produces a lifting force which lifts the main valve disc from its seat permitting steam to flow from A through C to the outlet B.



Relief Valve Details

Fig. 5

PE1-2-4-7

The advantages of the power-operated relief valve are as listed:

1. They can be operated by remote control.

2. They can be repaired while the boiler is in service because they can be isolated from the boiler by means of the gate valve shown in Fig. 4.

3. They are kept closed by full boiler pressure in comparison to spring loaded safety valves which are kept closed by the difference between steam pressure and spring pressure.

4. They can be set to open before the conventional code-required spring loaded safety valves and thus save wear and tear on these valves.

5. They can be used to purge pendent type superheaters of water during the boiler start up.

6. They can be used to reduce steam pressure when shutting down the boiler.

Safety Valve Code Requirements

The ASME Code Section I deals with safety valves for power boilers in paragraphs PG 67 to PG 72 inclusive.

As mentioned on Page 1 of this lecture, each boiler must have at least one safety valve or safety relief valve and if the boiler is above a certain size then it must have two or more safety valves or safety relief valves.

The terms "safety valve", relief valve", and safety relief valve" have often in the past been used interchangeably with resulting confusion. The following definitions are therefore offered:

A safety valve is an automatic, direct-pressure-actuated, pressure relieving valve characterized by pop action and suitable for vapor or gas services.

A relief valve is an automatic, direct-pressure-actuated, pressure relieving valve with no pop action and usually with no definite blow-down or reclosure point. It is used primarily for liquid service.

A safety-relief valve is an automatic, direct-pressure-actuated, pressure relieving valve which can be adjusted for either pop or non-pop action and is suitable for vapor, gas or liquid services.

As also mentioned on Page 1 of this lecture the safety valve or safety relief valve capacity for each boiler of the conventional drum-type design shall be such that the valves will discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6 percent above the highest pressure at which any valve is set and in no case to more than 6 percent above the maximum allowable working pressure.

One or more safety valves shall be set at or below the maximum allowable working pressure and the set point of the other valves if used shall not exceed the maximum allowable working pressure by more than 3 percent.

The ASME Code, however, allows any one of the following options in the case of a once-through forced-flow steam generator with no fixed steam and water line and equipped with automatic controls and protective interlocks responsive to steam pressure:

1. Spring-loaded safety valves, capable of relieving 100% of the steaming capacity of the boiler, shall be installed as for conventional drum-type boilers.

2. One or more power operated relief valves, set to open at the maximum allowable working pressure at the superheater outlet, shall be provided having an aggregate capacity from 10% to 30% of the required relieving capacity for the boiler. The remaining 70% to 90% of relieving capacity shall be provided by spring loaded safety valves which may be set above the maximum allowable working pressure. The set pressures however, shall be such that when all the valves are operating (spring-loaded plus power-operated) the pressure will not rise more than 20 percent above the maximum allowable working pressure of any part of the boiler.

3. The capacity of the spring-loaded safety valves in option 2 may be reduced to not less than 10% of the required relieving capacity providing the following conditions in addition to those in option 2 are met:

(a) the boiler generates at least 450 000 kg per hour of steam and is installed in a unit system wherein a single boiler supplies a single turbine-generator.

(b) the boiler is provided with automatic devices responsive to variations in steam pressure including at least:

- modulation of firing rate and feedwater flow in proportion to steam output.
- reduction of fuel rate and feedwater flow when steam pressure exceeds the maximum allowable working pressure by 10% thus over-riding the firing rate and feedwater controls mentioned above.
- complete stoppage of fuel and feedwater to boiler before pressure reaches 20% above the maximum allowable working pressure.

PE1-2-4-9

(c) the spring-loaded safety valves must be at least two in number and set to open at a pressure no higher than 20% above the maximum allowable working pressure.

(d) a fail-safe circuitry is provided to stop the flow of fuel and feedwater to the boiler when the spindle of either of the required two spring-loaded safety valves moves.

(e) the power supply for all controls shall include at least one source located within the plant which will actuate the controls in the event of failure of the other power sources.

An advantage of both options 2 and 3 is the fact that the spring-loaded valves can be set at an overpressure of up to 20% above the maximum allowable working pressure. This means that when the steam pressure is at maximum allowable working pressure the spring-loaded valves will not tend to simmer.

Superheater Safety Valves

The ASME Code states that every attached superheater shall have one or more safety valves near the outlet and the capacity of the valve or valves may be included in determining the number and size of the safety valves for the boiler providing there are no intervening valves between the boiler and the superheater safety valve. In any case the safety valves on the boiler proper must provide at least 75% of the total required relieving capacity.

The superheater safety valve or valves should be set so as to pop before the drum safety valves in the event of loss of the load. In this way overheating of the superheater is avoided as there will be a flow of steam maintained through the superheater until the fires can be shut down.

If a power-operated relief valve is used it is normally set at a lower pressure than the spring-loaded superheater safety valve and it will always be the first valve to operate, in this way reducing wear and tear of the spring-loaded valve.

If the superheater is separately fired and can be isolated from the boiler then it shall have one or more safety valves equal in total capacity to 99 kg/m^2 of superheater surface and these valves can not be used in determining the number and size of the safety valves for the boiler.

In the case of a reheater, it shall have one or more safety valves having a total capacity at least equal to the maximum steam flow for which the reheater is designed. The capacity of these reheater safety valves shall not be included in the required relieving capacity for the boiler and superheater.

Safety Valve Capacity

The capacity of a particular design of safety valve is determined by means of tests which are made with steam under conditions similar to actual operating conditions. Tests under these conditions are also used to determine the lift, popping and blowdown pressures for each safety valve design.

The capacity tests are used to establish a discharge coefficient K which is then used in the capacity formulae given in PG-69.1.2.

The capacity that is stamped on the safety valve by the manufacturer must not be more than 90 percent of the value as determined by the afore mentioned tests.

The required safety valve capacity for a boiler is determined on the basis of kg of steam generated per hour per m^2 of boiler heating surface as given in Table PG-70. In every case, however, the capacity shall be such that all the steam generated by the boiler can be discharged without the pressure rising more than 6 percent above the maximum allowable working pressure as specified in PG-67.2.

The safety valve capacity can be checked in any one of the three following ways:

1. By means of an accumulation test wherein all the steam outlets from the boiler are shut and the fires forced to a maximum. Under these conditions the safety valve capacity must be sufficient to prevent an excess pressure greater than 6 percent above the maximum allowable working pressure. This method must not be used on a boiler with a superheater or reheater or on a high temperature water boiler.

2. By measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity based on the heating value of the fuel. The sum of the safety valve capacities marked on the valves shall be equal to or greater than this evaporative capacity.
(See A12 to A17 in Section I ASME).

3. By determining the maximum evaporative capacity by measuring the feedwater. As in 2. above, the sum of the safety valve capacities marked on the valves shall be equal to or greater than the maximum evaporative capacity.

Safety Valve Installation and Operation

A safety valve or safety relief valve must be connected to the boiler independent of any other connection and attached as close as possible to the boiler in an upright position with the spindle vertical. No valve of any type shall be placed between the safety valve or safety relief valve and the boiler or on the discharge pipe from the safety valve or safety relief valve if such a discharge pipe is used.

If a discharge pipe is used its cross sectional area shall not be less than the full area of the valve outlet and the pipe should be as short and straight as possible. An ample gravity drain must be provided in the discharge pipe at or near each safety valve or safety relief valve where water of condensation may collect. In addition, each valve must have an open gravity drain through the casing below the level of the valve seat.

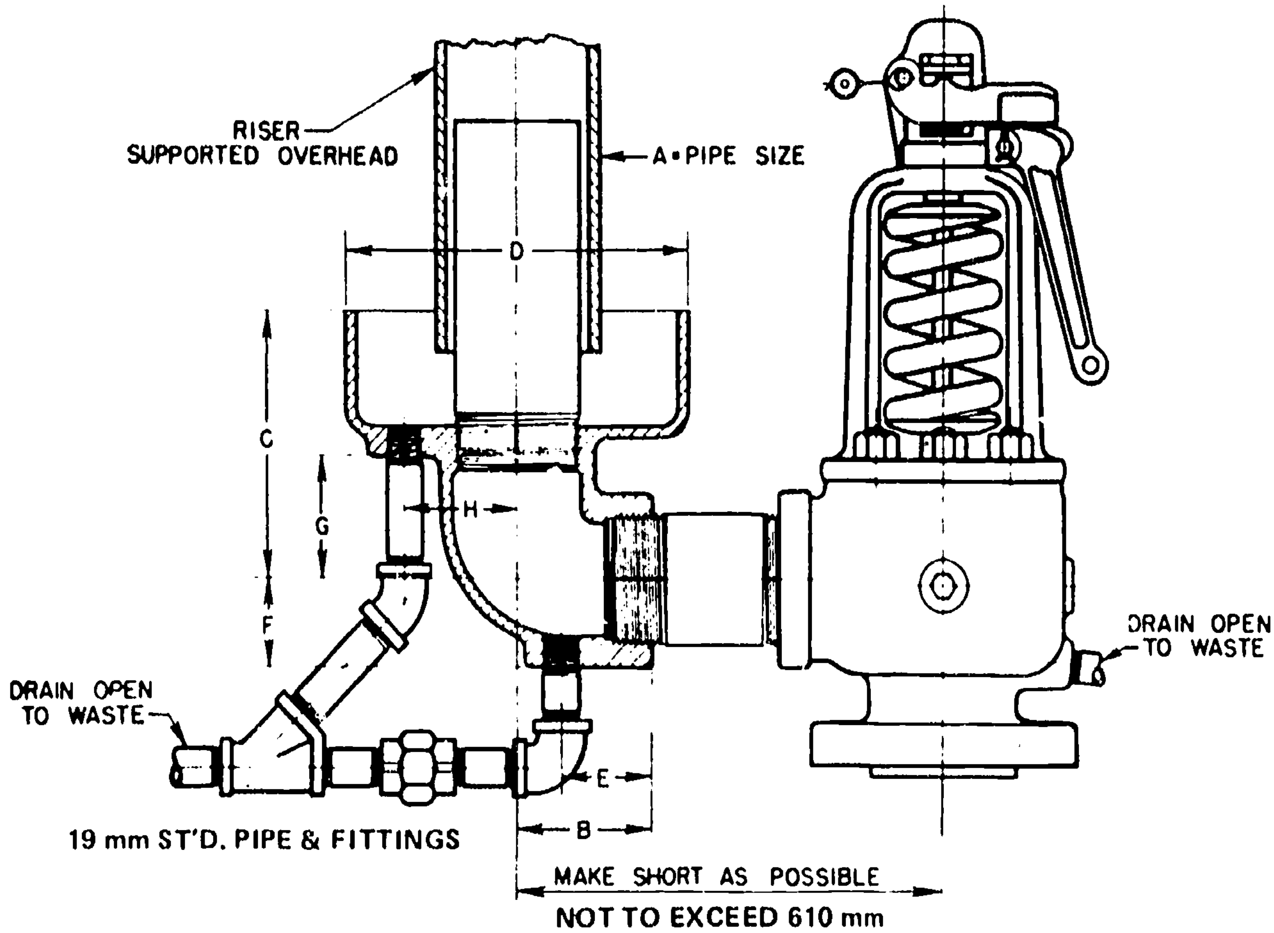
Fig. 6 shows the discharge piping arrangement and dimensions for a typical safety valve.

The term "blowdown" as used in connection with safety valves refers to the difference between the opening or set pressure of the valve and its closing pressure. All safety valves on conventional drum type boilers shall close at a pressure not lower than 96 percent of their set pressure except that all drum safety valves on a single boiler may close at a pressure not lower than 96 percent of the set pressure of the lowest set drum safety valve. In any case the minimum blowdown shall be 14 kPa. For safety valves for pressures between 690 and 2100 kPa inclusive, the blowdown shall not be less than 1 percent of the set pressure.

Safety valves used on forced-flow or once-through steam generators with no fixed steam and water line, and safety relief valves used on high temperature water boilers may be set to close after blowing down not more than 10 percent of the set pressure.

To insure that the valve is not stuck in the closed position, each safety valve or safety relief valve shall have a lifting device by which the valve disc may be lifted from its seat when there is at least 75 percent of full working pressure on the boiler.

DISCHARGE ELBOW AND DRIP PAN UNIT



Safety Valve Outlet & Elbow Pipe Size in mm	64	76	102	127	152
A	89	102	152	200	200
B	68	95	81	114	156
C	110	178	210	171	264
D	216	241	280	318	349
E	41	64	88	48	98
F	49	57	75	90	106
G	56	83	95	100	130
H	70	79	95	111	127

Safety Valve Discharge Piping
(Manning, Maxwell and Moore Limited)

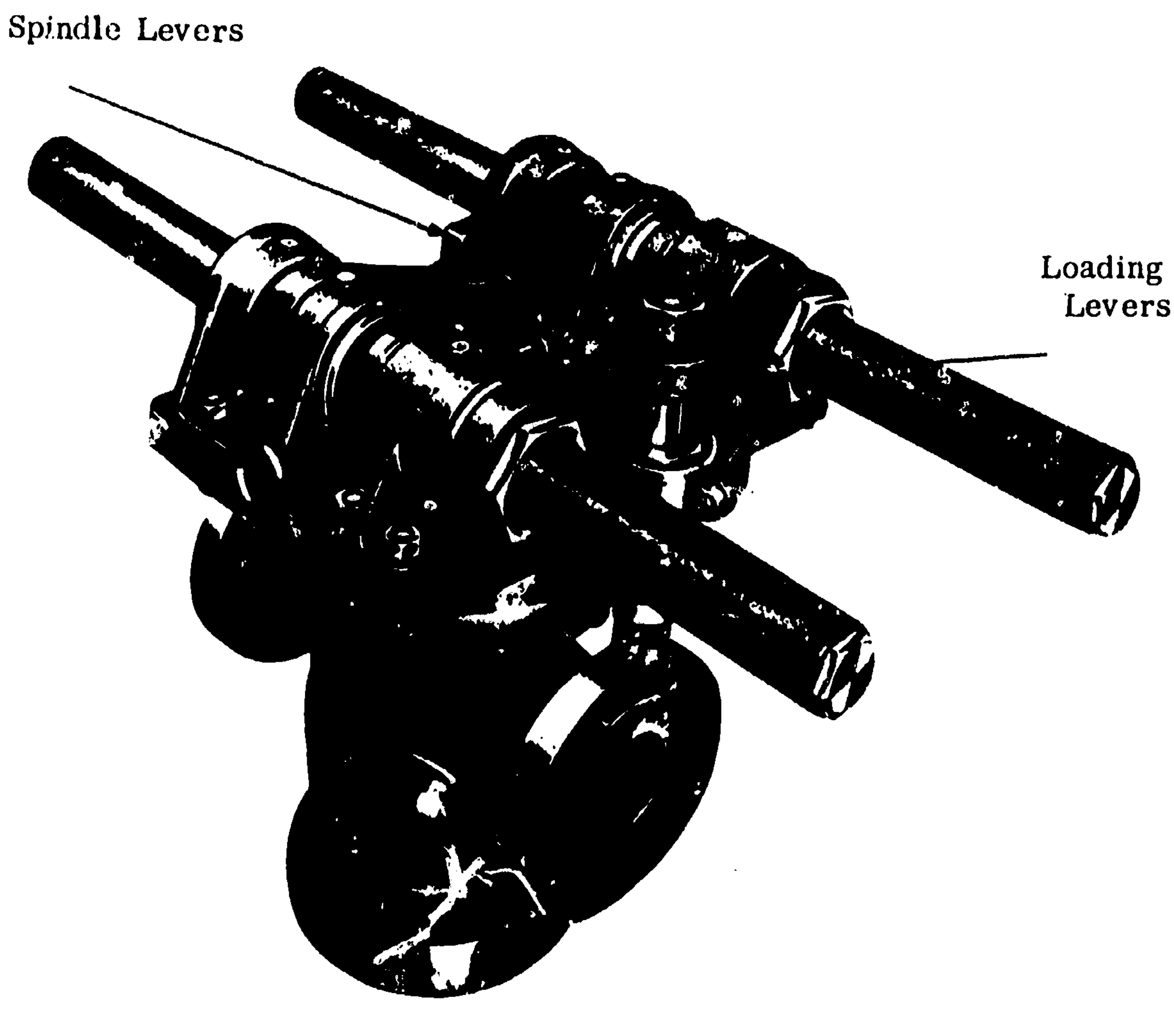
<u>Fig. 6</u>

Torsion Bar Safety Valves

The majority of safety valves handling steam at saturation temperature are of the carbon steel coil spring type as shown in Figs. 1, 2 and 3. However where high temperature steam is handled, as at the superheater outlet, difficulties may be encountered in maintaining the correct spring tension under the high temperature conditions. Also for very high pressures, say above 6000 kPa, considerable accuracy in spring design is necessary in order to maintain the close control of the opening and closing of the safety valves.

For these reasons, torsion bars are frequently used as the form of spring most suitable for extreme conditions as this design of spring can be manufactured to produce the highest accuracy in physical characteristics.

Fig. 7 illustrates a torsion bar safety valve suitable for high pressure, high temperature service.

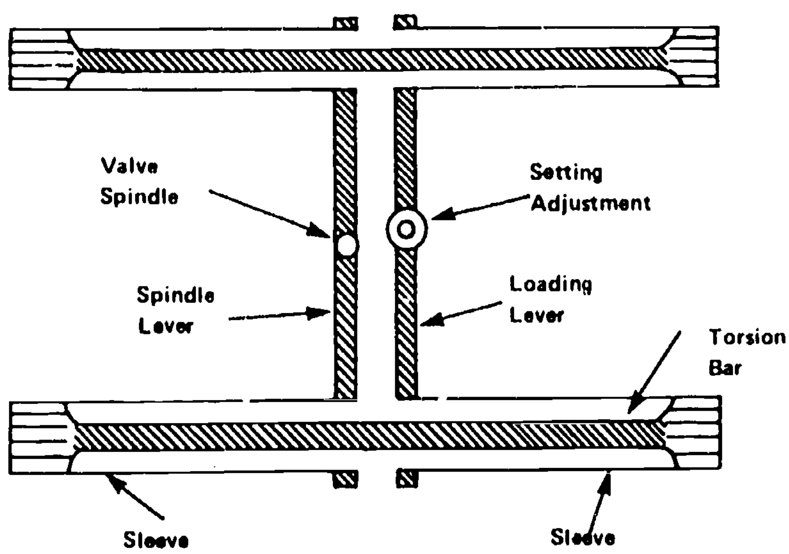


Torsion Bar Safety Valve

(Hopkinsons)

Fig. 7

Referring to Fig. 7, the valve disc, seat and other internal parts are the same as those of a conventional coil spring valve. In this type, however the valve disc is held down upon its seat by the spindle levers which act on top of the valve spindle. The spindle levers are each attached to the end of a slee e and the other end of each sleeve is splined to a torsion bar within each sleeve. The other end of each torsion bar fits within and is splined to the end of another sleeve and the other ends of these sleeves are attached to the loading levers.



Torsion Bar, Lever and
Sleeve Arrangement

Fig. 8

Fig. 8 shows a cross-sectional view of the torsion bars, sleeves, and levers. Screwing down the load adjustment will move the loading levers and cause the torsion bars to twist and exert the necessary load on the valve spindle by means of the spindle levers.

WATER COLUMNS AND GAGE GLASSES

In order to visually determine the level of water in the boiler at least one water gage glass must be fitted to the boiler. The gage glass or gage glasses may be fitted directly to the boiler shell or drum but usually a water column is used to which the gage glass is attached.

The use of a water column is prefered because the column acts as a stabilizer and tends to dampen agitation of the water thus making the level easier to read. In addition, the column collects sediment that would otherwise deposit in the glass. Another function of the column in some boilers is to provide a place for the installation of high and low level alarms or for the installation of control components. Also, on boilers where gage cocks are required, these are installed on the water column.

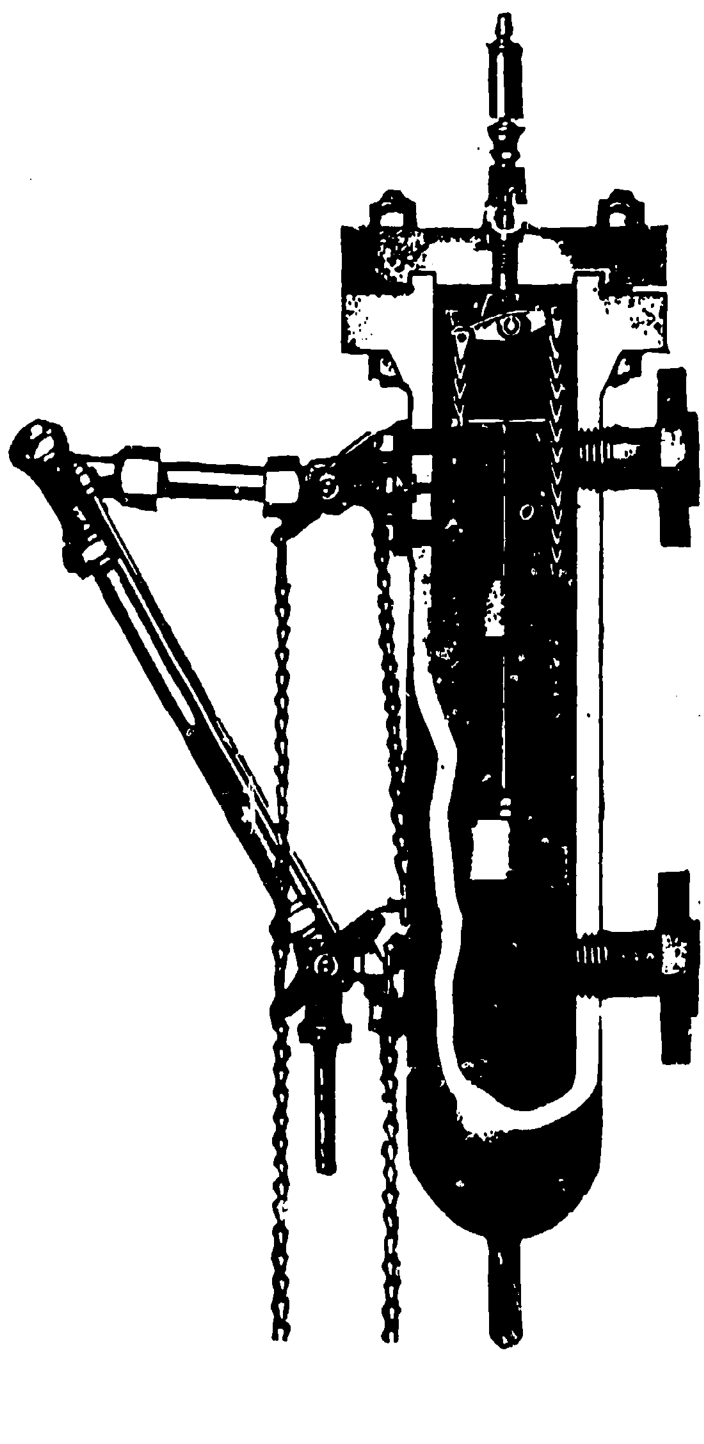


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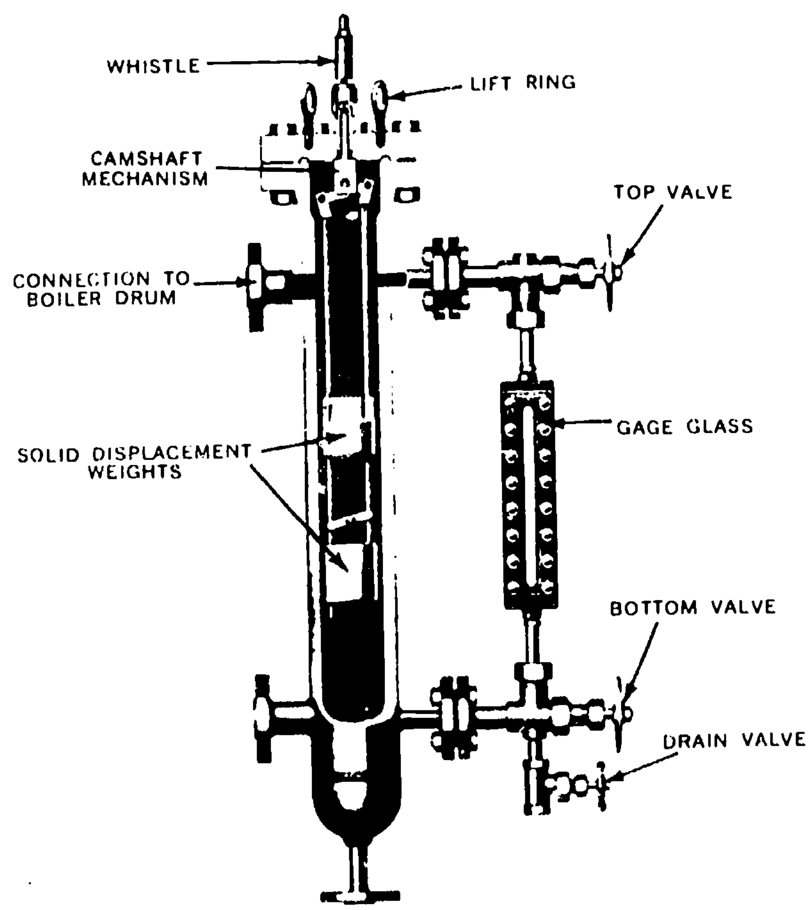
Fig. 9 shows a water column with attached tubular type gage glass. The gage glass is attached at an angle to the water column in order to give better visibility from the operating floor.

The water column in Fig. 9 also features a high and low level alarm arrangement and the activating float-weights for this are shown in the illustration. Another feature shown is the chain operated gage valves.

The tubular type of gage glass is not recommended for pressures above 2800 kPa. For the higher pressures, a flat glass type of gage is used consisting of glass plates bolted to a steel forged housing. This type of gage glass is shown attached to the water column in Fig. .



Water Column with Flat Glass
(Jerguson Gage and Valve Company)

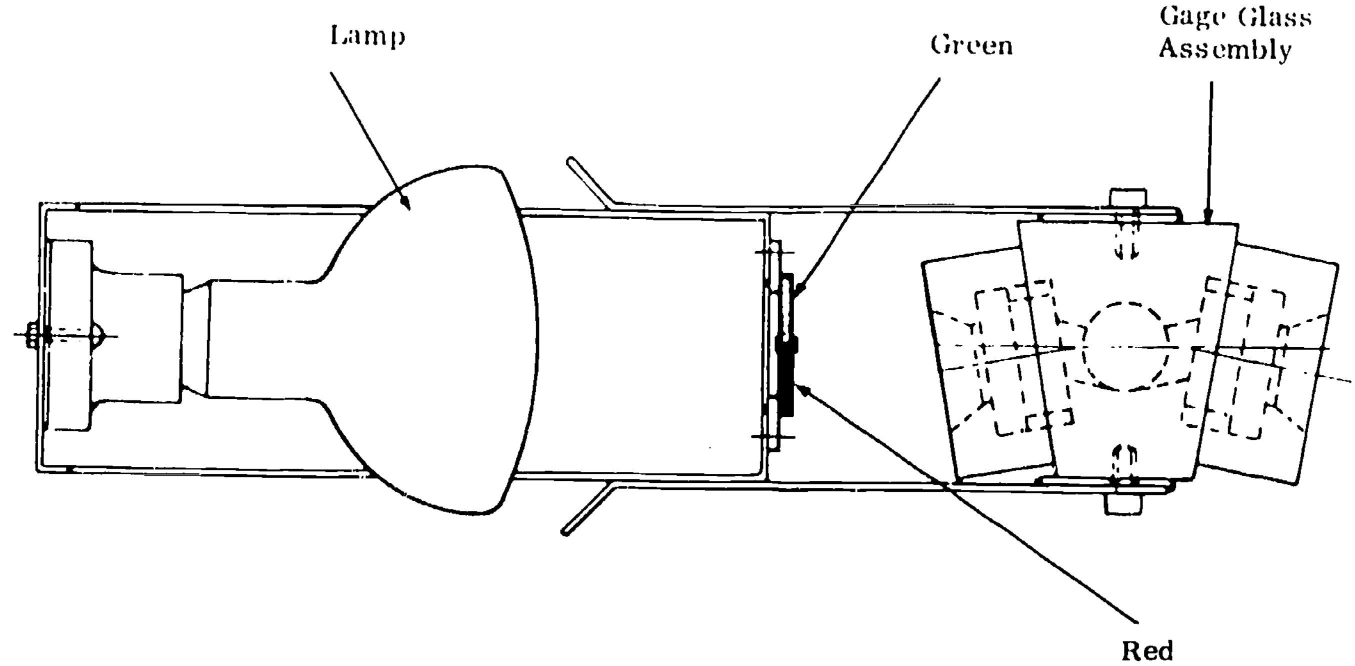
Fig. 10

The column in Fig. 10 is also fitted with a high and low level alarm arrangement. The material used for the column is heavy walled seamless steel tubing and it is suitable for pressures to 6200 kPa.

Bi-color Gage Glasses

In the case of large boilers, where the drum is a good distance above the operating floor, a bi-color gage glass is usually empl yed to give better visibility of the water level.

The arrangement of this type is sketched in Fig. 11.



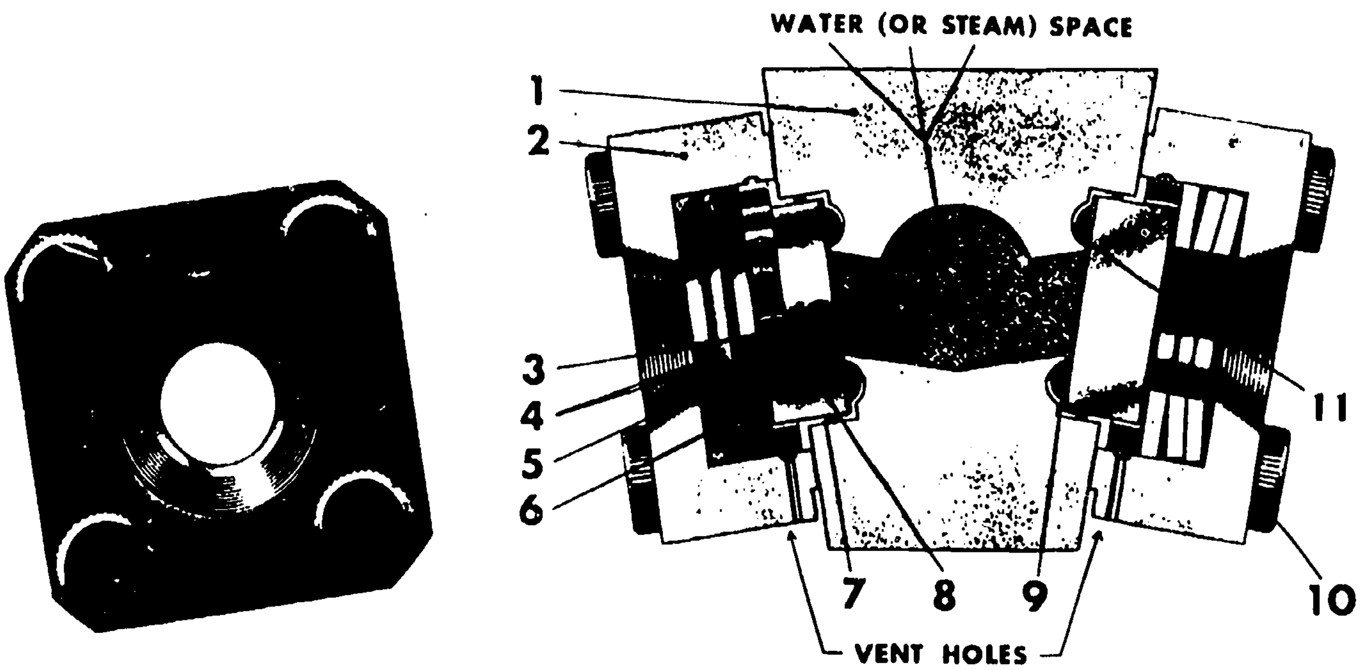
Bi-color Gage Glass
(Yarway Corporation)

Fig. 11

Referring to Fig. 11, the light from the lamp shines through a vertical screen consisting of two strips of clear colored glass, one green and one red. The gage glass is so placed in relation to the glass strips that the green light will not pass through the gage unless it is refracted by water in the gage. Similarly the red light can only pass through that part of the gage which does not contain water.

The gage glass assembly is a high pressure design suitable for pressures up to 20.7 MPa. Rather than using single pieces of flat glass for the back and the front of the gage, this design uses individual port assemblies. Each port assembly consists of a flat glass, washers, gaskets, cover and screws.

Fig. 12 illustrates the port arrangement.



Head-on view of cover

Horizontal section through body and covers

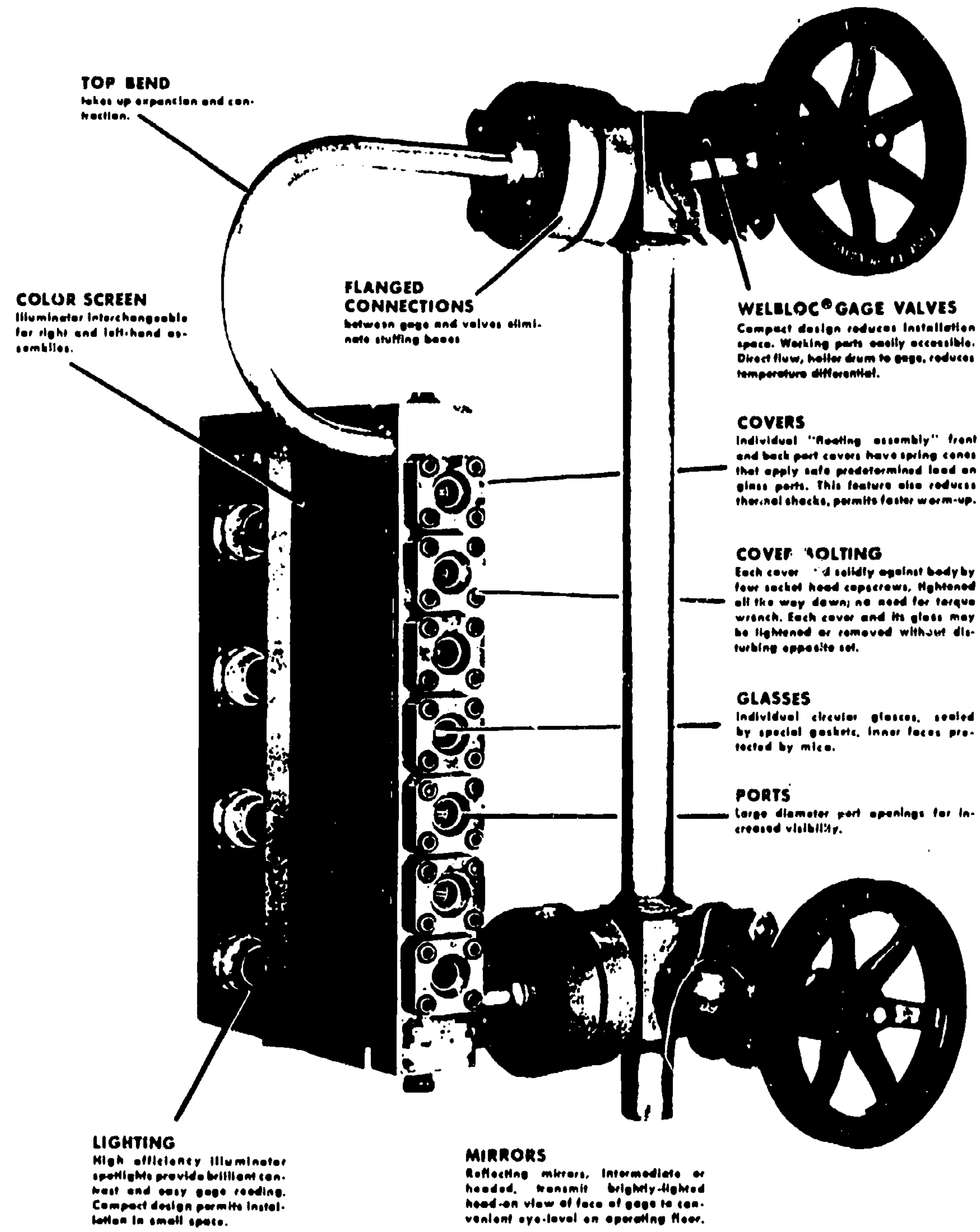
High Pressure Gage Glass
(Yarway Corporation)

Fig. 12

The numbered parts in Fig. 12 are as follows:

1. stainless steel body
2. carbon steel cover
3. pyrex round flat glass
4. stainless steel spring cones
5. stainless steel washer
6. asbestos gasket
7. stainless steel clip rings
8. stainless steel retaining rings
9. mica shields to prevent erosion and corrosion of the round flat glasses
10. steel capscrews for cover
11. asbestos sealing gaskets

Fig. 13 shows the arrangement of a bi-color multi-port gage glass. The gage is attached to a circulating tie-bar instead of to a water column. The tie-bar has top and bottom connector blocks with gage valves plus a bottom connection for a drain line.



Multi-Port Gage Glass with Tie-Bar
(Yarwav Corporation)

Fig. 1:

PE1-2-4-20

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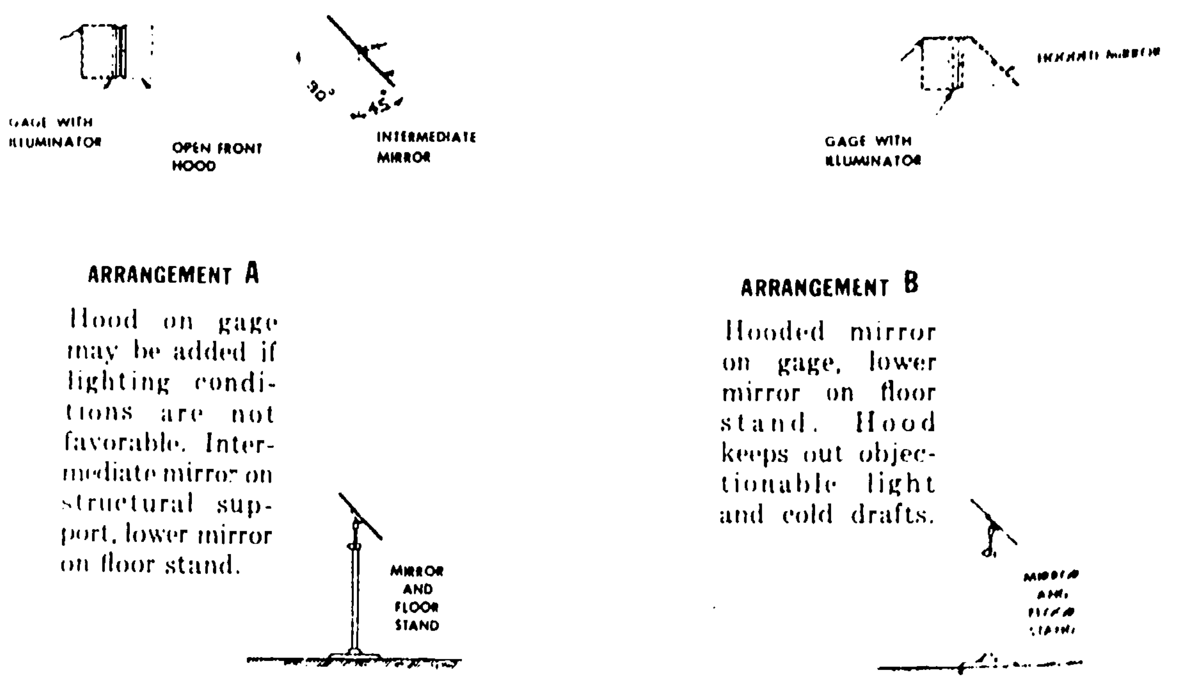
Remote Indication

In the case of large boilers having the drum and attached gage glass a good distance above the operating floor, it is necessary to transmit the water level reading to some spot visible to the operator on the operating floor.

One method of accomplishing this is by the use of mirrors as illustrated in Fig. 14, A and B.



Gage Glass Mirror Arrangements

Fig. 14

Another method of remote indication of water level appears in Fig. 15.

Referring to Fig. 15, the operating element consists of a large sensitive diaphragm, one side being connected to the steam space of the boiler and the other to the water space.

A condenser at the boiler drum is provided to maintain a fixed head of water on the steam space side, while the water space side is subjected to a varying head dependent upon the water level in the boiler. This varying head is balanced by a spring in the instrument and causes the diaphragm to move in accordance with the water level. The full boiler pressure, being on both sides of the diaphragm, is therefore balanced and has no effect on the movement of the diaphragm, which is actuated only by the difference in heads.

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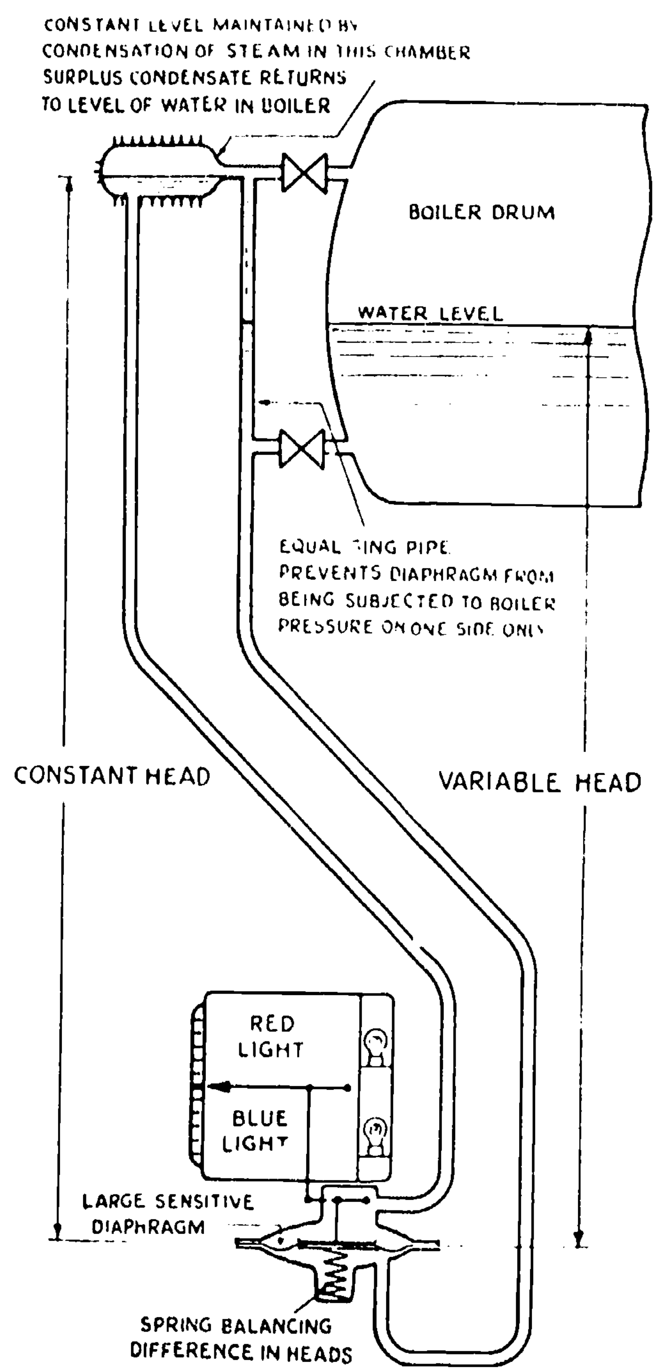


Remote Water Level Indicator

Fig. 15

Ample power is obtained by use of a large diaphragm, a variation of 6 mm in the head on the diaphragm producing an operating force of nearly 1 newton, and the indicator responds to exceedingly small variations in water level.

A small stainless steel spindle, passing through a self-sealing frictionless gland, transmits the motion of the diaphragm to the outside of the diaphragm chamber, where it actuates a special form of leverage mechanism. This gives a straight line movement of the pointer along the scale, this movement accurately corresponding to that of the water in the gauge glass.

There is a red-colored glass screen directly in front of the upper lamp and a blue-colored screen directly in front of the lower lamp. A reflecting shutter which moves with the pointer divides the two parts and directs red light to the steam space of the translucent indicator front and blue light to the water space.

Gage Glass Error

During normal boiler operation the gage glass generally indicates a water level lower than the actual level in the boiler drum. This is because the water in the gage glass and in the water connection from the gage glass to the drum is cooler and denser than the water within the drum.

This error may be quite substantial. For example, in a boiler operating at 13 800 kPa the level in the gage glass may be 20 percent lower than the actual level in the drum. The amount of the error depends upon the temperature difference between the water in the gage and its connection and the water in the drum. This difference in temperature is affected by such factors as the ambient temperature, velocity of the air flowing past the gage, and the amount of gage surface radiating heat to the atmosphere.

Code Requirements

The ASME Code Section I states that each boiler, except those with no fixed water and steam line such as the forced flow steam generator or the high-temperature water type, shall have at least one water gage glass. With the exception of electrode type electric boilers, those boilers operating at over 2800 kPa shall have two water gage glasses.

In the case of power boilers having drum safety valves set at or above 6200 kPa, two independent remote level indicators may be used instead of one of the required gage glasses. When both these remote indicators are in operation the gage glass may be shut off provided it is maintained in a serviceable condition.

The lowest visible part of the gage glass shall be at least 51 mm above the lowest permissible water level which is the lowest level that the boiler can be operated at without danger of overheating any part of the boiler.

Boilers of the horizontal firetube type shall have at least 76 mm of water above the highest point of the tubes or crown sheet when the water is at the lowest visible part of the gage glass.

The pipes connecting a water column to a boiler shall be at least 25 mm size. If the gage glass is connected directly to the boiler without an intervening water column then the gage glass connecting pipes shall be at least 25 mm size.

The CSA Code B51 states that the water column connecting pipes shall be as short as possible and arranged with crosses having suitable plugs for clean out purposes. Also shut-off valves shall be fitted in the water and steam connecting pipes to the water column but these are not mandatory in the case of a boiler having a working pressure of over 5900 kPa or in the case of a low pressure boiler. Furthermore these shut-off valves shall be of through flow construction such as the O.S. and Y. with rising spindle, the lever lifting gate type, or a stop-cock with plug held in place by a guard or gland and marked in line with passage.

The foregoing-requirements with others are found in the ASME Section 1 PG-60.1 to 60.4 inclusive.

PRESSURE GAGES

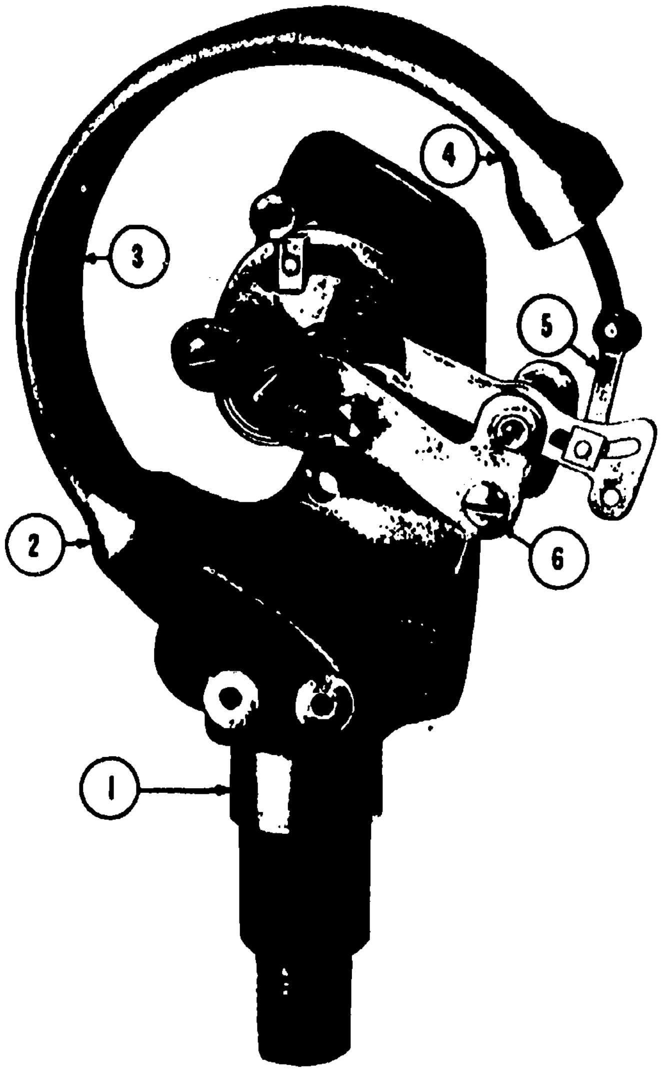
Each boiler must have a pressure gage to indicate the pressure within the boiler and the gage must have a range and dial graduation of at least $1\frac{1}{2}$ times the maximum allowable working pressure. The gage connection must be to the steam space of the boiler or water column or to the water column steam connection.

Pressure gages may be of three basic types namely: the Bourdon spring, the bellows, or the metallic diaphragm.

1. The Bourdon Spring Gage

The Bourdon spring gage is the type used for the main pressure gage on a boiler. The main components of this gage are shown in Fig. 16.

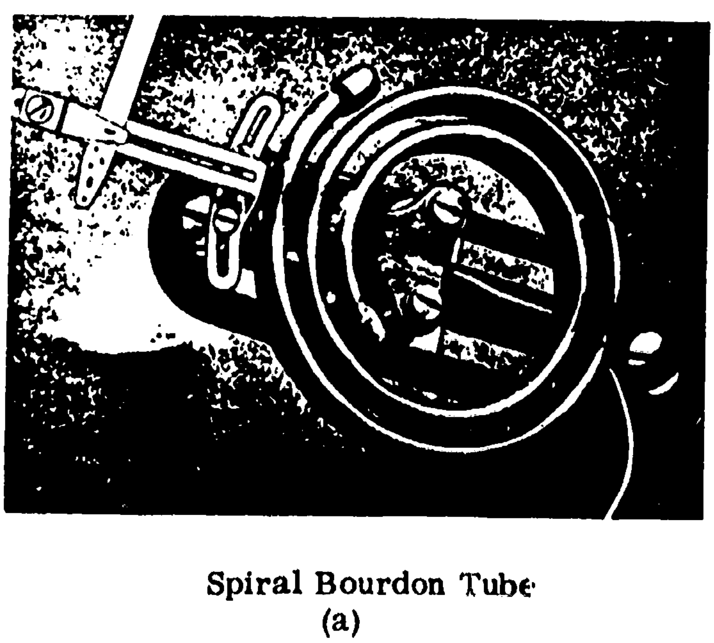
The main component or heart of the gage is the C shaped Bourdon tube or spring (3). It is oval in cross section and is closed off at one end (4) and open to pressure at the other end (2) through the socket (1). When pressure is applied to the inside of the oval tube it tends to assume circular cross section and to partially unwind or straighten out. Thus the closed end (4) will move and the movement is linked mechanically to a pointer by means of the links (5) and (6).



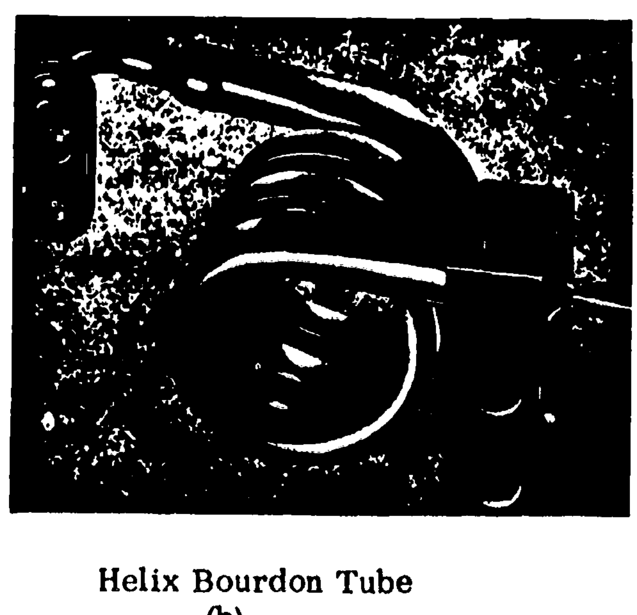
In addition to the C-type Bourdon gage as shown in Fig. 16 there are two variations of the Bourdon tube; the spiral and the helix and these types are illustrated in Fig. 17.

Bourdon Tube (Spring) Gage

Fig. 16



Spiral Bourdon Tube
(a)



Helix Bourdon Tube
(b)

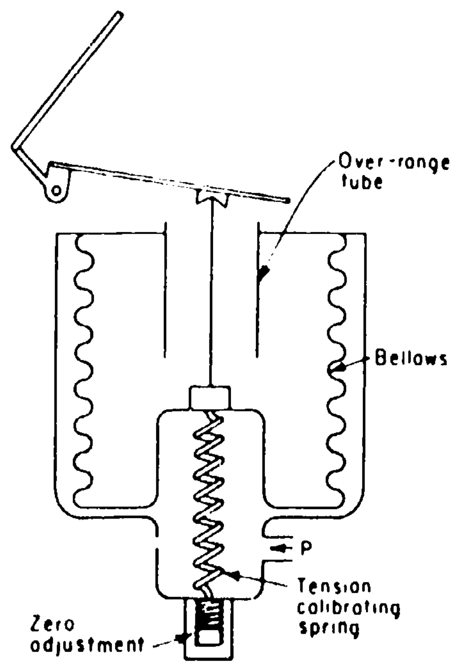
Fig. 17

When the Bourdon tube is wound in a spiral as in Fig. 17 (a) much greater tip movement can be achieved than with the ordinary C-type Bourdon tube. A similar effect is obtained by forming the Bourdon tube into a helix as in Fig. 17 (b).

Not only do the spiral and helix type give significantly greater tip movement but they also take up less space than the C-type Bourdon tube and thus are frequently used to move the pointer or recorder pen in a pressure recorder.

2. The Bellows Gage

This type which is shown schematically in Fig. 18 has for its main element an elastic bellows which may be made of brass, stainless steel, phosphor bronze, monel or copper.



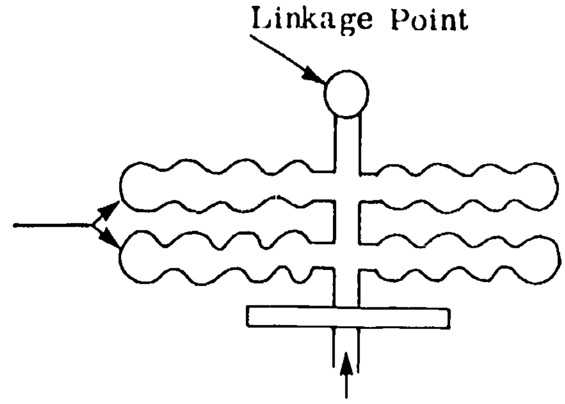
Bellows-Type Gage

Fig. 18

Referring to Fig. 18, when pressure is applied to the outside of the bellows the push-rod is forced out of the unit thus moving the indicator by means of a mechanical linkage.

This type generally has a pressure range of from 0 to 70 kPa.

3. The Metallic Diaphragm Gage



Metallic Diaphragm Gage

Fig. 19

The metallic diaphram gage, which is shown schematically in Fig. 19, is made up of a number of metallic capsules rigidly connected together. The pressure is applied within the capsules causing them to expand in direct relation to the pressure and thus move the linkage.

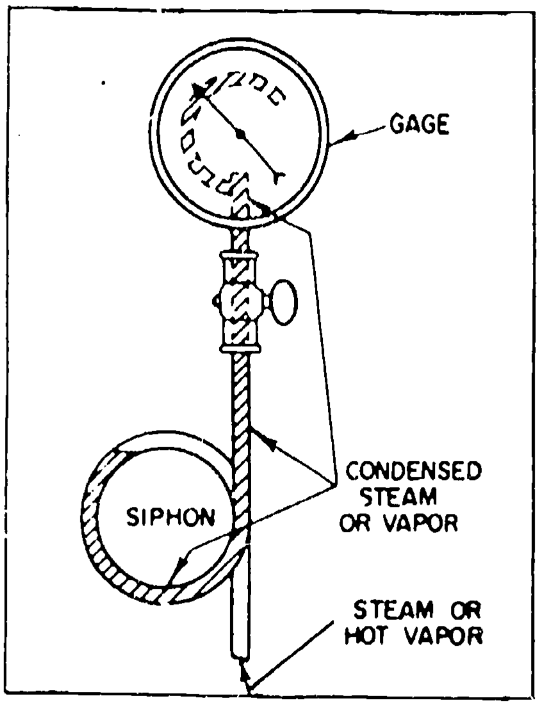
The pressure range for this type is usually from 0 to 200 kPa but occasionally they may be used for pressures up to 1400 kPa.

There is another type of diaphragm gage which uses a non-metallic or "limp" diaphragm and this type is suitable for measuring draft pressures up to 250 Pa of water.

To sum up: the Bourdon spring gage is the type used to measure boiler pressures with the C-type used for the main dial gage and the helix or spiral type used usually for recording indicators. The bellows and diaphragm types are used for lower pressures such as those in pneumatic control applications or for draft measurement.

Pressure Gage Siphons

When gages are used with steam some method must be used to prevent the hot steam from entering the Bourdon tube or other element. This is necessary because the high temperature of the steam will affect the soldered connections of the gage and also will affect the elasticity of the tube or element. In addition the linkage parts will expand due to the heat thus affecting the accuracy of the gage.



Siphon Operation
(Ametek/U.S. Gage)

Fig. 20

Fig. 20 shows a simple attachment called a siphon which traps condensed steam and thus maintains a liquid seal between the hot steam and the gage element.

The siphon is usually the external coil type as shown in Fig. 20 but sometimes an internal siphon is built into the gage.

Gage Installation

As mentioned, the gage should be fitted with a siphon to prevent steam from entering the gage element. Also the gage case should be sealed to prevent dirt or dust from fouling the precision gears of the movement.

When the gage is installed below the point of connection to the boiler drum, a column of water will exist in the connecting line and it is necessary to adjust for this static head by the zero adjustment of the gage. Also the column of condensate above the siphon must be compensated for when the gage is mounted above the point of connection.

Unless it is of special design the gage should be installed in a vertical upright position. If not, the bearing loads in the linkage will be changed and the weight of the element will affect the movement.

If the gage is mounted in a location where there is excessive vibration then there will be more rapid wear of moving parts such as gear teeth, bearings and hairspring and the pointer may become bent or loose on its spindle.

Code Requirements

The ASME Code requires that each boiler shall have a pressure gage attached to the steam space of the boiler or water column and fitted with a shut-off valve or cock and with the dial graduated to at least $1\frac{1}{2}$ times the pressure at which the boiler safety valve is set. Also a connection must be provided on the boiler for the sole purpose of attaching a test gage so that the accuracy of the boiler gage can be checked.

In the case of a forced-flow steam generator with no fixed steam or water line, pressure gages shall be fitted in the following locations: at the boiler or superheater outlet after the last section which absorbs heat; at the boiler or economizer inlet; upstream of any shut-off valve used between any two sections which absorb heat.

In all cases the material used for pressure gages shall be suitable for pressures, temperatures and fluids encountered.

The above requirements are all discussed in the ASME Code Section I PG-60.6.

FEEDWATER CONNECTIONS

Included under this heading are the valves, fittings, and piping required to convey feedwater to the boiler.

Feedwater Supply

Boilers having more than 47 m^2 of water heating surface shall have at least two means of feeding water except that boilers using gaseous, liquid, or solid fuel in suspension where the heat input can be stopped quickly, need only have one means of feeding.

The source of feeding shall be capable of supplying water at a pressure of 3 percent higher than the highest setting of any safety valve on the boiler. However if the boiler is a forced flow steam generator with no fixed steam and water line then the source of feeding need only supply water at a pressure not less than that existing at the boiler inlet under maximum operating conditions.

In the case of boilers using solid fuel not in suspension or when the boiler setting is such that overheating could result if the feedwater supply was interrupted then one of the two required feedwater sources of supply must be steam operated.

Feedwater Valves

The feedwater line to the boiler must be fitted with a check valve near the boiler and a stop valve between the check valve and the boiler. A combination stop-and-check valve or nonreturn stop valve if used can only be considered as a stop valve and a check valve must be installed in addition. When two or more boilers are supplied from a common source, a globe or regulating valve must be installed on the branch line to each boiler and this valve must be located between the check valve and the source of supply. Also when globe valves are used in the feedwater line the inlet must be under the disc so that if the valve disc becomes separated from the valve spindle the feedwater supply can still be maintained.

In the case of a forced-flow steam generator having no fixed steam and water line, a stop valve must be installed in the feed line at the boiler, however the check valve near the boiler need not be installed provided there is a check valve at the boiler feed pump discharge or elsewhere in the feed line between the pump and the stop valve at the boiler.

Feedwater Piping

The feedwater must be introduced into the boiler in such a way that it will not impinge directly upon surfaces exposed to high temperature gases or direct radiation from the fire. Also the feedwater must not discharge close to any riveted joints and, if necessary, a baffle shall be fitted to the discharge end of the feed pipe in order to divert the flow away from the riveted joints. Furthermore the feedwater must not be introduced through the blowoff line.

The required thickness of feedwater piping shall be calculated using the formulae given in PG-27.2.2. For example:

$$t = \frac{PD}{2\,SE + 2\,y\,P} + C$$

or

$$t = \frac{PR}{SE - (1 - y)\,P} + C$$

These formulae involve dimensions, pressures, temperatures, stresses, and constants which, in the latest edition of the code available at the time of writing are given in Imperial units. To make calculations in SI units the student must convert the formulae symbol dimensions to SI units and use the formula as given in the code.

t = minimum required thickness in mm.

P = maximum allowable working pressure in kPa. This pressure is always gage pressure in these formulae unless otherwise specified.

P shall not be taken as less than 690 kPa and also must not be less than the pressure required to feed the boiler.

For piping from the boiler to and including the required stop valve and the check valve in a conventional type boiler the value of P shall be greater than the maximum allowable working pressure of the boiler by either 25 percent or 1550 kPa whichever is the lesser.

In the case of a forced-flow steam generator having no fixed steam and water line the value of P for feedwater piping from the boiler to and including the required stop valve shall not be less than the expected maximum pressure to which that part of the steam generator will be subjected during operation.

When two or more boilers are fed from a common source, for the piping between the required check valve and the globe or regulating valve in the branch line including any bypass piping around the globe or regulating valve up to the shut-off valve in the bypass, the value of P shall be not less than the pressure required to feed the boiler.

D outside diameter of cylinder in mm.

R inside radius of cylinder in mm.

E efficiency of longitudinal welded joints or of ligaments between openings, whichever is lower.

The efficiency of a welded joint is the ratio between the strength of the weld and the strength of the plate itself. The efficiency of the ligaments is the ratio of the strength of the metal between openings such as tube holes and the strength of the solid plate. The values allowed for E are listed in the code. See PG-27.4 Note 1. As E is a ratio it does not have units to convert.

S maximum allowable stress value at the operating temperature of the metal in kPa. These stress values for various materials and temperatures are listed in Tables PG-23.1 and PG-23.2 in the code appendix. Both the stress values and the temperatures are given in imperial units and must be converted to SI units before using in the formulae.

The value of S in the formulae in PG-27.2.2 shall not exceed that permitted for the temperature of saturated steam at the maximum allowable working pressure of the boiler except in the case of a forced-flow steam generator having no fixed steam and water line the value of S shall not exceed that permitted for the maximum expected temperature at the feedwater inlet.

C = minimum allowance for threading and structural stability, in mm. Values of C are listed in the Code. See PG-27.4 Note 3. These values are given in inches and must be converted to mm before using in the formula.

y = a temperature coefficient. Values of y for various temperature ranges are listed in the code. See PG-27.4 Note 6. y is given no units and therefore no conversion is involved.

When threaded steel pipe is used for feedwater piping at pressures over 690 kPa and temperatures equal to or greater than 104°C it shall be seamless and of a quality at least equal to SA-53 or SA-192 and of a mass at least equal to Schedule 80 in order to provide additional mechanical strength.

When threaded wrought iron, threaded copper or threaded brass pipe is used for feedwater piping it shall have a wall thickness at least equal to that required for steel pipe of a corresponding size and the material used shall be suitable for the pressure and temperature conditions.

The foregoing requirements for feedwater connections are further explained in the ASME Code Section I PG-27.2.2, PG-58, and PG-59 and in the CSA B51 Section 10.7.

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 1

1. Describe the operation of the following safety valve types:
   (a) jet flow
   (b) huddling chamber
   (c) nozzle reaction

2. Sketch an electromagnetic relief valve system and explain the purpose of each part.

3. Discuss the reasons for using power-operated relief valves in certain installations.

4. Describe briefly the safety valve arrangements allowed by the ASME Code for once-through forced-flow steam generators with no fixed steam and water lines.

5. Describe in general how the safety valve capacity would be determined for a conventional boiler having a superheater and a reheater.

6. Sketch a cross section of a hig ressure gage glass and describe its construction.

7. Calculate the required thickness of feedwater piping to be used between the boiler and the feedwater stop valve. The boiler is a conventional design having a maximum allowable working pressure of 13.8 MPa. The piping is 273 mm O.D. and is plain end seamless carbon steel conforming to specification SA-106 B.

8. Discuss the type and the installation of a pressure gage suitable for the boiler in Q. 7.

9. Sketch and describe a remote water level indicator which makes use of a constant head chamber.

12.4

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Course
Power Engineering

SECTION 2

STEAM GENERATION

First Class
Lecture 5

BOILER FITTINGS II

BLOW-OFF CONNECTIONS

Boiler blow-off connections have several purposes. These include; removal of sludge or solid material from the boiler, lowering of the dissolved solids concentration of the boiler water, and draining of the boiler. Also in some cases the blow-off connection may be used to introduce the cleaning solution into the boiler during acid cleaning and to drain and flush the boiler after acid cleaning. In an emergency the blow-off connection may be used to lower excessively high boiler water level during operation to prevent carryover of water with the steam leaving the boiler drum.

Blow-off arrangements may be of three categories: bottom blow-off, continuous blow-off, and surface blow-off.

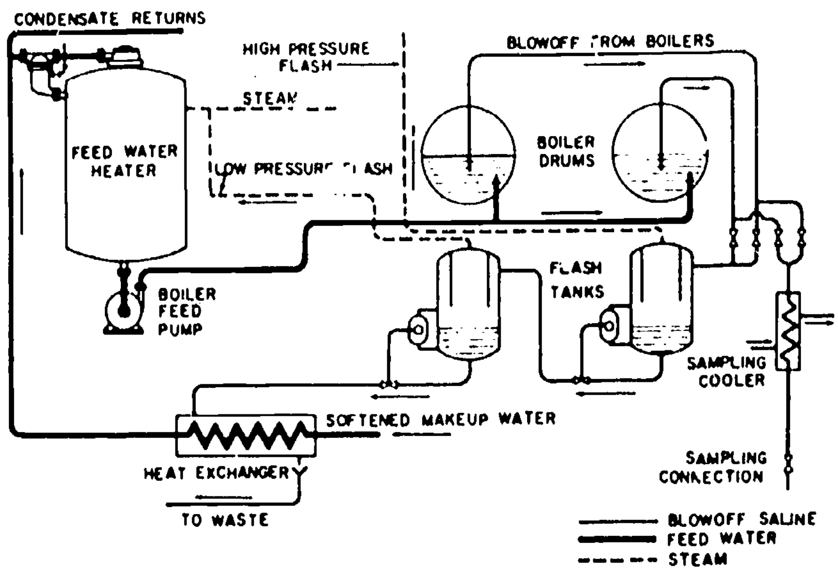
The bottom blow-off connections are made to the lowest parts of the boiler where the greatest concentration of sludge and sediment will form as the main purpose of the bottom blow-off is the removal of this sludge. On firetube boilers with cylindrical shells, the bottom blow-off connection is made at the rear and bottom of the shell. Watertube boilers normally have several bottom blow-off connections, these being made to the various mud drums and waterwall headers.

Continuous blow-off, or continuous blowdown as it is often called, is the continuous removal of concentrated water from the boiler drum. This differs from the bottom blow-off which is intermittent rather than continuous. The continuous blow-off arrangement consists of a collecting pipe located within the boiler drum in such a position that it will remove the most heavily concentrated water. In most boilers this position is several inches below the operating water level.

The amount of water continuously removed is controlled by a special regulating valve which is equipped with an indicator to show the amount that the valve is open. As the prime purpose of the continuous blow-off is to control the boiler water concentration, the setting of the regulating valve is made in accordance with the results of periodic tests of the boiler water.

An important advantage of continuous blow-off is that recovery of most of the heat from the blow-off water is possible.

Fig. 1 shows a typical heat recovery arrangement.



Continuous Blow-off Heat Recovery

Fig. 1

In this case (Fig. 1), the boilers are operating at high pressure so a two-stage flash tank system is used. The continuous blow-off water from the boiler drums is discharged into the first-stage high pressure flash tank. The flashed steam from this tank, being at a relatively high pressure, can be used in a process or for some other purpose. The water remaining in this high pressure flash tank is discharged to a second-stage low pressure flash tank. The low pressure flashed steam from this tank is used in a feedwater heater. The still hot water from this low pressure tank is then led through a heat exchanger where its heat is recovered by softened makeup water travelling to the feedwater heater. The continuous blow-off lines are equipped with a sampling connection and cooler in order that the boiler water concentration can be determined by test.

The cost of such heat recovery equipment will only be justified if there is an appreciable amount of continuous blow-off water at a high enough pressure to produce a usable quantity of flash steam.

Surface blow-off or blowdown connections are sometimes installed in boilers for the purpose of skimming sediment and oil from the surface of the boiler water. This type of blow-off is required when the water fed to the boiler foams when boiling. This foam contains impurities carried by the water and is drawn off through the surface blow-off. The surface blow-off line is located about water level in the boiler and it frequently has a connection in the form of a pan or scoop which rises and falls with the water level and thus skims off only the surface of the water. The scoop is held at the surface of the water by means of floats and is connected by means of a flexible connection.

Code Requirements

The requirements for blow-off connections as put forth by the ASME and the CSA are summarized in the following paragraphs.

PG-8.4.1 states that brass and bronze flanges and flanged or screwed fittings shall not be used in blow-off lines between the boiler and the required blow-off valves. Steel or other material must be used. Screwed fittings shall not be used where flanged types are specified.

PG-9 states that nonferrous pipe or tubes shall not be used for blow-off piping or any other service where they are exposed to the fire or products of combustion.

PG-27.2.2 gives the formulae for calculating the minimum required thickness of blow-off piping.

The value of P shall not be less than 900 kPa in any case and if it exceeds 900 kPa then the piping thickness shall not be less than Schedule 80. (Par. A-57)

The value of S in the formulae shall not exceed that permitted for the temperature of saturated steam at the maximum allowable working pressure of the boiler.

All fittings between the boiler and the blow-off valves shall be of steel for pressures over 900 kPa.

For pressures exceeding 690 kPa but not exceeding 1400 kPa, the blow-off valves may be of cast iron if equal at least to the requirements of the American National Standards for 1700 kPa. If steel valves are used they must conform to the American National Standards. (Par. A-58)

For pressures exceeding 1400 kPa the blow-off valves shall be of steel construction equal at least to the requirements of the American National Standards for 2100 kPa.

For pressures not exceeding 690 kPa the blow-off valves shall be equal at least to the requirements of the American National Standards for 900 kPa.

PG-59.3.1 states that for continuous blowdown systems, the pipe connections and all fittings up to and including the first shut-off valve shall be equal at least to the pressure requirements for the lowest set pressure of any safety valve on the boiler drum and with the corresponding saturated steam temperature.

PG-59.3.2 states that a surface blow-off shall not exceed 64 mm or the pipe size and the internal and external pipes shall form a continuous passage but shall be arranged so that the removal of one does not disturb the other.

Section PG-59.3 also states the following requirements:

Each boiler except forced-flow steam generators having no fixed steam and water line and high temperature water boilers shall have a bottom blow-off pipe fitted with a valve or valves. In addition, all waterwalls and water screens which do not drain back into the boiler and all integral economizers shall be equipped with blow-off valves or drain valves. In this case, drain valves may be used instead of blow-off valves if these valves are intended for use only to drain the boiler when it is not under pressure. Under these circumstances a single valve may be used provided it can be locked in the closed position or alternatively if the line is blanked off with a flanged and bolted connection on the downstream side of the valve.

The minimum size of blow-off pipe and fittings is 25 mm and the maximum size is 64 mm unless the boiler has 9.3 m^2 of heating surface or less in which case the minimum size is 19 mm.

If a bottom blow-off pipe is exposed to direct furnace heat it shall be protected by heat resisting material arranged to allow inspection of the pipe and when a blow-off pipe passes through a boiler setting provision for free expansion and contraction shall be made.

Ordinary globe valves and valves having dams or pockets that may collect sediment should not be used on blow-off connections. Straightway Y-type globe valves or angle valves may be used in vertical pipes. They may also be used in horizontal pipes providing they have the lowest edge of the seat opening at least 25 percent of the inside diameter below the centerline of the valve.

On all boilers, except those used for high-temperature water, traction and/or portable purposes, when the allowable working pressure exceeds 690 kPa, each bottom blow-off pipe shall have two slow-opening valves, or one slow-opening valve and a quick-opening valve or a cock.

Further in regard to the use of two blow-off valves, the two valves may be combined in one body provided the failure of one to operate can not affect the operation of the other.

Blow-off Valve Types

The basic types of blow-off valves commonly used are: the sliding disc, the seatless sliding plunger, the seat and disc, and the combination.

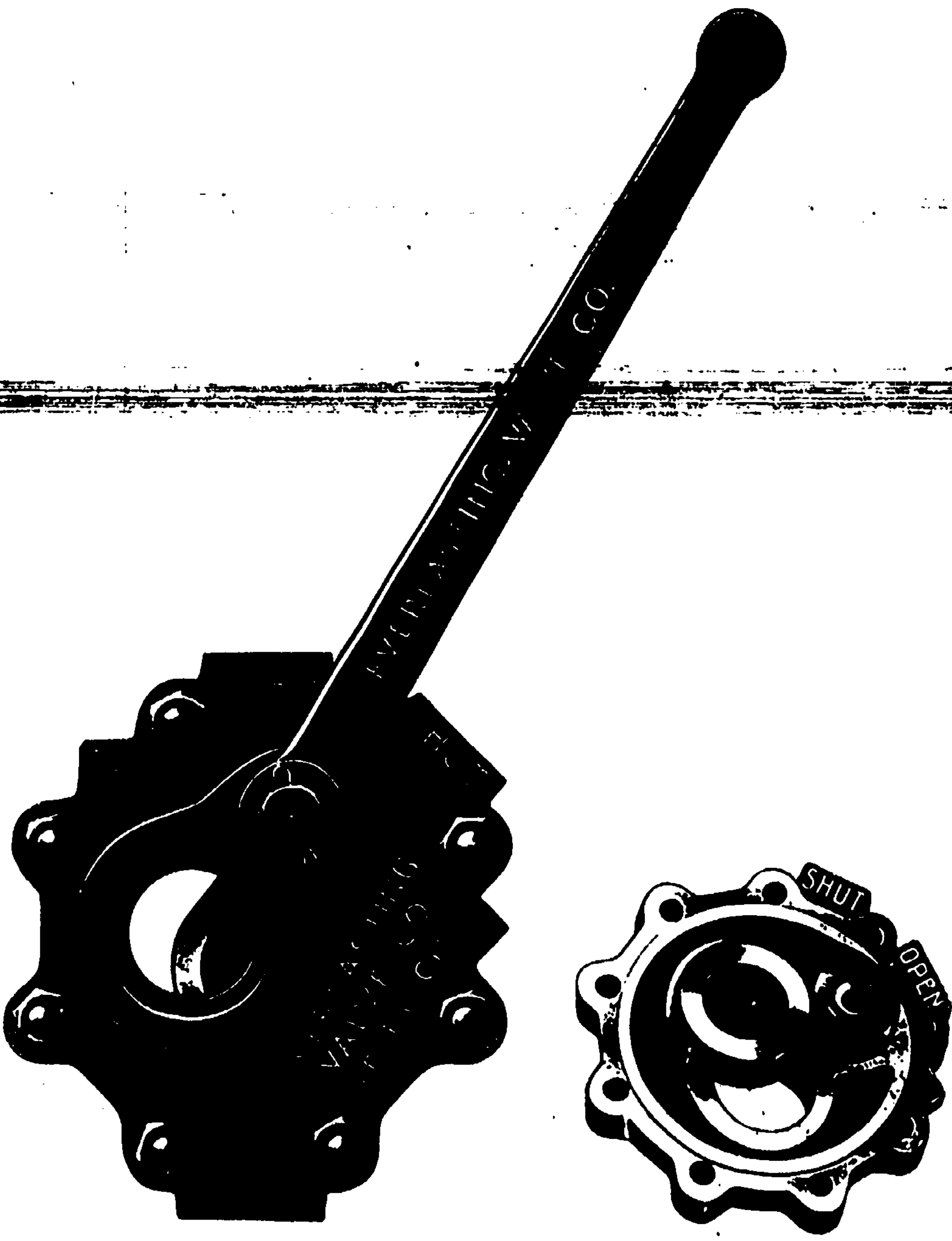
1. Sliding Disc Type

The general arrangement of a sliding disc valve is shown in Fig. 2 (a) while the details of the sliding disc appear in Fig. 2 (b).

When the valve is in the closed position the disc seals off the opening. With the valve in the open position the disc has moved off to one side leaving a straight through passage through the valve.

This valve is classed as a quick opening type and must always be used in conjunction with a slow-opening valve. It may, however, be converted to a slow-opening valve by means of a handwheel and gear arrangement which can be used in place of the operating lever.

When used as a quick opening valve it is operated by moving the lever through a short arc. This lever movement acts through a simple and direct acting mechanism to position the disc in the closed or open position.



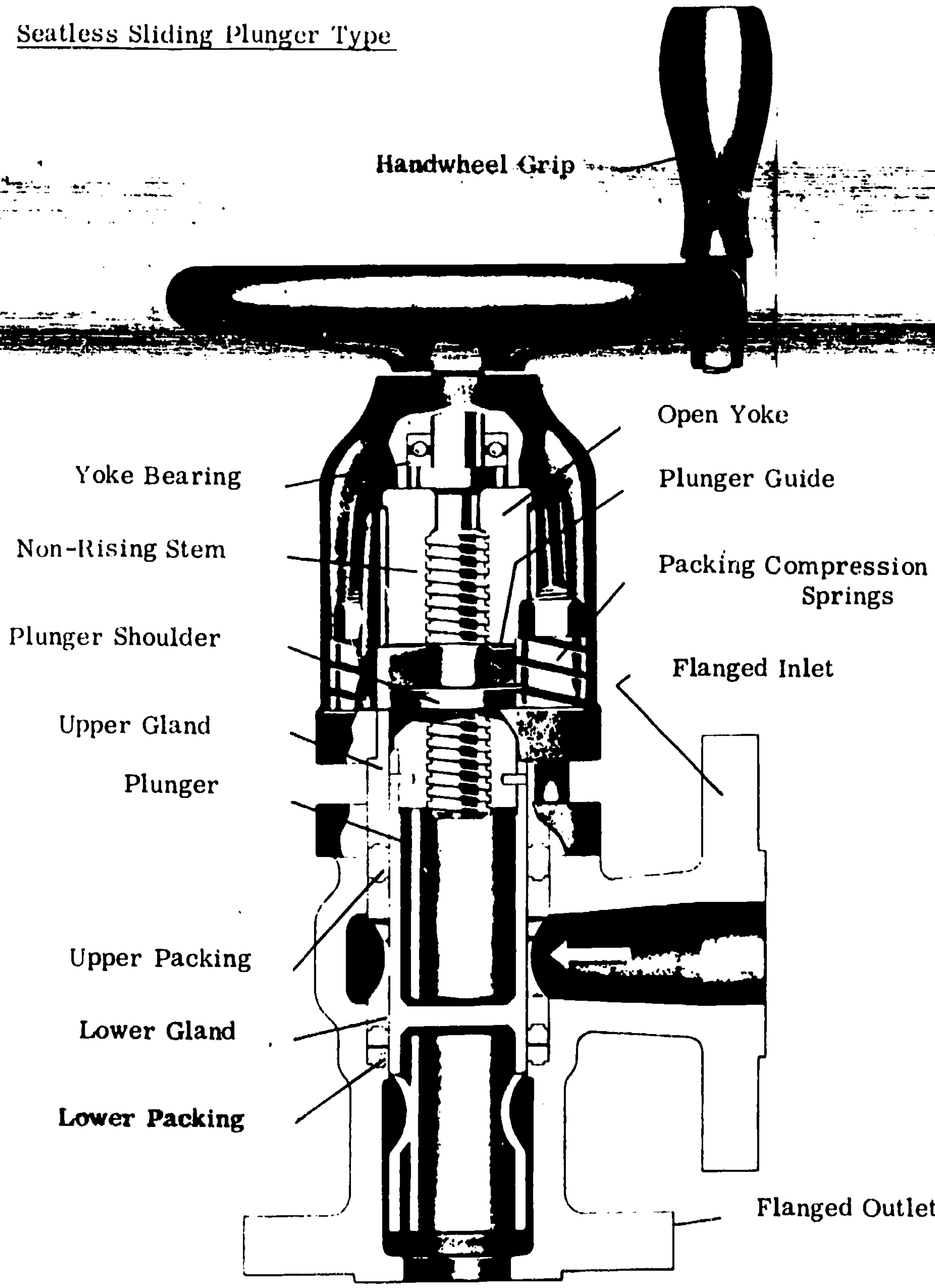
(a) (b)

Sliding Disc Blow-off Valve

Fig. 2

The movement of the disc provides a lapping action which helps maintain the tightness of the valve. Also, the sharp edges of the disc tend to shear or wipe away grit and boiler scale.

2. Seatless Sliding Plunger Type



Seatless Blow-off Valve

(Yarway Corporation)

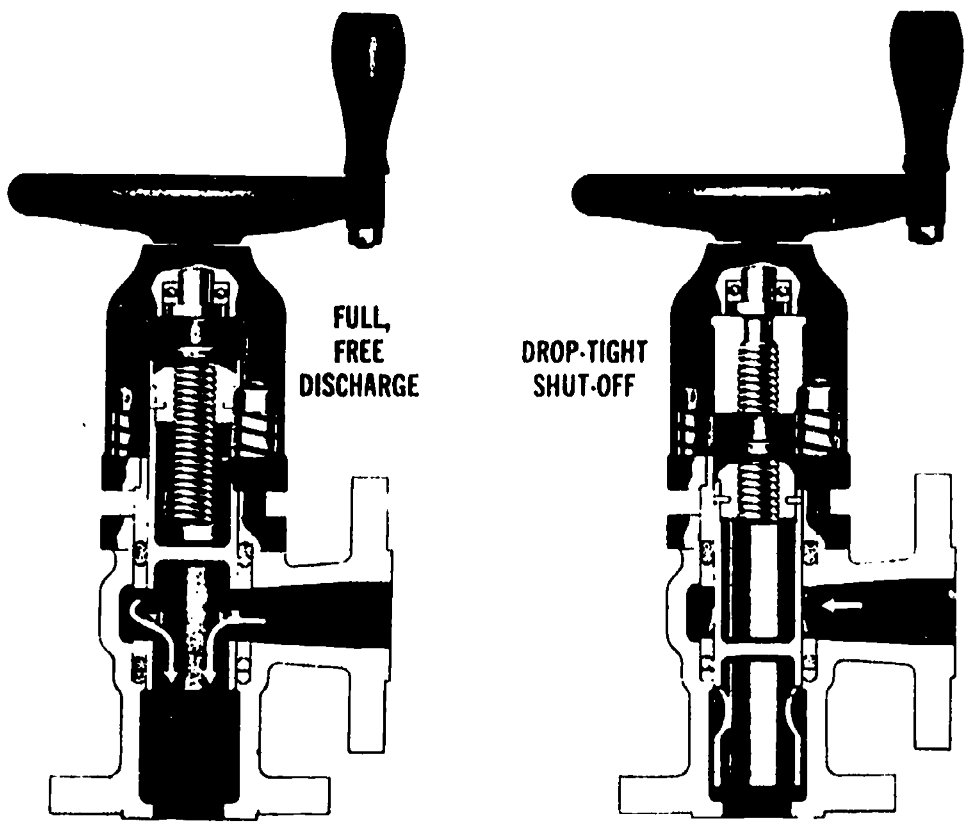
Fig. 3

(PE1-2-5-7)

The seatless valve illustrated in Fig. 3 is a slow-opening type which requires at least five 360 degree turns of the handwheel to move from full-closed to full-open and vice versa.

When the handwheel is turned to open the valve, the non-rising stem rotates and raises the plunger so that the plunger ports coincide with the body inlet ports. The discharge then takes place downward through the inside of the plunger and out through the valve outlet.

When the handwheel is turned to close the valve, the plunger is lowered so that the body inlet ports are closed off by the upper part of the plunger.



Seatless Valve Operation

(Yarway Corporation)

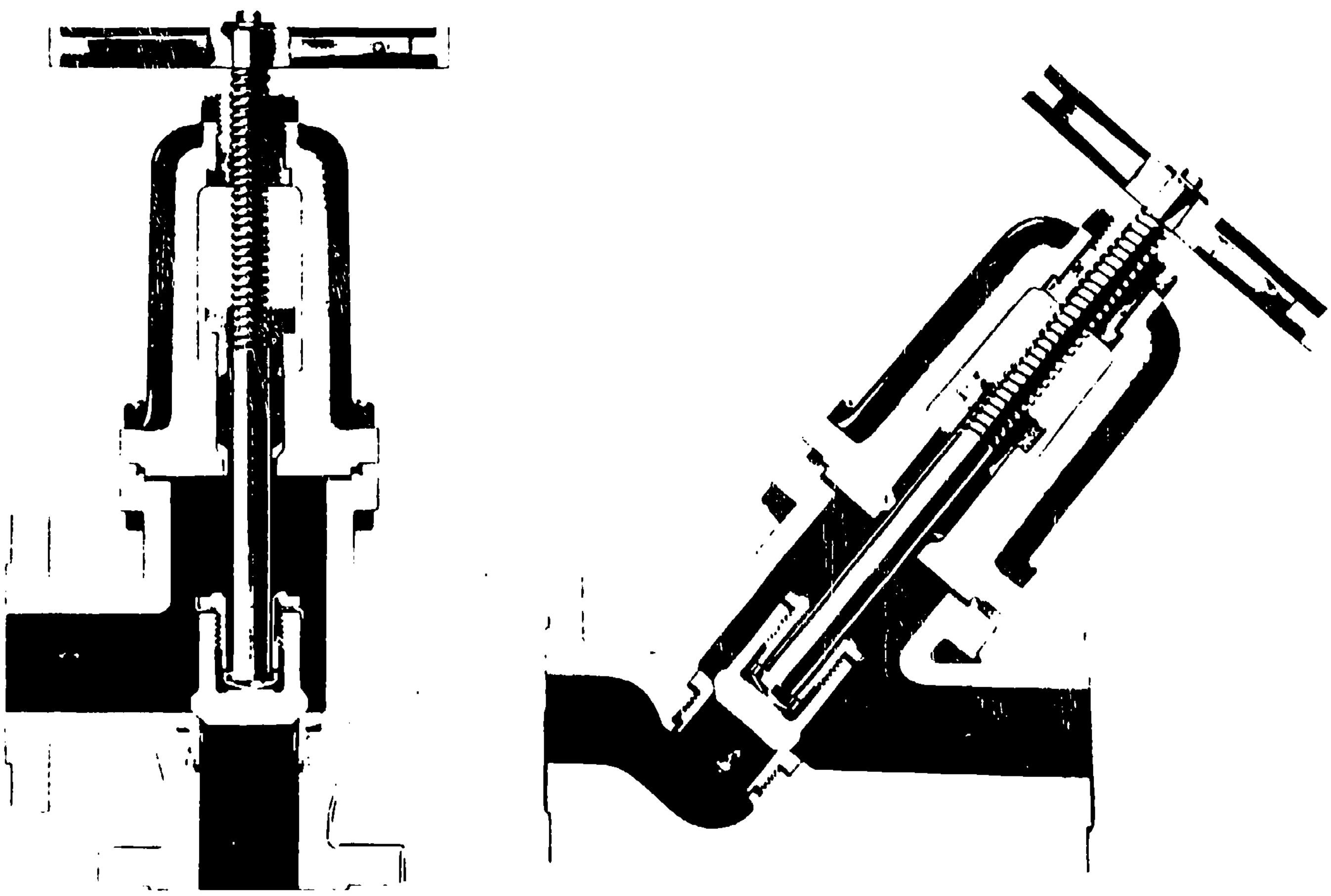
Fig. 4

The position of the plunger when the valve is open and when the valve is closed is shown in Fig. 4.

3. <u>Seat and Disc Type</u>

The seat and disc valve is a slow-opening type. It features a rotating rising stem with an attached disc on the bottom. The disc is free to rotate and mates with the valve seat in the body. Both the disc and the seat have hard-faced surfaces of material such as stellite or monel.

The valve may be an angle type or a straightway " Y " type and these two designs appear in Fig. 5.



Sectional View of Angle Valve

Sectional View of Straightway " Y " Valve

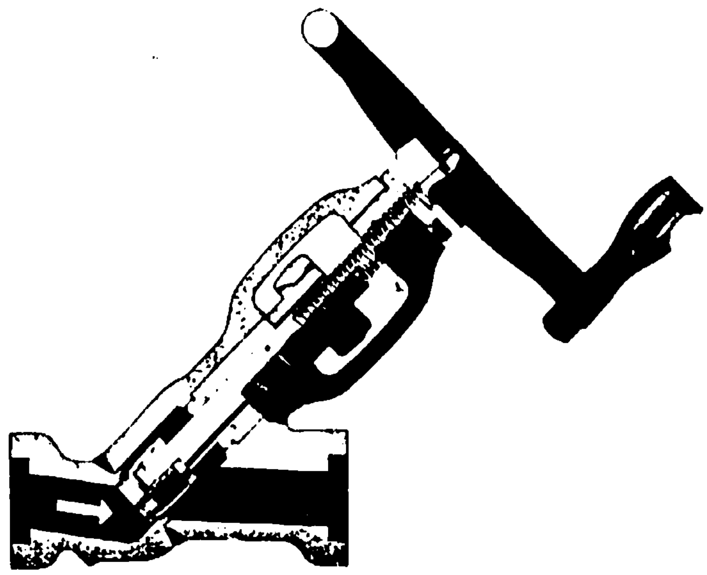
Seat and Disc Valves

(Yarway Corporation)

<u>Fig. 5</u>

Both the valves in Fig. 5 feature replaceable threaded seats.

The valve shown in Fig. 6 on the other hand has an integral welded-in stellite seat and is known as a hard seat valve.



Integral Seat Blow-off Valve

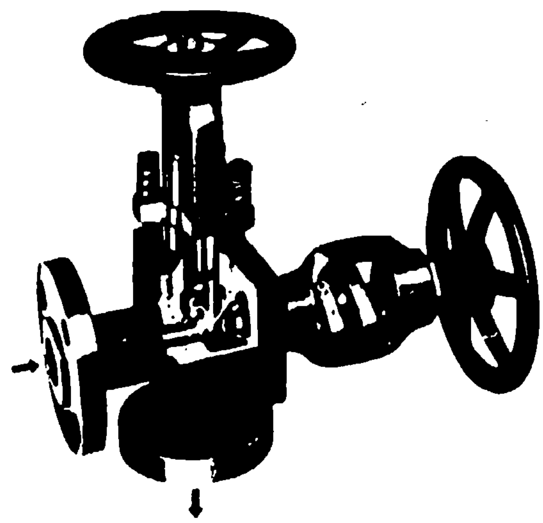
(Yarway Corporation)

Fig. 6

4. Combination Type

Two blow-off valves may be combined in one body and this design is used by some manufacturers as it results in a compact unit and eliminates the bolted or welded connection between the two valves.

A combination valve unit is shown in Fig. 7. The inlet valve of this unit is of the integral seat type while the discharge valve is of the seatless sliding plunger design.



Combination Valve Unit

(Yarway Corporation)

Fig. 7

Blow-off Valve Operation

The ASME Code Section V11 recommends the following in regard to blow-off valve operation:

If a quick opening valve such as the type in Fig. 2 and a slow-opening valve such as that in Fig. 5 are installed together on a boiler then the quick-opening valve would normally be opened first and closed last and the blowing down would be accomplished with the slow-opening valve.

If the blow-off installation consists of a hard-seat valve as in Fig. 6 followed by a seatless valve as in Fig. 3, (or the arrangement in Fig. 7) the hard-seat valve shall be opened last and closed first.

If the blow-off installation consists of two seatless valves of the type in Fig. 3, then the valve nearest the boiler or steam generator shall be opened last and closed first. If this is not done, the water trapped between the outer and inner valves would be placed under compression by the plunger travel after port closure.

If the blow-off installation consists of two identical valves, the sequence of operation should provide that the same valve is always opened last and closed first, so as to save the other valve from erosive throttling service to assure tight closing of the installation.

In order to determine the amount of blow-off, the concentration of solids in the water should be determined at least daily.

If the amount and frequency of blowing-off is not determined by water analysis, then the boiler should be blown-off once every 24 hours by opening the blow-off valve wide and then closing it.

Blowing-off is most effective when performed at periods of low steam output.

Boiler waterwalls should not be blown-off except when the boiler is banked or in accordance with the boiler manufacturer's specific instructions. This is to avoid disruption of the water circulation within the boiler.

When the gage glass is not visible to the operator blowing-off the boiler, another operator should be stationed where he can see the gage glass and signal to the operator blowing-off the steam generator. Never permit an operator at the blow-off valve to leave it until the operation is completed and the blow-off valve closed. Never permit an operator to blow-off more than one boiler at a time.

Blow-off Tanks

The CSA Code B51 states that, where the blow-off from any boiler, having a working pressure exceeding 103 kPa, is discharged into a closed sewer system, an approved blow-off tank or other suitable approved device shall be placed between the boiler and sewer for the purpose of reducing the pressure and temperature of the water entering the sewer.

The arrangement of this required blow-off tank is such that it always remains partially full of water. When the hot water from the blow-off enters, the cooler water in the bottom portion of the tank is displaced and overflows to the sewer while the high temperature water remains in the tank. The tank is fitted with a large open vent to prevent pressurization and is fitted with a siphon breaker to keep the tank from emptying.

The requirements for the design of blow-off tanks are listed in the CSA B51.

BOILER STOP VALVES

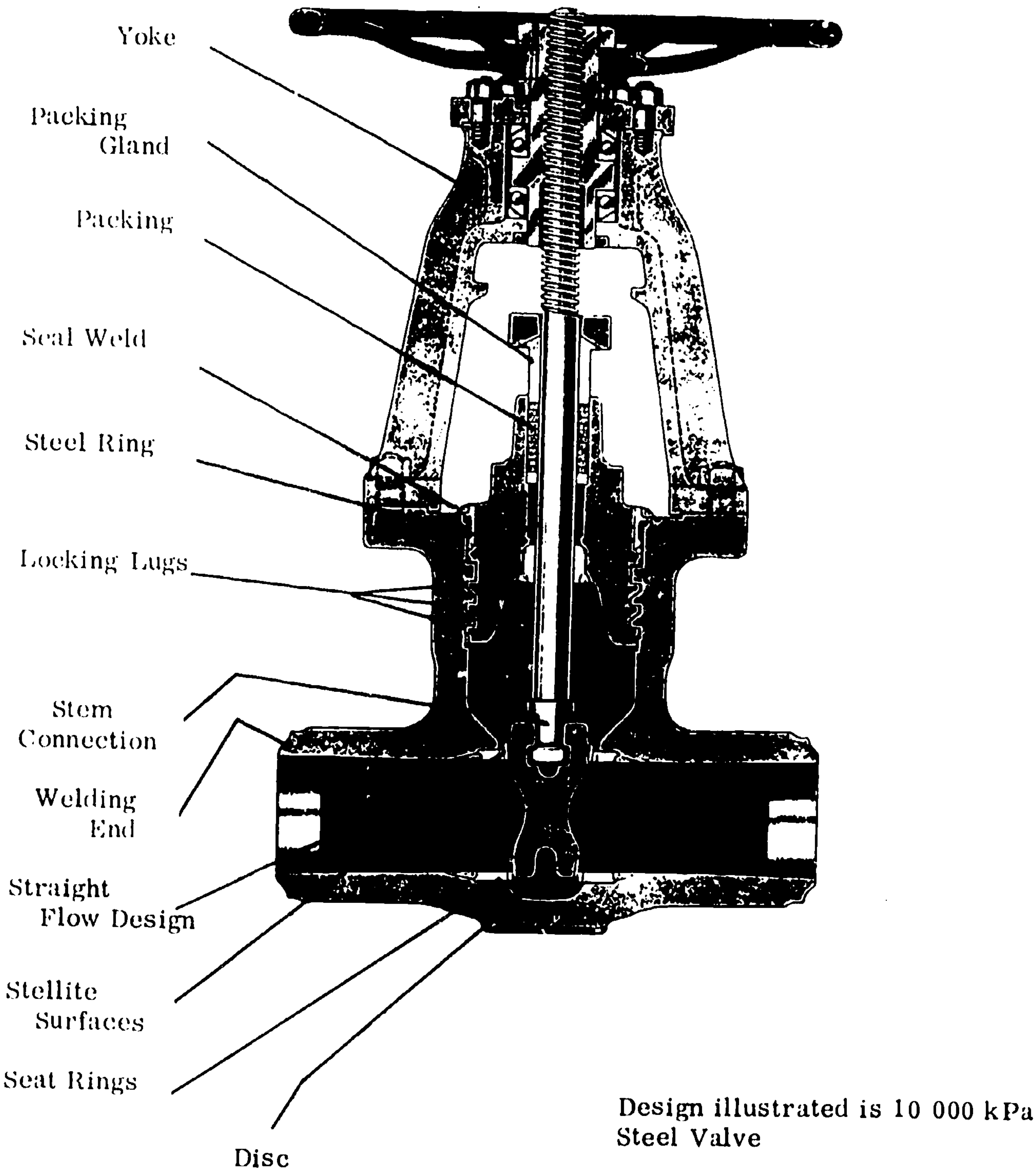
The ASME Code Section 1 A-54 requires that each steam outlet from a power boiler (except safety valve connections) be fitted with a stop valve located as close as practicable to the boiler.

If the outlet is over 51 mm pipe size then the valve should be of the outside-screw-and-yoke rising-spindle design. Alternately, a plug cock type valve may be used provided the plug is held in place by a guard or gland and the valve is equipped with a slow-opening mechanism and equipped to indicate from a distance whether it is closed or open. In the case of a single boiler and prime mover unit installation the required stop valve may be omitted provided the valve at the prime mover is equipped to show if it is open or closed and also is designed to withstand the required hydrostatic pressure test of the boiler.

When boilers are connected to a common header, the connection from each boiler having a manhole opening should be fitted with two stop valves having an ample free-blow drain between them. The discharge of this drain should be visible to the operator while manipulating the stop valves. The stop valves should consist preferably of one automatic non-return valve (set next to the boiler) and a second valve of the outside-screw-and-yoke type. Alternatively two halves of the outside-screw-and-yoke type should be used.

Outside-Screw-and-Yoke Stop Valves

The basic design of a gate type stop valve is shown in Fig. 8.



Gate Type Outside-Screw-and-Yoke Stop Valve

(Lunkenheimer)

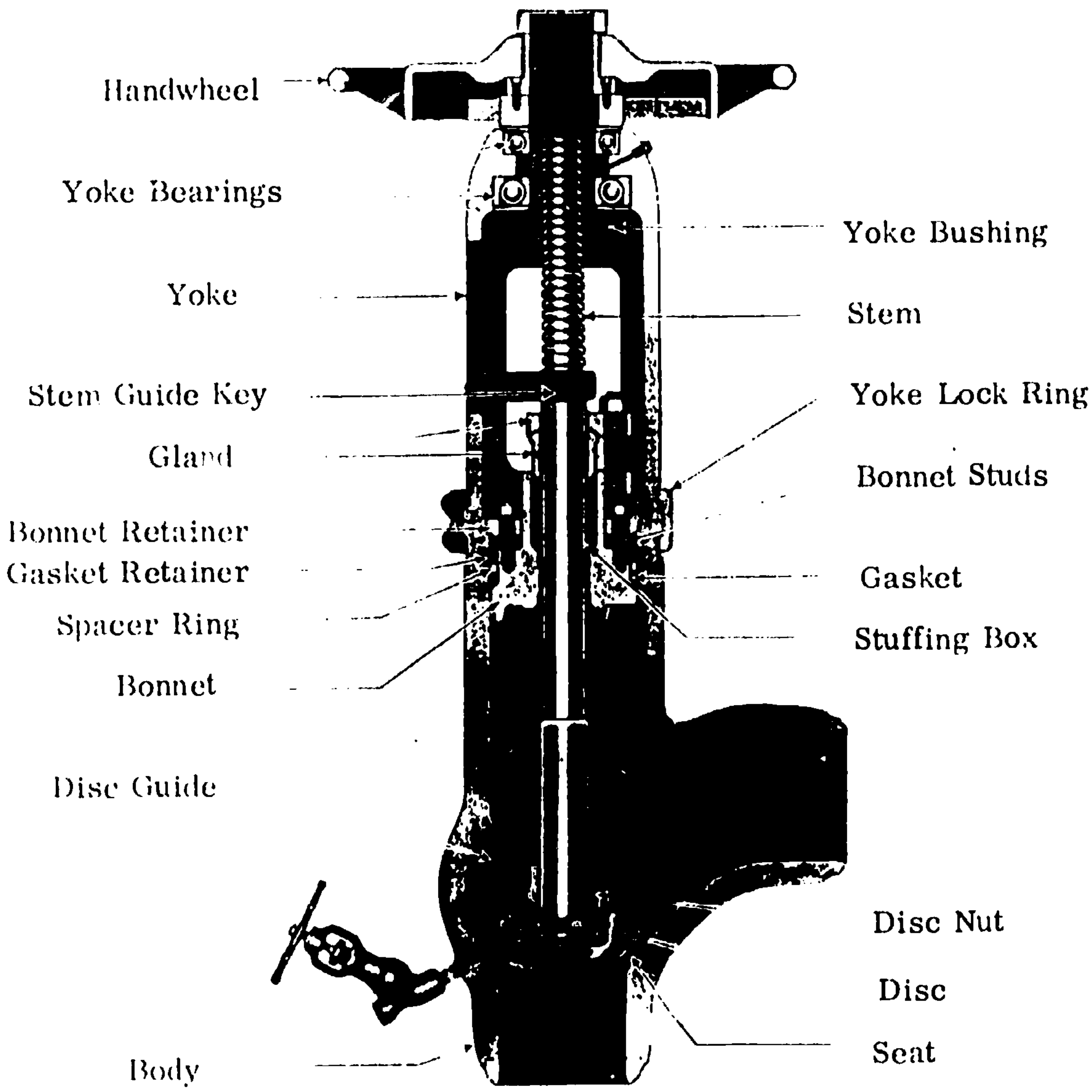
Fig. 8

(PE1-2-5-14)

BEST COPY AVAILABLE

This stop valve (Fig. 8) features an outside-screw-and-yoke with rising spindle. The handwheel is carried on the yoke and does not rise with the spindle. The locking lugs secure the bonnet to the valve body and are engaged by lowering the bonnet into the body and turning 45°. The bonnet is then seal-welded to the body. The steel ring below the seal weld prevents stress at the bonnet joint due to welding.

Fig. 9 shows the basic design of an angle type stop valve.



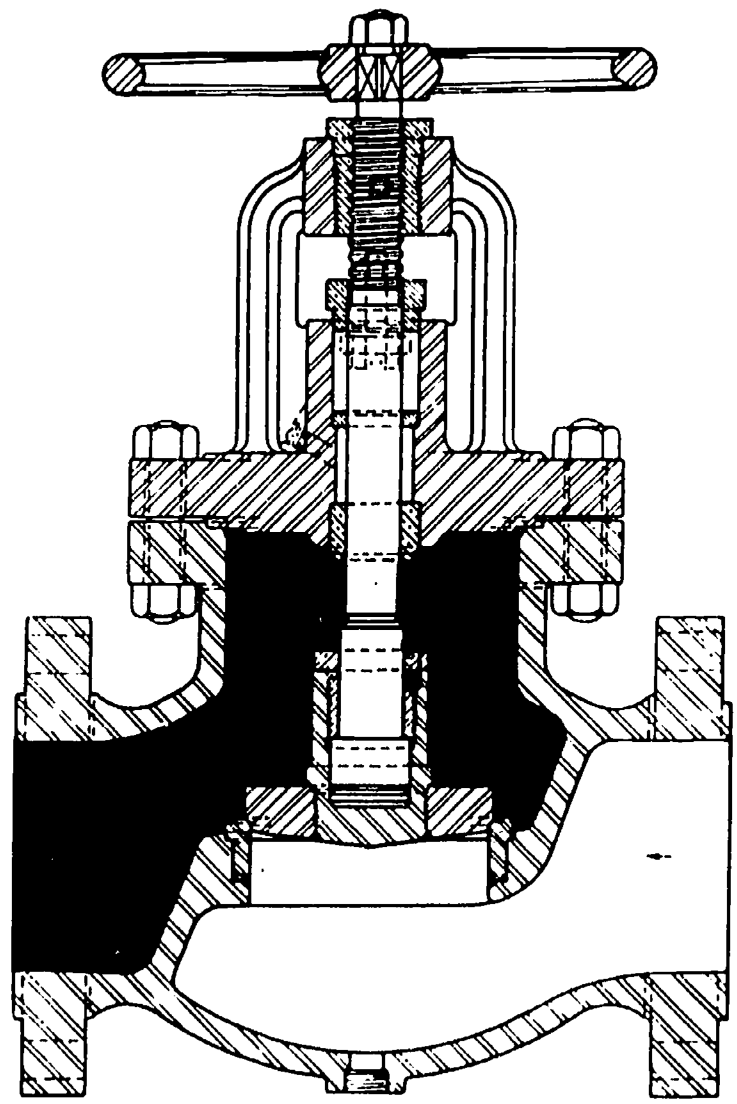
Angle Type Outside-Screw-and-Yoke Stop Valve

(Edward Valves Inc.)

Fig. 9

The angle stop valve in Fig. 9 is also of outside-screw-and-yoke construction with rising stem. Like the valve in Fig. 8 the handwheel is carried on the yoke and does not rise with the stem. The valve is equipped with a drain for removing condensate from above the disc when the valve is closed.

Fig. 10 shows the basic design of a globe type stop valve.



Globe Type Outside-Screw-and-Yoke Stop Valve

(Schutte and Koesting Co.)

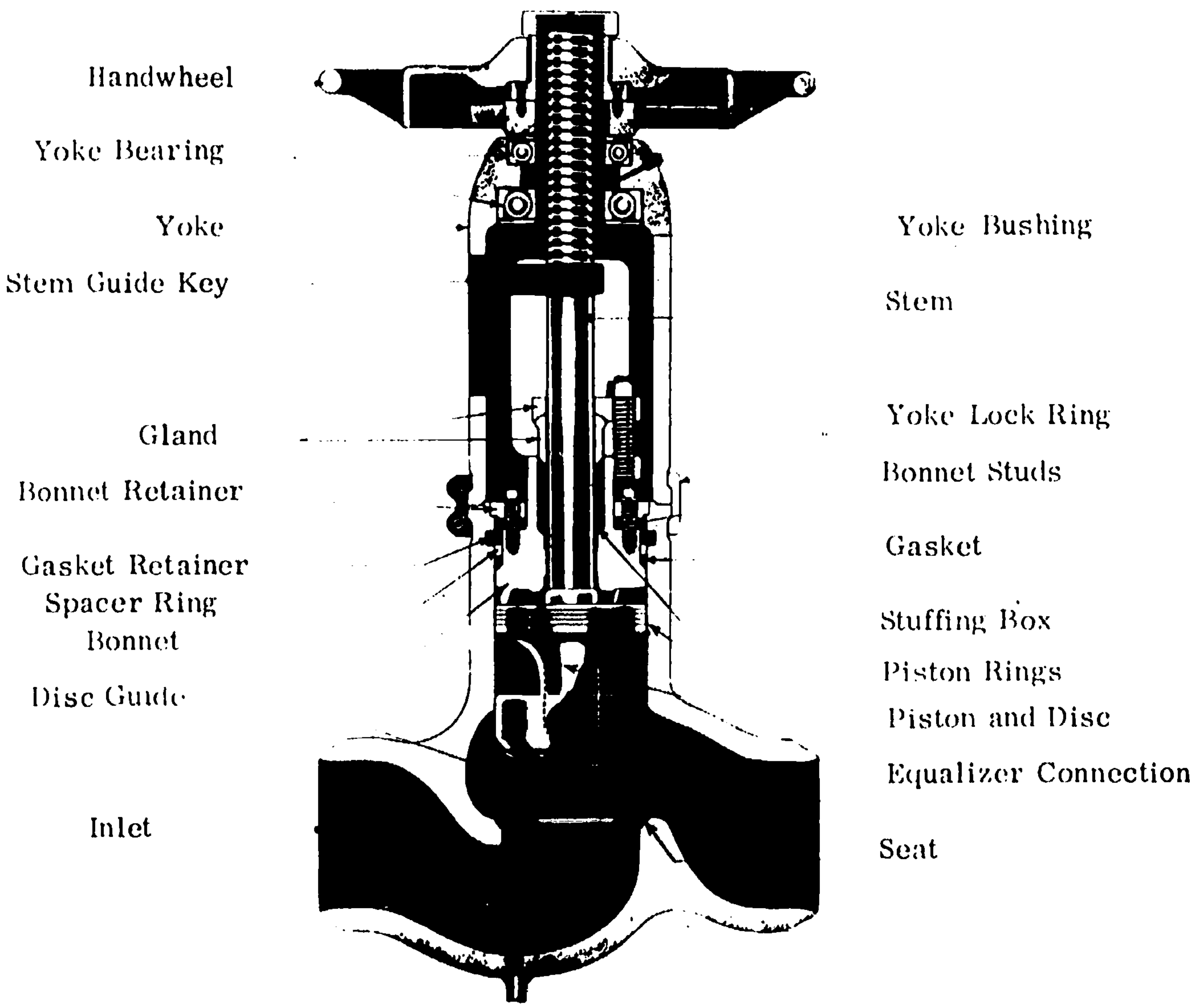
Fig. 10

The globe valve in Fig. 10 is an outside-screw-and-yoke type with a rising spindle. However, unlike the valves in Fig. 8 and Fig. 9, the handwheel is carried on the spindle and rises with it.

Non-Return Stop Valves

The non-return stop valve, also referred to as a stop-and-check valve is installed at the boiler outlet in cases where the boiler is connected to a common main with other boilers. Its purpose is to prevent a reverse flow of steam into the boiler from the common main. It achieves this purpose by means of a free moving piston and disc arrangement which opens when the pressure at the valve inlet is greater than the pressure at the valve outlet and which closes when these conditions reverse.

The non-return valve is made in a variety of designs and a globe type is shown in Fig. 11.



Globe Non-Return Valve

(Edward Valves Inc.)

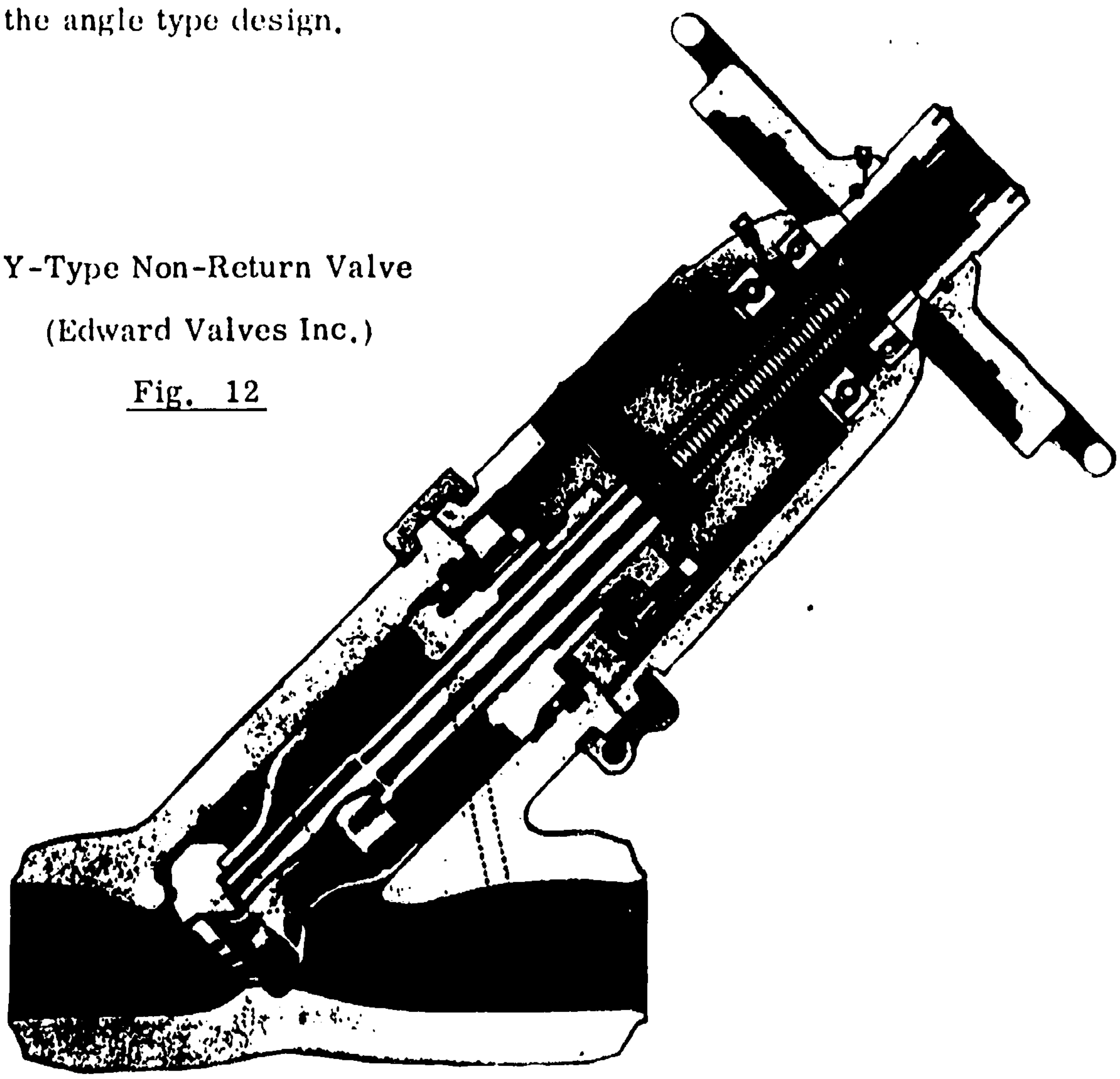
Fig. 11

(PE1-2-5-17)

The valve in Fig. 11 features a rising stem with the handwheel carried on the yoke. When the handwheel is turned to raise the stem, the bottom of the stem withdraws from the disc-piston and the valve is free to open when the pressure at the inlet is greater than that at the outlet. When the handwheel is turned to lower the stem, the stem will hold the disc-piston tightly against the valve seat and the valve cannot open under any circumstances.

The equalizer connection shown in Fig. 11 connects the relatively high pressure area over the disc-piston to the high velocity, lower pressure area at the valve outlet. This allows the piston to be pushed up into the chamber below the bonnet when the valve opens. If the pressure at the outlet increases above that at the inlet the equalizer connection will transmit this higher pressure to the area above the piston and the valve will close thus preventing a reverse flow of steam.

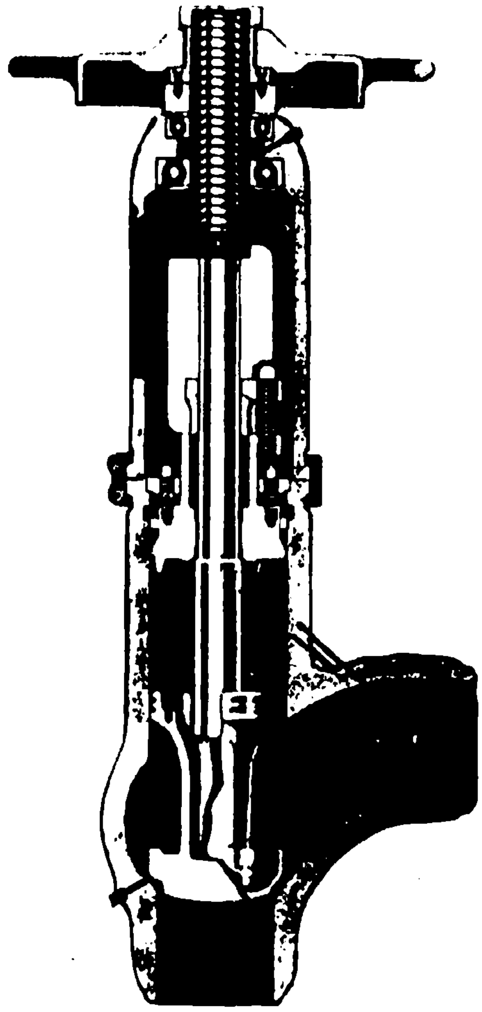
Fig. 12 shows a non-return valve having a Y-type body and Fig. 13 illustrates the angle type design.



Y-Type Non-Return Valve

(Edward Valves Inc.)

Fig. 12



Angle Type Non-Return Valve

(Edward Valves Inc.)

Fig. 13

Like the valve shown in Fig. 11, the valves in Fig. 12 and Fig. 13 feature an equalizer connection and the angle type valve in Fig. 13 is fitted with a drain connection directly above the valve seat.

The non-return valves illustrated in this section are all of the welding end design but they are also available in the flanged design.

DRUM INTERNALS

The term "drum internals" is generally taken to mean all the devices installed within the boiler steam drum including various types of steam separators, steam washers, chemical feed lines, boiler feedwater lines, and continuous blowoff and surface blow-off lines.

1. Steam Separators

The separation of the steam from the steam-water mixture discharging into the drum from the riser tubes is affected by a number of factors. These include; the difference in density between the water and the steam, the ratio of water to steam in the steam-water mixture leaving the risers, the rate of steam generation and of water circulation, the concentration of dissolved solids in the boiler water, and the size of the steam drum.

The difference in density between the water and the steam decreases as the boiler operating pressure increases. Therefore the force of gravity available for the separation of the two will also decrease and at high operating pressures it is necessary to use quite extensive separating equipment.

A high ratio of water to steam in the mixture leaving the risers will also amke the separation process more difficult.

In order to prevent overheating of tubes an adequate circulation of water must be maintained through the boiler circuit therefore the separating equipment must be designed so as not to have too great a pressure drop across it. This factor is not as critical in a forced circulation boiler as in a natural circulation type.

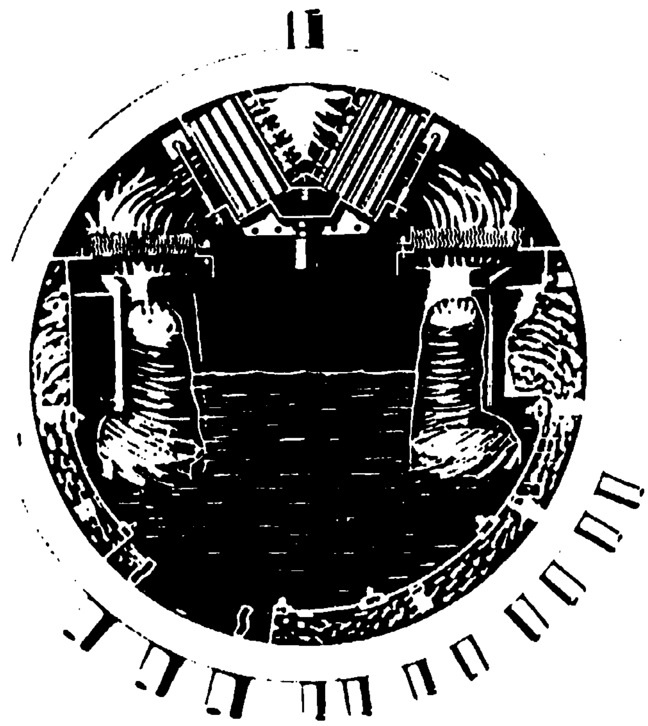
At high steam generating rates the drum water level will be high due to "swell" and this will make carryover of water with the steam leaving the drum more likely. Also the distance from the water level to the drum steam outlets will depend upon the drum size.

The higher the concentration of dissolved solids in the boiler water the greater will be the tendency for foaming to occur within the drum with resulting decrease in separation of water and steam.

As noted previously, at lower operating pressures (up to say 2000 kPa), separation of water and steam can be accomplished by gravity and without the use of mechanical separators. At higher pressures mechanical equipment is necessary and this equipment is usually arranged in stages.

The primary stage involves the use of separators which may be of various designs employing a change of flow direction, or use of impact plates or baffles, or use of centrifugal force to disengage the moisture particles from the steam.

The secondary stage involves the use of wire mesh screens or corrugated plates, both of which provide a large surface area upon which the moisture can deposit as the steam passes through.



Primary and Secondary Separators

(Babcock and Wilcox)

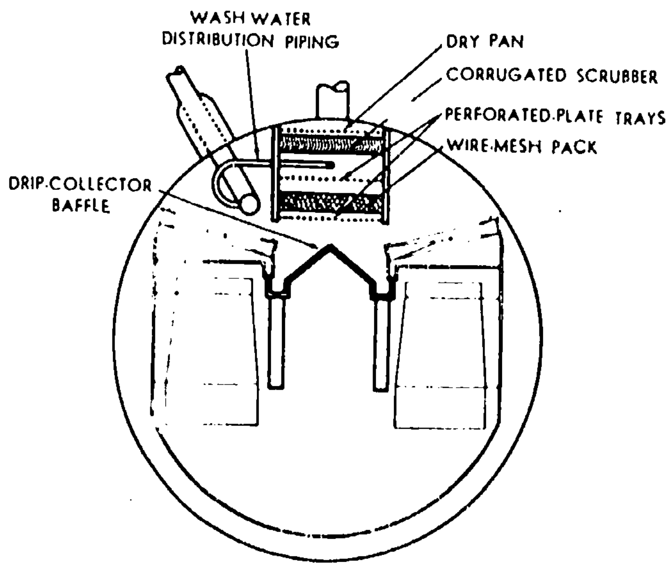
Fig. 14

Fig. 14 shows the arrangement of primary and secondary separators in a high pressure boiler drum. The primary separators are the cyclone type wherein centrifugal force is used to separate the steam from the water. The steam-water mixture enters the cyclone cylinder in a tangential manner. The water collects against the cylinder walls and flows downward and is discharged at the bottom of the cylinder. The steam, being less dense, moves to the centre of the cylinder and flows upwardly passing through a small corrugated scrubber at the top of the cyclone cylinder. The steam then passes through the secondary separators which are large corrugated scrubbers located near the top of the drum. The large surface of these scrubbers intercepts any remaining water particles as the steam flows between the closely fitted plates. The water then drains from the bottom of the scrubber assembly to the water below in the drum.

2. Steam Washers

In some cases steam washing is carried out between the two steps of separation already mentioned. Steam washing is the process of rinsing the steam leaving the primary separators with feedwater in order to absorb the vaporized silica carried by the steam and so prevent the formation of objectionable deposits on turbine blades.

An arrangement of primary and secondary separators with a steam washer is shown in Fig. 15.



Steam Washer

(Babcock and Wilcox)

Fig. 15

Referring to Fig. 15, the steam leaving the centrifugal type primary separators flows upwardly through a wire mesh pack located between perforated-plate trays. It then comes in contact with the wash water which is flowing downwardly counterflow to the steam. The washed steam then flows through a corrugated scrubber section to the drum outlet.

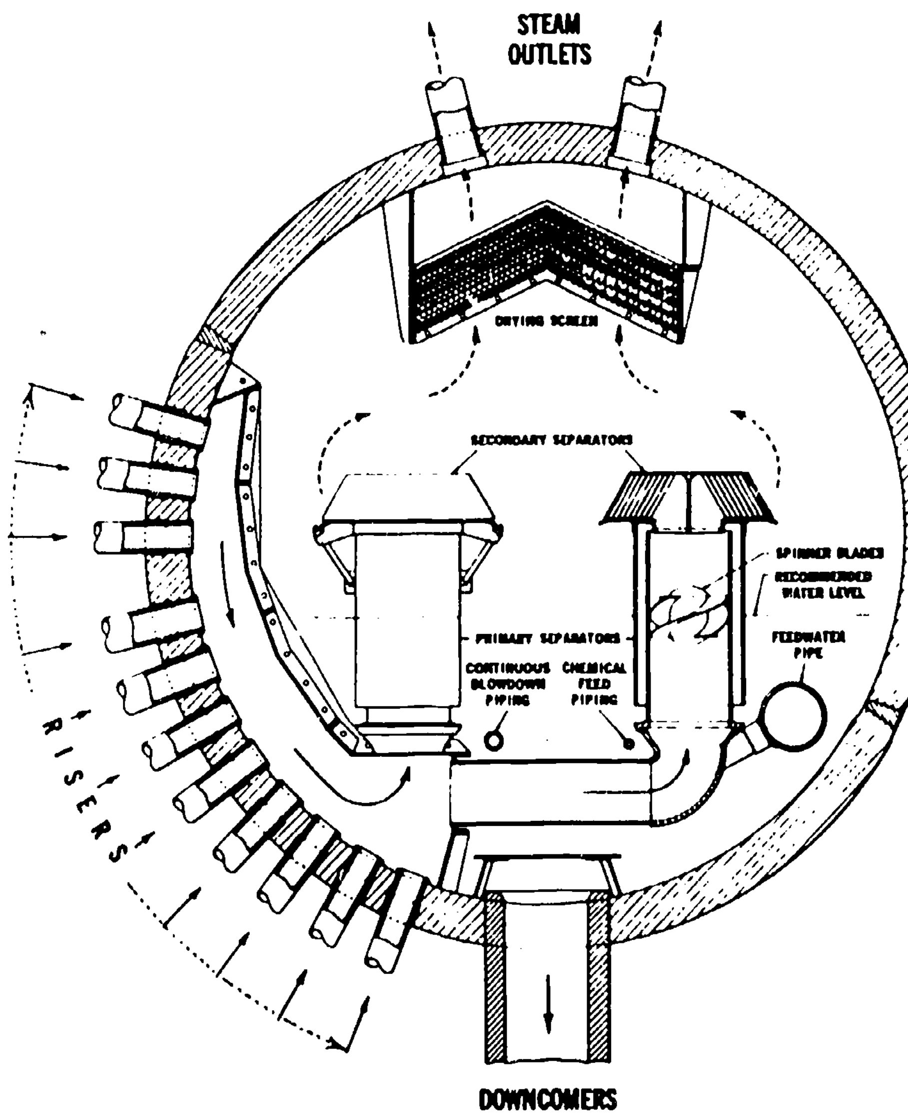
3. Feedwater Lines, Chemical Lines, Blowdown Lines

The feedwater entering the drum is distributed by means of an internal feedpipe which is submerged in the water within the drum. This internal pipe must be arranged in such a way so as to avoid discharge of the comparatively cold feedwater against the drum wall. In a high pressure boiler the drum wall thickness is well over 100 mm and severe thermal stresses can be set up if the wall is subjected to extreme temperature variation. Usually the feedline is arranged to mix the feedwater with the drum boiler water before entering the downcomer tubes.

(PE1-2-5-22)

Chemicals which are used for the control of scale, corrosion, and sludge within the boiler are fed into the drum by means of an internal pipe. This chemical line is positioned in such a way so as to insure rapid mixing of the chemicals with the entering feedwater. It is usually in the form of a perforated pipe and it must be flushed periodically with clean water to prevent it plugging with deposits.

The blowdown lines contained within the drum include the continuous blowdown and in some cases a surface blowdown or blowoff. The surface blowoff is located at the boiler water level and is used to withdraw impurities floating on the water surface. The continuous blowdown line however is located some distance below the water level where the water having the greatest concentration of dissolved solids is thought to be found. It should also be located in such a way that it does not draw off entering feedwater or treatment chemicals.



Drum Internals

(Combustion Engineering)

Fig. 16

Fig. 16 shows the arrangement of drum internals for a high pressure boiler.

(PE1-2-5-23)

SOOT BLOWERS

During operation, the steam generator or boiler heating surfaces tend to become fouled from an accumulation of ash produced during the combustion of the fuel. In order to keep the steam generator at its maximum efficiency this accumulation of ash and slag must be removed at regular intervals from the furnace walls and convection areas by means of soot blowers.

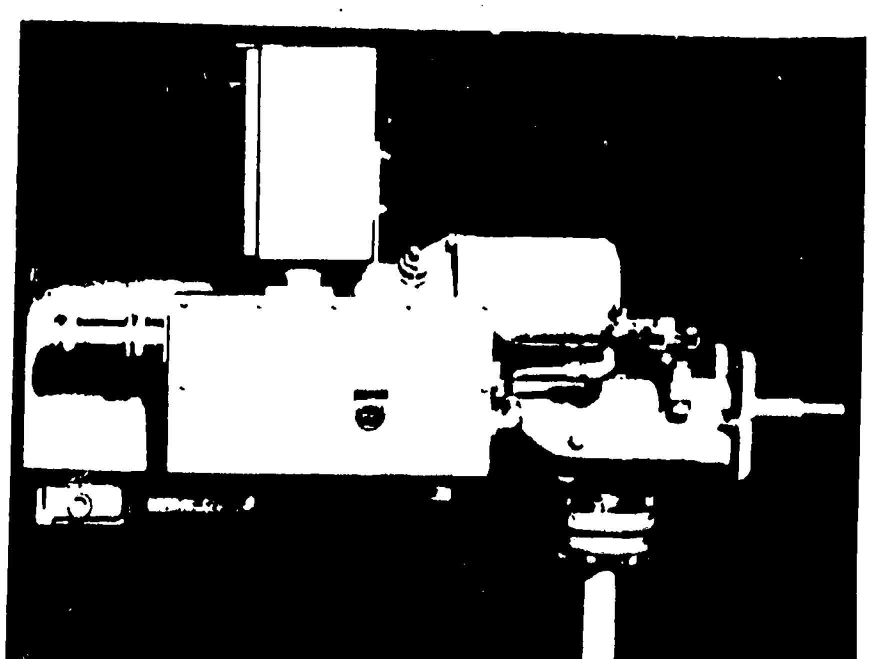
The number of soot blowers required and their location depend upon the ash characteristics of the type of fuel burned as well as the size of the furnace.

Natural gas is a clean burning fuel which deposits only a small amount of dust on the heating surfaces and therefore does not require the use of soot blowers.

Fuel oil has a low ash content which forms a thin layer on the furnace walls. This thin layer does not require soot blowers to remove it but rather is removed once a year by water washing when the steam generator is out of service. However, ash deposit tends to build up in the reheater and superheater sections and in these locations sootblowers are normally required.

Coal is the fuel which requires maximum use of soot blowers. The combustion of coal generally produces a molten ash or slag in the area of the burners. In the high temperature convection passes such as the superheater sections a sintered (caked) ash is deposited. In the low temperature sections such as the economizer and air heater the ash may have a dust-like form or, if high sulphur coals are used, a solid corrosive deposit may be produced.

The soot blowers used to remove the slag from the furnace walls are the short single nozzle retractable type as shown in Fig. 17.



Single Nozzle Retractable Wall Blower

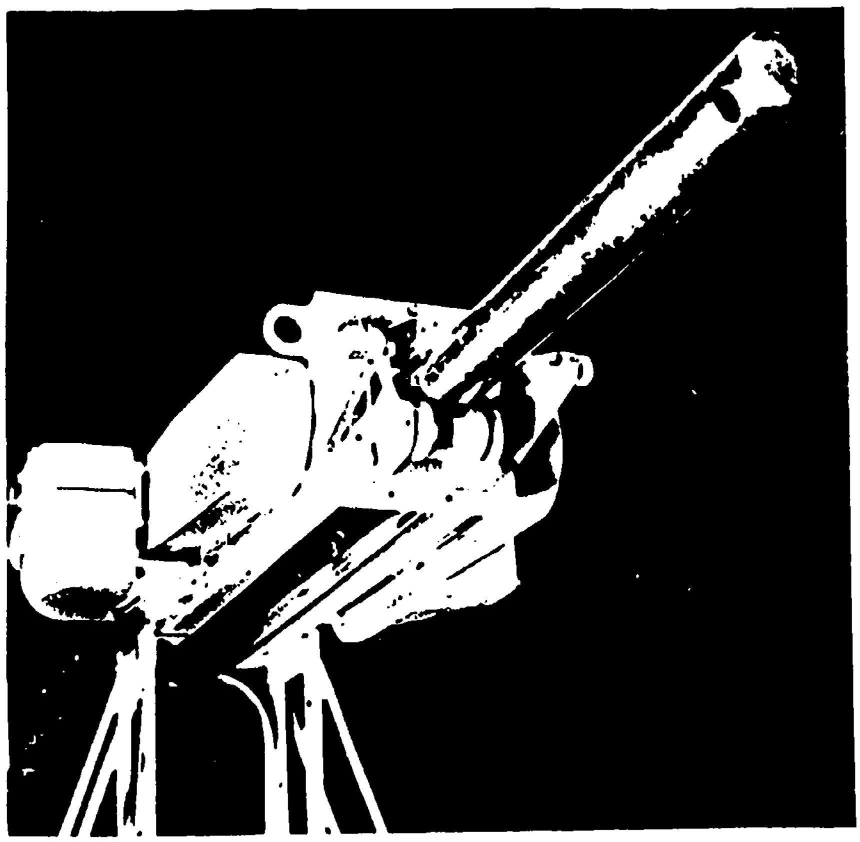
(Copes-Vulcan, Inc.)

(PE1-2-5-24)

Fig. 17

In this type one motor is used to extend and retract the blowing nozzle while another motor is used to rotate the nozzle a full 360 degrees. The blowing medium, which may be steam or air, or even water, is delivered with maximum impact to drive sintered slag and clinging masses from the tubes.

Long retractable double nozzle soot blowers are used to remove ash deposits from high temperature convection sections such as the secondary superheater. The complete width of the section must be transversed and the blowers may be located on both sides or on one side only and they may be up to 18 m in length.



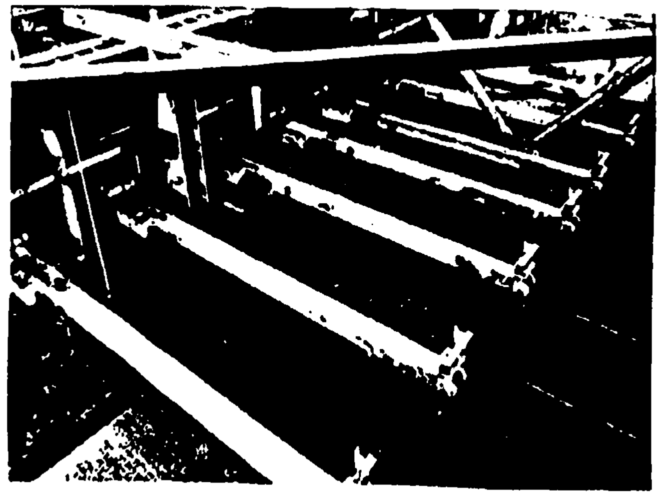
Long Retractable Blower

(Copes-Vulcan, Inc.)

Fig. 18

Fig. 18 shows the appearance of a long retractable double nozzle blower and Fig. 19 shows the arrangement of several of these blowers in place around the steam generating unit.

In the low temperature passes the blowers used may be of the stationary mutiple nozzle type extending across the width of the pass or section. However, if the width of the section is such that a blower tube in excess of 6 m is required then retractable blowers are likely to be used.



Retractable Blower Arrangement

(Copes-Vulcan Inc.)

Fig. 19

Blower Mediums

At the present time the commonly used cleaning mediums are steam and compressed air. Less common is the use of solid pellets or shot for cleaning certain boiler sections. Out of service cleaning frequently makes use of water as a cleaning medium.

If steam is used it should be dry and free from condensate as entrained condensate in the steam will cause tube erosion and for this reason superheated steam should be used if available. To avoid condensate problems the steam piping system must be designed to provide the necessary slopes for condensate drainage and the system should have properly located drain traps. The steam supply should be turned on to heat up the piping system before operation of the soot blowers. The condensate formed during this heating up period can be removed by means of a steam trap or drain valve. The branch piping from the soot blower header to each soot blower should be connected to the top of the header and should have enough slope to drain condensate back to the header. The steam valve at the blower must be kept in good condition to prevent leakage of steam into the blower and resulting formation of condensate during the periods between operation.

As stated previously, the use of compressed air as the cleaning medium is quite general and it has been found that this medium has equal cleaning ability to that of steam. It also will produce tube erosion if carrying entrained moisture, therefore similar precautions must be taken when using air to those taken when using steam in order to prevent condensate formation and entrainment.

The use of solid pellets or shot for difficult cleaning problems such as those found in many types of recovery boilers has gained a certain amount of favor. The method, which is used mostly for air heater and economizer surfaces, consists of allowing the pellets to drop by gravity onto the surfaces and to ricochet from one surface to another. A hopper at the bottom of the air heater or economizer is used to collect the pellets which are then returned by a pneumatic system to the distributing chamber at the top for recycling. Most of the ash removed by the pellets is carried away in the flue gas stream. Large particles fall with the pellets into the collecting hopper and are recirculated with the pellets until they are broken up into fine particles which can be removed by the flue gas stream.

Advantages for this method of cleaning include the fact that the same quantity of pellets will clean an entire vertical section no matter what the height. In addition, the pellet system does not require platforms and walkways around the boiler to the same extent as do the steam and air systems and the pellets have a more positive cleaning action than steam or air.

Soot Blower Control

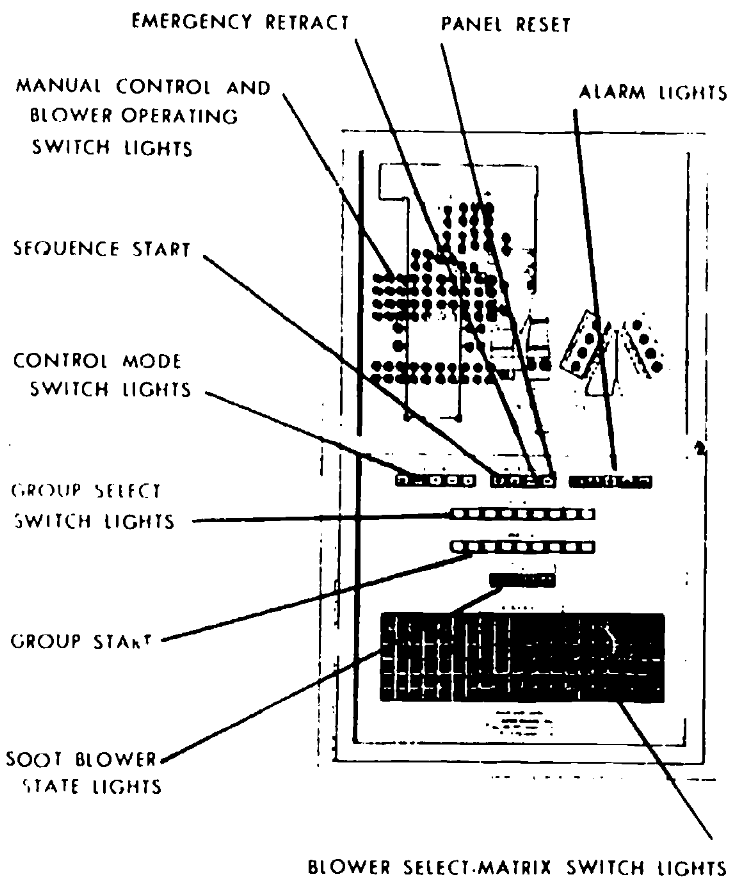
Depending upon the size and capacity of the boiler unit and the number of blowers installed, various control methods for soot blower operation may be employed. For small industrial boilers, hand operated and controlled soot blowers are used. Large industrial and central station boilers use various degrees of automatic control ranging from simple push button stations to automatic pre-programmed cleaning cycles.

The control panel for an elaborate system used in a central station is shown in Fig. 20. This panel incorporates the boiler diagram with indicating lights for each blower, alarms and switches.

This system (Fig. 20) can be started manually, by clock, or automatically from boiler signals. It provides a constant check on such soot blower operating conditions as: soot blower "blowing", control power failure, motor overload, low header pressure, no blowing medium, normal time exceeded, low receiver pressure (air only), and no rotary motion.

In general, an automatic system should provide the following:

1. Individual blower selection and remote operation, out of sequence.
2. Capability of selection of a sequence, interruption of that sequence, and return to normal.
3. Easy identification of the system status, mode of operation, and blower operation.
4. Capability to alarm and identify type and location of any malfunction plus the ability to provide speedy corrective action.



Soot Blower Control Panel

(Copes-Vulcan, Inc.)

Fig. 20

(PE1-2-5-28)

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 5

1. Sketch and describe a method of recovering heat from boiler blow-off.

2. Describe the construction and operation of a non-return stop valve.

3. Sketch an outside-screw-and-yoke stop valve and describe its construction.

4. Describe the location and the purpose of each of the following connections:

   (a) surface blow-off

   (b) bottom blow-off

   (c) continuous blow-off

5. According to the ASME, where are bottom blow-offs required and what are the maximum and minimum sizes of such connections.

6. Define the following terms:

   (a) sliding disc valve

   (b) slow-opening valve

   (c) seatless valve

   (d) hard-seat valve

   (e) blow-off tank

7. Explain why steam separators are necessary in large high pressure steam generators.

8. Sketch and describe a steam separating arrangement for a high pressure boiler, showing the location of riser and downcomer tubes in relation to the separating equipment.

9. Describe the general construction and the usual location of the following sootblowers:

   (a) single nozzle short retractable type

   (b) single nozzle long retractable type

10. Discuss the general requirements of an automatic soot blowing system.

(PE1-2-5-Q)

INSTRUCTIONAL LEARNING SYSTEMS

7.5

BOILERS -- OPERATION

Goal:

The apprentice will be able to describe steps in boiler operation.

Performance Indicators:

1. Describe hydrostatic testing.
2. Describe drying out the refractory.
3. Describe "boilout".
4. Describe setting of safety valves.
5. Describe procedures for start-up of boiler.
6. Describe procedures for operating a boiler under normal conditions.
7. Describe procedures for operating boiler under emergency conditions.
8. Describe types and causes of boiler explosions.
9. Describe procedure for shut-down of boiler.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Boiling out
* Flame-out
* Foaming
* Forced draft fan
* Furnace explosion
* Hydroset
* Hydrostatic testing
* Induced draft fan
* Pressure explosion
* Priming
* Purging
* Safety valve compression screw
* Thermocouple
* Turnbuckle

Introduction

A boiler operator must follow a set of prescribed procedures for starting, operating and shutting down a steam generation plant. These procedures are necessary for safe and successful operation of a boiler.

This package discusses the basic practices for operation of boilers. The material is targeted at those that will be operating and maintaining boilers--not boiler mechanics.

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Pre-operation Activities

Hydrostatic Testing

Boilers that are new or recently overhauled should be tested under pressure for leaks. A hydrostatic test places the boiler under 1.5 times as much pressure as it was designed to take. Pinhole leaks and cracks can be detected in the boiler. High quality water of atmospheric tenperature should be used for the test.

Drying Out The Refractory

The refractory of a new boiler must be dried out before placing it into full steam production. A low firing rate that will maintain 95 C water temperatures is needed for drying the refractory.

Boiling Out The Waterside

The waterside of new boilers should be boiled out to get rid of grease and dirt that has accumulated during its construction. The boiling out can take place at the same time the refractory is being dried out. The boiler is filled with clean water and 25 % of the required "boiling out" chemicals are added. The boiler manufacturer's recommenmdations must be fcllowed on amounts of chemicals. After the fireside drying is complete, the other 75% of the chemicals are added and the firing rate is increased. The boiler pressures are raised to one-half of their working pressures. Blow-off valves are operated every 2-4 hours to remove the sludge. When the flow-off water becomes clear, the boil out is complete.

Safety Valve Setting

At the end of boil out, the main steam lines, superheater and reheater should be blown out. Once these have been blown out, the safety valves should be set. A <u>htdroset</u> unit is attached to the safety valve spindle by means of a <u>turnbuckle</u>. Pressure is put on the safety valve by a hydroset pump until it reaches it setting. If the valve does not act when its setting is exceeded the value setting must be adjusted with the <u>safety valve compression screw</u>. A hydroset unit and safety valve are shown in the following diagram.

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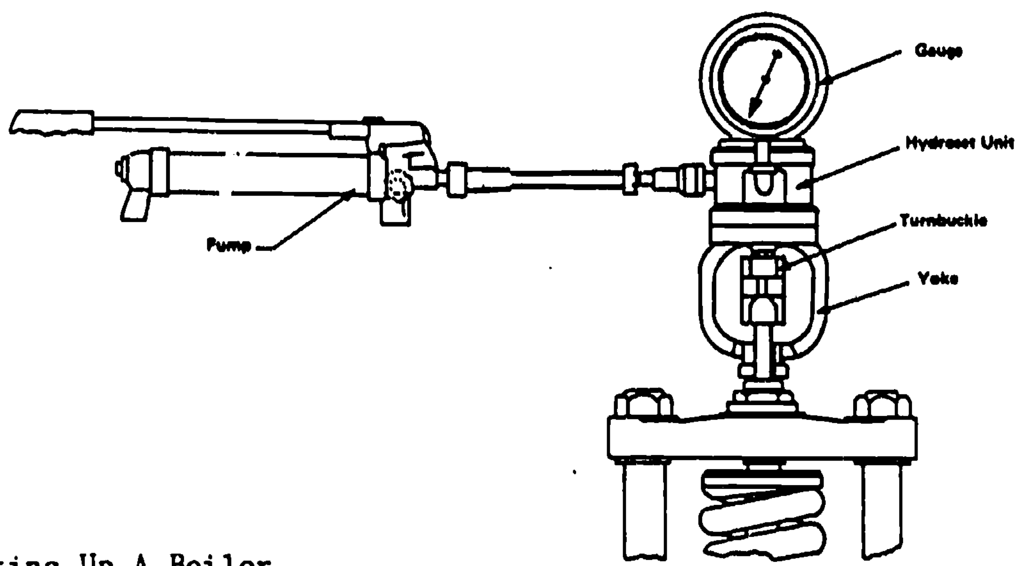

Starting Up A Boiler

1. Fill with high quality water.
2. Keep vents open during filling to allow air to escape.
3. Purge the furnace before lighting. Use 25% of full load of air flow and make at least five volume changes in multiple burner units and eight volume changes in single burner units.
4. Light the burners.
5. Control temperature of flue gas that flow to superheater or reheater by regulating firing rate.
6. Protect drums and headers from rapid temperature change during time that pressures are being raised. If boiler serves one turbine unit, the turbine should be started when one-half the working pressure is reached. This starts a flow of steam through the superheater and regeater. The turbine should not be placed under load.
7. Measure temperature of flue gas in the furnace sections by means of thermocouples. Temperature change rate must not be over 40 C per hour for rolled tube joints or 200 C per hour with welded joints.
8. If system has headers, open drain valve on non-return valve and crack open the header valve. After pressure has equalized, open the header valve wide. Open non-return valve and close drain valve once the boiler is feeding into the system.

Operating Boiler Under Normal Conditions

Maintain Water Levels

Boilers are equipped with gauge glasses and water columns to indicate water

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levels in the boiler. Some boilers have alarms for high and low water levels. Water columns should be blown down according to the manufacturer's recommendations. Blow-down shows the operator whether the water column is accurately measuring the water level. Boiler feed pumps must be checked for bearing temperatures and lubricated when needed. Stand-by feed pumps should be started and allow them equal operation time with the regular feed pump. The water level control system must be checked regularly.

Water Supply

Feedwater supply must be properly treated. Water testing tells the operator how many chemicals need to be added to the feedwater. Blow-down requirements can also be determined by testing. Testing should be done at 24 hour intervals or more often in some cases.

Combustion

Flue gas should be analyzed by recording analyzer or by visual examination of flame color. Fuel burning and draft equipment must be checked and burners cleaned. Fuel temperature becomes important in oil fired furnaces. Air temperature must be watched in coal fired furnaces. An operator must maintain the proper ratio of fuel and air that is fed to the furnace.

Soot Blowing

Soot and ashes clog up the heating surfaces and result in inefficiency of steam production. When soot and ashes build up, they must be blown out with the soot blowers. Soot blowers use either steam or air to remove soot and ashes from the heating surfaces. When the temperature of the flue gas becomes high, the soot blower should be turned on. Blowers should only be turned on when the boiler is loaded beyond 50% of its rated output. Furnace draft must be increased during soot blowing to prevent blowback of dust through furnace doors.

Dust Collectors

An operator must make sure that dust collector tubes are clear. Dust must be collected from the hoppers regularly to avoid plugging of outlets.

Ash Removal

Ash removal is a chore for operators that fuel with coal. Dumping grates and

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grate stokers are used in many coal fired plants. The operator must check on the type of ash removal equipment to make sure it is working properly.

Boiler Blow-off

Continuous blow-off rates and times are established by manufacturers. Within a plant, the frequency of blow-off is usually determined by the person in charge of feedwater treatment. Waterwall blow-off should only be done at times when the boiler is banked or operating at low levels.

Inspections

Operators should make a general inspection of the boiler plant each shift or more often if possible. Leaks and problems should be detected as early as possible. All fittings and gauges should be carefully checked and a written record made on the findings of that inspection.

Keeping Logs

Routine duties and the time of their performacne should be recorded on a log sheet, i.e. soot blowing, blow-off. Problems should also be recorded along with notes or comments on the problem. All entries should show date and time of the inspection, action or problem.

Operating A Boiler In Trouble

Emergencies do occur in boiler operation. The operator must know what to do in case of an emergency.

Low Water Level

There are many conditions that cause a low water level to occur. Actions will depend somewhat on the nature of the condition that caused the problem. In most cases, the fire should be cut off as quickly as possible. The gauge glass or water column should be blown-down to determine if the condition is being accurately measured. The air supply should be cut off and the boiler steam outlet closed to avoid rapid pressure changes that might stress and damage the metal. Where combustion can be stopped immediately, the feedwater should be shut off. If fueled with coal, it is difficult to stop combustion immediately, the feedwater should be left on.

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High Water Levels

High water levels can result in damage to turbine blades and piping failures. Water is passed on with the steam instead of separating in the drum. In emergencies created by high water level the operator should:

1. Shut off feedwater
2. Shut off fuel
3. Shut off air
4. Close turbine stop valves or header valves to prevent water from entering the turbine
5. Use blow-off valves to bring water level down to normal

Priming and Foaming

Water is sometimes carried over with steam into the turbine. This condition is known as priming. It may be due to a high water level or it may result from foaming. When large amounts of bubbles form in the drum, it si called foaming. Foaming is controlled by blow-down and addition of feedwater. Sometimes, anti-foam chemicals are used to prevent foaming.

Fan Failure

Failure of the draft fans allow combustible gases to fill the furnace. The fuel should be cut off at once. If the induced fan fails, the fuel and forced draft fan should be shut off.

Flame or Ignition Failure

A flame failure occurs when the flame is extinguished for some reason. It is often referred to as a flame-out. If fuel continues to flow into the furnace during a flame-out, combustible gases collect and might cause an explosion. When a flame-out occurs, the fuel should be shut off immediately. Some boilers have automatic flame-out devices which shut down the fuel supply. Alarms may be attached to gas analyzer devices for signalling flame-out conditions. The furnace should always be purged with a flow of air after a flame failure.

Loss of Load

Sudden loss of load causes a rapid rise in boiler pressure. The safety valves will open as a result of that pressure. Combustion controls will react to cut down the firing rate. The operator must decide whether the shut the boiler down

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or continue operating at a low firing rate.

Boiler Explosions

Boiler explosions may be due to the ignition of combustible gases in the furnace--a furnace explosion or too much pressure breaking a boiler part--a pressure explosoin. Explosions cause property damage and loss of life to those in the vicinity. The most common causes of furnace explosions are:

1. Failure to purge the furnace before start-up.
2. Fuel added to main burner without pilot flame.
3. Pilot flame is too weak to ignite main burner.
4. Loss of main burner flame in a flame-out.
5. Lighting a burner from other burners which cause an accumulation of gases in an area before it is ignited.
6. Incomplete conbustion due to improper air supply.
7. Insufficient air flow through a banked stoker-fired furnace.
8. Improper soot blowing procedures.

Pressure explosions are caused by:

1. Operating boiler at pressures beyond that for which it was designed.
2. Weak materials that fail at normal working pressures due to stress, overheating and erosion.

Shutting Down a Boiler

Boilers are shut down for cleaning, inspection and repair. The basic steps for shut down are:

1. Switch combustion controls from automatic to manual when load is reduced to 25%.
2. Run stoker hoppers and pulverized coal mills empty.
3. Cut burners out sequentially.
4. Leave burner air registers in firing position.
5. Trip main fuel supply valve.
6. Purge for 5 minutes.
7. Shut down fans and close burner registers.
8. Cool slowly and regulate cooling by thermocouples.

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9. Close feedwater valves and header stop valves.
10. Close down non-return valve.
11. Open drain between header stop valve and non-return stop valve.
12. Open economizer recirculating valve.
13. Open drum vents after pressure drops to 175 kPa.
14. Drain boiler.
15. Close, lock and tag valves.
16. Isolate the fuel supply.

Assignment

* Read pages 1 - 21 in supplementary reference.
* Complete job sheet.
* Complete self-assessment and check answers with answer sheet.
* Complete post-assessment and ask the instructor to check your answers.

Job Sheet

OBSERVE START-UP, OPERATION AND SHUT-DOWN PROCEDURES

* Ask an operator to let you observe operational procedures.
* Observe the steps in starting up a boiler.
* Observe the steps in normal operations.
* Observe the steps in shut-down.

It may not be possible to observe all of these procedures but the apprentice should take the initiative in learning good operational procedures. Close observation of an experienced operator is a good way to learn procedures.

•Self Assessment

Match the following terms with their appropriate description.

___	1. Boiling out	A.	Passing air through boiler to remove combustible gases.
___	2. Drying out refractory	B.	Record of actions and problems in boiler operation.
___	3. Gauge glasses and water columns	C.	Unit used to set safety valves.
___	4. Hydrostatic testing	D.	Causes water to pass to the turbine along with steam.
___	5. Thermocouples	E.	Removal of grease and sludge from boiler by blow-off until water is clean.
___	6. Hydroset	F.	Removes ash from burner surfaces of boiler.
___	7. Purging	G.	Tests boiler pressures to 1.5 times rated pressure.
___	8. Soot blower	H.	Devices used in measuring temperature of flue gas.
___	9. Log	I.	A low firing rate and 95 C water temperature needed.
___	10. High water level	J.	Show water level of boiler.

Self Assessment Answers

E 1.

I 2.

J 3.

G 4.

H 5.

C 6.

A 7.

F 8.

B 9.

D 10.

Post Assessment

1. Operators should make a general inspection of all fittings and gauges at least once a ______________________.

2. Water carried over to the turbine with steam is called ______________.

3. Large amounts of bubbles in the drum is called ____________________.

4. Two types of fans are used to move air through the boiler--the forced draft and _________________________ draft fan.

5. A __________________ results when there is a momentary lapse in fuel supply to the burners and they lose their flame.

6. The two major types of boiler explosions are ____________________ and ______________________ explosions.

7. An operator should switch combustion control equipment from automatic to manual when the load is reduced to _____%

8. Forcing air through a boiler to remove combustible gases is called _____________________.

9. A __________________ test places the boiler under 1.5 times as much pressure as its design rating.

10. The accuracy of gauge glasses and water columns can be tested by __________________ ____________________.

Instructor Post Assessment Answers

1. Shift
2. Priming
3. Foaming
4. Induced
5. Flame-out
6. Furnace and pressure
7. 25
8. Purging
9. Hydrostatic
10. Blow-down

Supplementary References

* Correspondence Course. Lecture 9, Section 3, Third Class. Steam Generation. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

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SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATION

First Class
Lecture 10

BOILER OPERATION, MAINTENANCE, INSPECTION

Successful operation of a boiler is closely related to continuous and adequate maintenance, supplemented by periodic inspections to determine the condition of the boiler and its auxiliaries. In addition to this, the proper operating techniques must be followed while the boiler is in service.

In the case of a new boiler, thorough inspection, cleaning and testing must be carried out after construction and before the boiler is put into operation.

This lecture will deal primarily with natural circulation watertube boilers of modern design but most of the instructions and recommendations contained herein will also apply to other designs of boilers, both large and small. Information and illustrations contained in the sections on Boiler Start Up, Operating Safety Precautions, Boiler Cleaning, and Boiler Repair have been abstracted in part from the volume "Steam, Its Generation and Use" by the kind permission of Babcock and Wilcox Canada Ltd.

HYDROSTATIC TEST

New boilers or boilers which have undergone major repairs or which have been out of service for an extended period of time shall be subjected to a hydrostatic test of 1.5 times the design pressure. The water used for the test should be at a temperature no less than the surrounding atmosphere and in no case less than $21^{\circ}C$. This is necessary to prevent condensation forming on the outside of the tubes and plates which would make the detection of leaks difficult. The water temperature, however, should not be so high as to prevent touching and close inspection of the parts.

The water should also be of high quality to avoid corrosion and fouling problems. Any sections of the boiler which will be drained immediately after the test can be filled with clear filtered water. Nondrainable parts, on the other hand, should be filled with distilled or demineralized water which has been treated for proper pH and oxygen remc .

When filling the various parts of the boiler, care should be taken to vent all air from these parts, otherwise a dangerous condition will develop. Air trapped by the water will compress and, in the event of a leak, will expand producing hazardous high-pressure water jets. A good guide to the effectiveness of the air venting carried out during the filling of the boiler, is the time taken to raise the hydrostatic pressure after the boiler shows full. An excessive time taken to raise pressure indicates that the test pump is compressing air trapped somewhere in the boiler.

In the case of a new boiler, the hydrostatic test is carried out before the refractory and casing have been installed and the test must be witnessed by an authorized inspector. In the case of a boiler being returned to service after a major repair outage, a hydrostatic test at normal working pressure may be sufficient if this is approved by the authorized inspector.

For a hydrostatic test at 1.5 times the design pressure, gags must be used to prevent safety valves from opening or blank flanges may be used in the case of flanged valves. In order to prevent excessive pressure on the safety valve spindle and to protect the valve seating surfaces, the safety valve gag should not be applied until the hydrostatic pressure has reached at least 80% of the valve set pressure. The gags and blank flanges must be removed after completion of the test.

After satisfactory completion of the hydrostatic test, in the case of a new boiler, the refractory, insulation and casing are installed and the boiler is dried out and boiled out.

DRYING AND BOILING OUT

The refractory of a new boiler must be dried out before the boiler is put into service and, in addition, the water side of the boiler must be boiled out to remove oil, grease and other contaminants from the internal surfaces.

The drying and boiling out are usually done at the same time. The boiler is filled with distilled, demineralized or clean raw water until approximately 25 mm shows in the gage glass and then about 25% of the boiling out chemicals are added. The chemicals used for the boil out may be a combination of several of the following: caustic soda, soda ash, sodium phosphates, sodium nitrate, sodium nitrite, sodium sulphite, sodium silicate. A satisfactory mixture is 3 kg caustic soda, 3 kg disodium phosphate and 1 kg sodium nitrate for each 1000 kg of water in the boiler. However, the boiler manufacturer's recommendations regarding this should be adhered to.

Due to the caustic nature of the boil out chemicals, a temporary gage glass should be used during the drying and boiling out period. The gage should be checked to see that it correctly registers the boiler water level.

During the drying out operation the firing rate should be such as to maintain a slight vapor leaving the open drum vents. This would indicate a water temperature of about 95°C and in many cases this may be obtained by the use of pilot burners only.

When the refractory is considered to be reasonably dry, the remainder of the boiling out chemicals are added to the boiler. The boiler firing rate is then increased to raise the pressure in stages to approximately one half the design working pressure. (Some authorities recommend only 0.2 operating pressure or 200 kPa, whichever is lower, for the boiling out procedure). As the pressure is raised, the drum vents are closed at about 170 kPa, and during the pressure raising, the unit should be checked to see that it can expand freely.

During the boiling out period the blow-off valves are operated at intervals of from two to four hours to blow out sludge and sediment from mud drums and headers. Additional feedwater and chemicals are added as necessary.

The boil out is considered complete when samples from the blow-off show that the water is becoming clear. Then the fires are shut down and the boiler pressure allowed to drop with the drum vents being opened before the pressure reaches zero. The boiler is then drained and manhole and handhole covers removed and the boiler is flushed out with a high pressure water hose before any deposits can become baked upon the surfaces.

After the boiling and flushing out are completed there will still be iron oxide and mill scale remaining in the boiler and in the feedwater system. Therefore, in the case of boilers designed for 5500 kPa and over, it is advisable to acid clean the unit. This acid cleaning is usually deferred until the boiler has been operated at high capacity for a sufficient time to ensure that the scale and oxides have been carried from the feedwater system to the boiler.

The procedure of acid cleaning will be described later in this lecture.

SAFETY VALVE SETTING

The safety valves are usually set at the conclusion of the boil out. However, as the safety valves are susceptible to damage from wet steam or grit, the setting of the valves should be done after the superheater, reheater and main steam lines have been blown out thoroughly to rid them of moisture, scale and other foreign material.

Before blowing out the piping it should be checked to make sure it is properly installed and supported. A special connection is usually made to the end of the steam line and carried to a point out of doors where no damage will be done by the escaping steam and debris. This outside connection must be firmly fastened down so that it cannot move under the reaction force of the escaping steam.

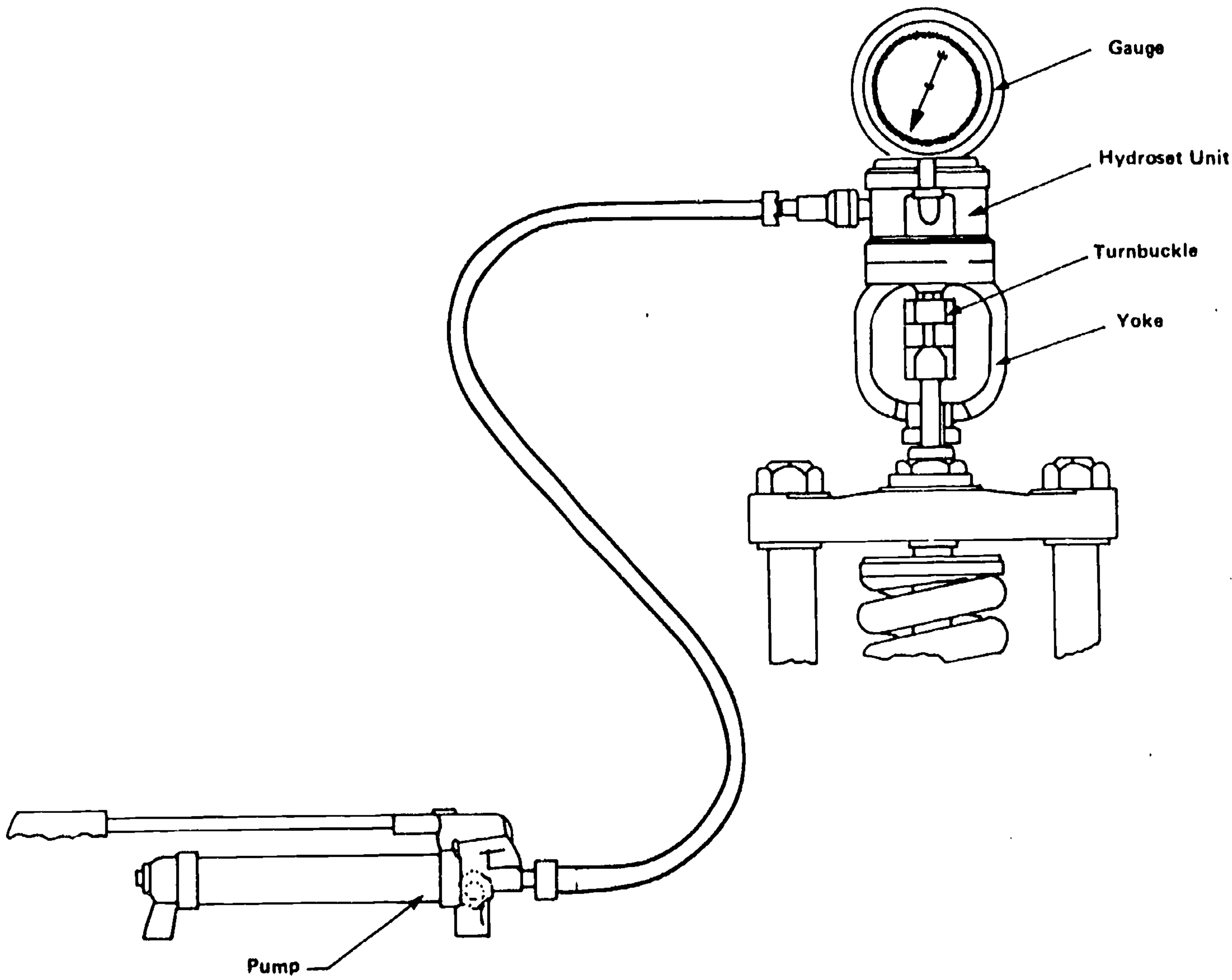
Two or three blows of each section of piping are usually done at about 50 percent of normal pressure. The valve used to control the steam flow should be gradually opened to the wide position and held for several minutes and then gradually closed again. A motor-operated valve is preferred for this job.

The safety valves are checked for proper operation by raising the steam pressure until each valve opens. The other safety valves, if the boiler is equipped with more than one, are held shut by means of a gag or clamp. The pressure at which each valve opens and closes is recorded and the valve is adjusted until the correct setting is obtained.

Safety valves for very high pressure boilers cannot tolerate even minimal wear to seating surfaces without losing their steam-tightness. Therefore these valves are not normally allowed to open and blow-off until closing during the testing. In other words their closing pressure is not tested. Instead, the safety valve set point is checked without allowing the valve to open fully. This can be done by either of two methods. One method makes use of special gags which restrict the lift of the valve and cause it to close immediately after it begins to simmer. The second method involves the use of a hydraulic jack to open the valve when boiler pressure is at its normal value.

Fig. 1 shows the hydraulic jack arrangement for testing safety valves.

Referring to Fig. 1, the safety valve lifting gear is removed and the hydraulic jack (hydroset) yoke is set on top of the safety valve compression screw. Then by means of a turnbuckle the safety valve spindle is secured to the hydroset unit. The safety valve set pressure and the pressure at which the boiler is operating are both known and so the hydroset pressure needed to open the valve can be determined. Then, by means of the pump supplied, the necessary hydroset pressure is applied and the safety valve should spit or simmer at this point if the valve is correctly set. If not, then the safety valve compression screw must be adjusted until the safety valve does simmer when the exact required hydroset pressure is applied.



Safety Valve Hydraulic Testing
(Dresser Industrial Valve and Instrument Division)

Fig. 1

After the set points of all safety valves have been checked then they are sealed by the Boiler Inspector who has witnessed the tests.

BOILER START UP

When starting up the boiler to put it into service it should be filled with high quality water and the temperature of this water should be such that it does not cause thermal stresses in the boiler metal. The differential between the water temperature and the metal temperature should not be greater than 40°C.

When filling the boiler the vents should be opened to make sure no air is trapped and that all boiler tubes are filled with water.

Before lighting up the unit it is essential that the furnace be thoroughly purged. In multiple burner units the purge is done with 25 percent of full-load air flow until five volume changes are made. Single burner units are usually purged with 70 percent air flow until eight volume changes are made.

During the pressure raising period it is normally not necessary to add water to the boiler therefore there is no flow through the economizer and, depending upon the economizer location, steam may be generated and trapped within the economizer. This may be avoided by allowing boiler water to recirculate through the economizer.

Also, during the pressure raising period, there is no steam flow through the superheater or the reheater. Therefore the temperature of the flue gas entering these sections must be controlled to keep tube temperatures below 480°C in the case of carbon steel tubes and below 500 to 540°C for alloy tubes. This control of the flue gas temperature is usually achieved by regulating the firing rate and selecting burners located higher or lower in the furnace wall. Excess air variation and gas recirculation are also methods of control.

The temperature of the flue gas entering the various furnace sections is measured by means of retractable thermocouples which can be withdrawn after steam flow is established through the tubes.

In addition to the superheater and reheater, the drums and headers must also be protected from thermal stresses. In the case of those components which have rolled tube joints, the rate of temperature change must not be greater than 40°C per hour. This temperature change refers to the saturation temperature of the water which changes as the pressure is being raised. For headers having welded tube joints, the rate of temperature change should not be greater than 200°C per hour. In the case of steam drums with welded tube joints, the rate of temperature change permissible depends upon the tensile strength of the metal, the drum diameter, the wall thickness and the pressure. Therefore the boiler manufacturer must be consulted for data regarding temperature limits for steam drums.

If the boiler is connected to only one steam using unit, such as a turbine, then the turbine may be started when the boiler pressure reaches about one half normal working pressure. This provides a flow of cooling steam through superheater and reheater. However, the turbine should not be placed under load until the boiler pressure has reached normal working pressure otherwise too great an increase in firing rate may be required resulting in steam temperature control problems.

If the boiler is serving only one unit, as above, then the stop valve at the boiler is usually omitted and only a turbine stop valve is installed. If, however, the boiler is connected to a common header with other boilers, then it must be provided with a non-return stop valve directly at the boiler and a header stop valve adjacent to the header with a drain valve between the two stop valves.

To cut a boiler into a pressurized header system, the following procedure is recommended by the ASME Code Section VII:

Open the drain valve on the non-return valve and crack open the header valve. This will allow steam to flow from the header to the pipe between the header valve and the non-return valve. At the same time any condensate present will be forced from the pipe through the drain valve. When the pressure has equalized on either side of the header valve, the header valve is opened wide. When the boiler pressure is still a few kPa below the header pressure, the non-return valve spindle is backed off to about the one quarter open position. Then when the boiler pressure reaches and just exceeds the header pressure the non-return valve will be opened automatically by the small difference between the boiler and header pressures. Once the boiler is feeding into the header, the non-return valve can be opened wide and the drain valve shut.

It should be stressed that before a boiler is put into service, all fittings, auxiliaries, and controls must be checked out for correct operation. The fittings include safety valves, pressure gages, water columns and gage glasses, blow-off connections, low water cut-offs, soot blowers, and chemical feed pumps. The auxiliaries are feed pumps, feedwater heaters, feedwater supply, draft fans, chimney, fuel burning and handling equipment and ash handling equipment. The controls include feedwater level controls, combustion controls, steam temperature controls, and fuel and ash handling controls.

NORMAL OPERATION

The main concern of the power engineer is to operate the boiler safely and efficiently. To do this he must maintain the boiler water level at the correct point and the steam pressure and temperature at the required values. In addition he must make sure that the most efficient combustion possible is being carried out in the boiler furnace at all times and that a maximum of the heat produced in the furnace is transferred to the water and steam in the boiler.

If the boiler load changes, then the water level will change and the feed-pump output must be changed in order to maintain correct level. Similarly, a change in boiler load will cause a variation in steam pressure, and to compensate for this, the amount of fuel and air supplied to the furnace must be adjusted. The temperature of the superheated steam will also tend to vary with load changes necessitating alterations to the temperature control system. Changes in the amount of fuel fed to the furnace will tend to alter the efficiency of the combustion and the air supply must be adjusted in order to maintain this efficiency.

Heating surfaces which become fouled with soot or ashes will reduce the heat transfer to the water and steam in the boiler and to avoid this the soot blowers must be operated when required.

The condition of the water in the boiler is of prime importance. Therefore the correct amount of chemical treatment and blowdown must be maintained.

In order to accomplish all the above conditions, the auxiliaries, controls, and fittings that are necessary to operate the boiler must be frequently checked for proper functioning. These are discussed in the following sections.

1. Water Level and Supply

For large boilers, two water columns equipped with gage glasses are the usual standard equipment. The columns and connecting lines must be blown down frequently enough to ensure that they are clear and that the gage glass indicates the correct level. If the water gage glasses are the flat-glass or the round-glass mica-protected types, then the manufacturer's instructions regarding blowing should be followed as excessive blowing will damage the glasses due to erosion.

Remote-operated water level recorders and indicators are often supplied and used as a supplement to the direct viewed gage glasses. In addition, high and low level alarms are frequently used. These recorders, indicators and alarms should be considered solely as operating aids and should not be relied on entirely. The operator should make frequent visual checks of the water column to compare the level with that shown by the remote recorders and indicators.

Close attention should be paid to the operation of the boiler feed pump with discharge and suction pressures noted frequently. Bearing temperatures should be checked frequently and proper lubrication of the pump and its driver must be seen to. The boiler operators must be familiar with the procedure for starting up the standby feed pump and stopping the in-service pump. This should be done at regular intervals in order that both pumps have approximately equal time in operation. An adequate supply of feedwater at the correct temperature must always be available for the feed pump. Correct operation of the feedwater regulator or water level control system must be checked and tested.

In order to avoid scale formation and corrosion in the boiler, the make-up water for the feedwater supply must be properly treated and the operation of water softeners, filters, etc., must be attended to. In addition to this, testing of the boiler water itself must be carried out and this will enable the required amount of chemical treatment and blowdown to be determined. The boiler water is usually tested once every 24 hours or in some cases oftener.

2. Combustion of Fuel

The admission of fuel and air to the furnace in conjunction with boiler load changes is normally done by means of an automatic combustion control system. The operator, however, must be able to take over the process from the control system in case of system failure and therefore he must become familiar with hand control operation.

Special attention must be paid to the combustion process occurring in the furnace. An Orsat analysis of the flue gas should be taken regularly and most plants make continuous analyses for CO_2 or O_2 content of the flue gas by means of recording type analyzers. The operation of these recording analyzers should be checked frequently by comparing their results to an Orsat analysis. Visual examination of the fire in the furnace is also helpful as the flame color and the amount of smoke or haze are indications of the completeness of combustion.

Fuel burning and draft equipment must be checked for proper operation. Burners must be cleaned when necessary and there must be an adequate supply of fuel available at all times. When burning heavy oil, the temperature of the fuel must be maintained at the correct value. If the fuel burned is pulverized coal, then the temperature of the air supplied to the pulverizers must be kept at the proper point. In the case of natural gas, oil fuel or pulverized coal, care must be taken at low firing rates to see that a stable flame is maintained at the burners.

In regard to the combustion control system, its function is to control the firing rate in the furnace in response to the load demand.

Indications of load changes used in combustion control systems may be variations in steam pressure, variations in steam flow, or variations in megawatt output in the case of a boiler supplying a turbo-alternator.

The combustion control system must not only vary the input of fuel and air into the furnace but it must maintain the desired ratio between the amount of fuel and the amount of air admitted to the furnace.

3. Soot Blowing

In order to ensure that a maximum of the heat produced in the furnace can be transferred to the water in the boiler, it is necessary that the heating surfaces be kept free from ashes and soot. This is done by operating the soot blowers when required. The frequency of soot blowing will depend upon the type of fuel used but usually once a shift is sufficient. The temperature of the flue gas leaving the boiler will indicate when soot blowing is required. If the heating surfaces are dirty, less heat from the flue gas will be transferred to the boiler water and the temperature of the leaving flue gas will be high.

The soot blowers should not be operated unless the boiler load is above 50 percent of rated output. This is to ensure that the burner flame will be strong enough to be stable and also to ensure that the fine dust will be carried rapidly from the furnace before an explosive mixture can be formed. The furnace draft should be increased during soot blowing so that a negative pressure exists within the furnace. This will prevent blowback of dust or flame through furnace doors or inspection openings.

The soot blowing medium, whether steam or air, must be free of moisture in order to prevent erosion. Alignment of soot blowers should be checked regularly to make sure the blowing medium does not impinge on baffles or on close-by tubes.

The type of fuel used, the boiler load, and the degree of combustion efficiency will determine how often soot blowing should be carried out.

Soot blowers are usually operated in the same order that the flue gases follow as they pass through the unit.

4. Dust Collectors

In the case of mechanical dust collectors, the main concern of operation is to keep the collector separating tubes clear so that each one can carry its share of the flue gas flow.

Collector hoppers must be emptied frequently to avoid plugging of the outlet ends of the elements. An indication of plugging is an increase in the pressure drop across the collector.

In order to avoid corrosion, the temperature of the gases passing through the collector should be kept above the dew point.

Sudden increases in boiler load may result in the picking up of large amounts of ash from low-velocity sections of the boiler and subsequent overloading of the dust collectors. Therefore, if it is possible, load increases should be gradual and a close watch should be kept of the level in the collector hoppers. Soot blower operation also tends to overload collectors but frequent blower operation will spread the dust load and reduce the possibility of over-loading.

The above precautions in respect to blower operation, load increases and hopper levels also apply to the electrostatic dust collector. In addition, the voltage must be kept up to normal and the elements must be properly aligned. Adequate rapping must be ensured either automatically or manually.

5. Ash Removal

If coal is the fuel used in the boiler then removal of ashes will be one of the routine duties of the operator. In smaller and medium sized coal burning plants, dumping grates are often used. These are operated intermittently when required as the ash builds up and interferes with air flow. In larger plants, continuous ash discharge is provided by means of travelling grate stokers. With this type, the operator must take care that unburned fuel is not discharged from the end of the grate together with the ash.

When pulverized coal is burned in the furnace, the furnace may be either the dry-bottom type where the ash is removed without being fused or melted, or the wet-bottom type where the ash is removed in a melted or liquid state.

In the dry-bottom type the hopper section at the bottom of the furnace must be kept cool enough to prevent fusing of the ash. The burners therefore must be adjusted so that the flames do not carry down too far into the ashpits. The ash should be removed fairly frequently to avoid caking together of the ash or avalanching of large amounts of ash.

In the wet-bottom furnace, the temperature must be maintained high enough to melt the ash and keep it in liquid form. The burners should be adjusted to sweep the lower furnace walls and the furnace floor in order to assist in keeping the ash melted. It may be difficult to keep the ash in a molten state during low load periods in which case the ash should be allowed to accumulate until higher load conditions will provide for melting of the ash which can then be tapped off.

6. Boiler Blow-off (Blowdown)

Extreme care must be taken when operating waterwall header blow-off valves. If they are opened when the boiler is steaming at other than low loads the circulation in the water wall may be reduced to such an extent that overheating of tube sections may result. Therefore, waterwall blow-off should be done at periods of low rating or when the boiler is in a banked condition. Under normal conditions waterwall header blow-off should not be necessary except in the case of industrial boilers operating with high make-up rates where,with certain types of water treatment,a heavy sludge may be precipitated in the headers.

In regard to the continuous blowdown, which is drawn off the steam drum from a point three or four inches below normal water level, written instructions for blowdown amounts and times should be issued to the operators by one person, usually the man in charge of feedwater treatment. This same individual should be responsible for specifying to the operators in writing the amount and times for internal treatment chemicals. If the amount of continuous blowdown is normally high then a heat exchanger arrangement should be used to recover as much heat as possible.

7. Additional Duties

In addition to the items discussed in the previous sections, the operator should make a general inspection of the entire plant once each shift. In this way, leaks which have developed in any of the pressure parts will be discovered. Usually the first indication of a leak is the sound of the steam or water escaping and the operator should be alert to any changes in the normal sound of the plant. Trouble in auxiliary machinery is also often indicated by noise or vibration of the particular piece of machinery.

All important changes regarding any part of the plant should be entered in a log sheet or log book. Routine duties such as soot blowing, ash removal, changes in continuous blowdown setting, start up and shut down of auxiliaries, etc., should be noted together with the times involved. Unusual occurrences such as failure of machinery, leaks developed, maintenance carried out, etc., should also be entered in the log.

8. Operating Safety Precautions

(a) Never enter a vessel unless all steam and water valves, including drain and blow-off valves have been closed, and locked or tagged. The exception to this is the drain between the boiler non-return stop valve and the header stop valve as this is an open ended drain and there is no possibility of steam or hot water backing up through it.

(b) Do not enter a confined space until it has been cooled, purged of combustible and dangerous gases, and properly ventilated with precautions taken to keep the entrance open. A responsible person stationed outside the space should be delegated to maintain contact with those working inside the space.

(c) Only low voltage lamps should be used when working within a vessel, and extension cords used should be properly grounded. Light bulbs and flashlights should be explosion proof.

(d) Never use toxic fluids in confined spaces.

(e) Never use volatile fluids in confined spaces unless adequate ventilation is provided for.

(f) Never open or enter rotating equipment until it has come to a complete stop and its circuit breaker has been locked open. If the equipment is such that it can be set in motion with very little force then it should be locked with a brake or other device to prevent rotation.

(g) Always secure the drive mechanism of dampers, gates, and doors before passing through them.

(h) Always wear tinted goggles or a tinted shield when viewing flames or furnace conditions in order to protect the eyes from harmful light rays and flying ash particles.

(i) Do not stand directly in front of open furnace ports or doors as pulsation due to firing conditions, sootblower operation, or tube rupture can cause blow-back of hot furnace gases. In the case of pressure fired furnaces, where aspirating air is used on inspection ports and doors, failure of this air supply will allow the escape of hot gases and even particles of ash and slag.

(j) When clearing slag from observation ports or from furnace walls do not use open-ended pipes as hot gases may blow through onto the handler.

(k) Make sure personnel are protected from falling slag, dust or other objects when working within the furnace or ashpit.

(l) Avoid contact with accumulations of fly ash. Although cold on the surface it may remain hot underneath for long periods of time.

(m) When handling a rod or probe in the furnace, be prepared for falling slag striking the rod and producing a lever action which may injure the handler.

(n) Personnel should be made aware that molten slag may wash away refractory and seals and leak out of the furnace causing injury to personnel or damage to equipment.

(o) When removing manhole and handhole covers, precautions should be taken to avoid injury to personnel from hot water which may be lying in drums and headers.

ABNORMAL OPERATION

The engineer in charge of the shift must be prepared for any emergencies which may arise. While it is impossible to forecast all possible emergencies, it is possible to plan procedures to be taken if certain abnormal conditions occur. Some of the conditions which may occur are: low water level, high water level, foaming and priming, fan failure, flame or ignition failure and loss of boiler load.

1. Low Water Level

Low water level in the boiler may be due to: malfunction of the water level control system, feedwater pump failure, feedwater supply failure, leakage from boiler due to tube rupture or other cause, or it may be due to a combination of the above. The procedure to be taken will depend in part on which of these is the cause of the low water condition. The primary and most important step is to shut off the fire as quickly as possible in order to prevent overheating of any part of the boiler. Small boilers, such as the packaged type which are fired with oil or gas fuel, are normally equipped with a low water fuel cut off device. This device usually consists of a float operated switch which shuts the burner fuel valve and air supply when the water drops to a predetermined level, possibly 25 mm above the bottom of the glass.

Large boilers, such as industrial and central station types where a shutdown must be avoided as much as possible, generally do not use the automatic low water fuel cut off device. Instead, an alarm system is used to warn the operator when the level approaches the bottom of the glass. This usually leaves enough time to remedy the situation before the level becomes dangerously low.

If the water level cannot be seen in the gage glass it may be that the glass is completely full or completely empty. The glass or column should then be blow down to determine if the glass is full or empty.

If the level is below the gage glass then the fuel and air supply should be shut off and the unit allowed to cool. If thermocouples are installed which measure the temperature differential through the drum shell, then feedwater may be fed slowly until the level returns to normal, providing allowable temperature differentials are not exceeded. When the unit has cooled down, it should be inspected for damage due to overheating.

In the case of a tube rupture, where the water is escaping rapidly from the boiler, the procedure is to shut off the fuel and to cut down the air supply, leaving only enough air flowing through the furnace to prevent steam from escaping from the furnace to the operating area. The steam outlet from the boiler should be shut to prevent a sudden drop in pressure and temperature within the boiler as this would cause severe stresses of the metal. If the method of firing is such that the combustion can be stopped immediately, as in the case of oil, gas, or pulverized fuel, then the feedwater supply should be shut off as well to prevent temperature shock to the metal from cool feedwater. When the boiler pressure has gradually dropped to zero then the normal cooling procedure should be followed. After cooling down, the boiler must be inspected thoroughly for further damage and the ruptured tube replaced.

Where the boiler is stoker fired or fired by any other method that does not allow the combustion to be stopped immediately, then the procedure is the same except that the feedwater supply is not shut off but is increased to the maximum possible. This is done in an attempt to maintain normal water level and thus prevent damage from overheating. At the same time, the burning fuel on the stoker grate must be smothered or dumped in order to stop the combustion as quickly as possible. When this has been done and there is no longer any danger of overheating any part of the boiler, then the feedwater supply can be shut off.

When the unit has cooled it should be inspected for evidence of overheating and cracks in drum and headers. If repairs are required they should be approved by the Boiler Inspector.

2. High Water Level

A high water level in a boiler or steam generator is to be avoided as it will result in water being carried over with the steam. This water will cause damage to turbine blades and engine cylinders and may result in piping failure due to water hammer.

One of the first indications of water being carried over from the drum is a sudden drop in superheated steam temperature if the boiler is equipped with a superheater. If this occurs or if the water level is found to be above the top of the gage glass, then the following procedure must be promptly carried out. Feedwater, fuel, and air must be shut off in that order. To protect engines and turbines, the flow of the water-carrying steam from the boiler must be stopped. If the boiler is connected to a common header with other boilers, then the header valve should be shut and all drains opened. If the boiler is supplying a single turbine only, then the turbine stop valve should be shut and all drains opened. To bring the boiler level down to the normal operating point, the blow-off valves can be used. When this is accomplished, normal operation of the boiler may be resumed.

3. Priming and Foaming

The term priming refers to the carrying over of water with the steam. It may be caused by high water level as described in the previous section or it may be caused by foaming.

The term foaming refers to the formation of large bubbles or foam in the drum steam space. This may be due to a high concentration of dissolved solids in the water, or it may be due to contamination of the water by soap-like materials.

When foaming occurs, there will be rapid fluctuation in the boiler water level and carrying over of water with the steam (priming) may begin. In addition, it will be difficult to detect the true water level in the gage glass.

Usually foaming may be checked by blowing down and feeding fresh feedwater. This will reduce the high solids concentration in the boiler. In extreme cases the fuel and air may have to be shut off in addition to the blowing down procedure until conditions return to normal. Special antifoam chemicals which are pumped into the drum are also used to prevent foaming from occurring.

4. Fan Failure

The majority of large boilers use draft fans. Usually a forced draft fan is used to supply combustion air to the furnace and an induced draft fan is used to draw the combustion products from the furnace and discharge them up the stack.

If the forced draft fan fails then the supply of combustion air will be interrupted. When this occurs the fuel supply must be shut off immediately as without air the fuel will no longer burn and the furnace will fill with combustible gases.

If the induced draft fan fails then the furnace pressure will rapidly rise due to air still being admitted by the forced draft fan. Therefore, the forced draft fan and the fuel supply must be shut off at once.

It is usual to equip the boiler with an interlock system which will automatically trip the forced draft fan and shut off the fuel supply if the induced draft fan fails. It will also shut off the fuel if the forced draft fan fails.

5. Flame or Ignition Failure

When firing with oil, gas, or pulverized coal, the burner flame may be extinguished due to momentary interruption of fuel supply, low fuel pressure, too high air flow, or instability during soot blowing. When this flame failure or "flame-out" occurs, the flow of fuel into the furnace must be stopped immediately. If not, then the furnace will rapidly fill with unburned fuel which could explode.

Some boilers, usually the smaller sizes fired with oil or gas, are equipped with a flame failure device which will shut off the fuel valve if the burner flame goes out. Larger boilers normally are not so equipped and it is the operator's responsibility to shut off the fuel supply on flame failure. Therefore the operator must keep a close watch on furnace conditions. Frequently television cameras and monitors are used to assist the operator in observing flame conditions in the furnace. Gas analyzers are often used and may be arranged to sound an alarm when combustibles appear in the flue gas as would be the case if a flame failure occurred.

After a flame failure occurs and the fuel has been shut off, it is necessary to purge the furnace with a flow of air for at least five minutes. This is done to clear the furnace of any combustible gas before relighting the burners. After the purge period is completed, the burner can be relighted by means of a torch or igniter.

6. Loss of Load

If a sudden loss of load occurs, the boiler pressure will rise rapidly and the safety valves will open. The combustion control system is usually arranged so that it will reduce the firing rate to a minimum value in this event. However, if the load is completely lost, the safety valves will continue to blow even with the reduced firing rate. The operator must then decide whether to shut down the boiler or continue to operate at the minimum firing rate. His decision will depend upon how long the load is expected to be lost to the boiler. Usually with a small or medium sized boiler, a shutdown and a subsequent start up will not involve a lot of equipment nor will it take a lot of time. However, with a large high pressure boiler equipped with superheater and reheater sections a complete shutdown is avoided if possible because of the time involved in putting the unit and its many auxiliaries back into service again.

BOILER EXPLOSIONS

Boiler explosions may be listed under two general classifications: furnace explosions which occur when an accumulation of combustible gases ignite and explode within the furnace or gas passes of the boiler; and pressure explosions which occur when a pressure part of the boiler, such as the drum, bursts due to too high a steam pressure or a structural weakening of the metal.

In either case the results of an explosion are almost always loss of life and extensive damage to property. The power engineer must therefore exercise constant vigilance during the operation of the boiler in order to prevent the occurance of an explosion.

If an explosion does occur, then the person in charge of the boiler or pressure vessel must notify the proper authorities.

Furnace Explosions

The most common causes of furnace explosions are listed as follows:

1. Failure to purge the furnace adequately before start-up. There may be an accumulation of combustible gases within the furnace of an idle boiler and when an attempt is made to light a burner in the furnace this gas will explode unless the furnace has been thoroughly purged first.

2. Admission of fuel to main burner before pilot flame or other ignition source is established. This will result in a flow of raw fuel into the furnace which will explode when the ignition is eventually provided.

3. Pilot flame or other ignition source too weak to provide ignition of main burner. As a result the main burner will not ignite right away and a flow of raw fuel into the furnace will take place which will eventually explode.

4. Loss of main burner flame. This may be caused by momentary interruption of fuel supply or air supply or the burner flame may be blown out by too great an air supply, particularly if the furnace is still cold. Another cause of "flame-out" could be water in the fuel in the case of oil or gas. If the main burner flame fails, the result will be admission of raw fuel to the furnace and probable explosion.

5. Attempting to light off one burner from other burners in operation. This will result in a concentration of fuel adjacent to the burner in question which will eventually ignite explosively from the other burner flames.

6. Incorrect amount of air supplied to the burner resulting in incomplete combustion. This will also result in an accumulation of combustibles within the furnace and subsequent explosion.

7. Insufficient air flow through a stoker fired furnace which has been shut down and banked. Volatile material will pass off from the banked fuel due to the heat of the furnace and an accumulation of combustible gases will result with possibility of explosion.

8. Improper procedure during soot blowing. If soot blowing is done when the boiler is below 50 percent of full load, the burners which will be unstable at low load may suffer a flame-out. In addition, at low loads a combustible mixture of soot and dust will not be swept from the furnace quickly enough.

Pressure Explosions

A failure of a pressure part of the boiler may be due to any of the following:

1. Pressure in excess of that for which the boiler was designed. This would occur if the safety valves failed to operate and the firing rate was greater than that required by the boiler load.

2. Weakening of the material to an extent where the pressure part will fail at normal working pressure. This may be due to any or all of the following:

   (a) Overstressing of material due to too rapid heating up of the boiler during start-up.

   (b) Overheating of the material due to low water level in the boiler.

   (c) Overheating of the material due to build up of scale, sludge, or oil on the heating surfaces.

   (d) Overheating of the material due to faulty water circulation within the boiler.

   (e) Weakening of the material due to corrosion.

   (f) Weakening of material due to erosion caused by incorrectly placed soot blowers or wet steam being used as the blowing medium.

BOILER SHUT DOWN

Boilers must be taken out of service at regular intervals for cleaning, inspection and repair.

When reducing load during shutdown the combustion controls should be switched from automatic to manual before the lower limit of the automatic system is reached, usually at about 25 percent load. Stoker hoppers should be run empty and the fuel bed burned out. Pulverized coal mills should be run empty. With oil and gas firing, the burners should be cut out sequentially as the load is reduced and the burner air registers left in the firing position. The main fuel supply valve should be tripped at the appropriate time.

After firing has been stopped, the setting should be purged thoroughly with an air flow of 25 percent of full load for at least 5 minutes. Then the fans are shut down and burner registers closed.

The unit should be cooled slowly until the furnace refractory is black and then moderate amounts of air can be blown through the setting to assist in the cooling process. On large units the use of thermocouples is advised in order to accurately regulate the rate of cooling.

After the non-return stop valve has closed and feedwater flow to the unit is no longer required, then the feed valves can be closed and the header stop valve. The stem on the non-return valve is run down to hold the disc upon its seat and the drain between the header stop and the non-return stop is opened. The economizer recirculating valve if installed is also opened.

When the steam pressure drops to 175 kPa the drum vents should be opened to prevent formation of a vacuum within the unit.

In order to prevent baking on of sludge the unit should not be drained until it has cooled sufficiently so that personnel can safely enter and remain in the furnace. When the boiler is one of a battery, make sure that blow-off valves are opened only on the boiler that is to be drained. As soon as the boiler is empty the blow-off valves including the continuous blow-off valves should be closed and locked or tagged. This locking shut or tagging should also be done with the feedwater valves, desuperheater injection water valves, chemical feed valves and the main steam valves.

In regard to isolating the fuel supply, oil burners should be disconnected and removed and on gas burning boilers the gas should be shut off by at least two valves in series with an open vent valve between them. A spectacle flange in the gas header may also be used to isolate the gas supply.

<u>BOILER CLEANING</u>

In regard to personnel entering the boiler drums, furnace or any other part of the setting, the following precautions must be observed:

1. Drum and setting must be cool and well ventilated.
2. Valves must be closed and locked or tagged to prevent any steam, water, fuel or any other undesirable substances from entering the boiler.

3. Draft fan motor circuit breakers must be locked out and tagged.
4. Only low voltage lighting should be used. All portable electrical equipment used in the steam generator should be adequately grounded to the steam generator.
5. A responsible person should be delegated to maintain contact with personnel working within the unit.
6. Overhanging slag and other deposits should be dislodged by bars or rods operated from outside the setting before personnel are allowed to enter the setting.
7. Cleaners should preferably work in pairs and should be warned of hazards from hot soot, dust, and slag. They should be provided with protective clothing, goggles and respirators when necessary.

Cleaning of Furnace and Setting

Many ash deposits are removable by water washing and steam generators are often provided with washing facilities either built-in or portable. These facilities must provide for ample drainage of the wash water and sluiced ash. In many plants the soot blowing system for the boiler can be used for washing by connecting the supply of wash water to the blower header system.

The wash water used should be hot and alkaline to prevent acid corrosion which could occur when the ash deposits contain sulphur. The wash water discharge should be checked periodically to ensure that adequate alkalinity is being maintained.

After washing is completed, the surfaces must be dried as thoroughly as possible. Frequently the water washing is done just before the unit is returned to service. If the unit is to remain out of service after washing then it should be dried out by firing at a low rate.

Internal Cleaning of Drums, Tubes and Headers

Before cleaning of the internal surfaces of drums, tubes, and headers, they should be examined to determine the effectiveness of the feedwater and boiler water treatment in preventing scale formation, sludge, and corrosion.

After this examination, a high-pressure hose water stream should be used to wash down the internal surfaces. This high pressure water will remove loose deposits and will also remove some of the scale adhering to the surfaces.

During the washing down the blow-off line should be disconnected and the water allowed to run to waste to prevent scale from plugging the blow-off valves and piping.

Any deposits still adhering to the surfaces after washing down must be removed by mechanical cleaning or chemical cleaning.

Mechanical Cleaning - The mechanical cleaners used to remove deposits from the inside surfaces of tubes consist of small motors driven by compressed air, or water. The motors are fitted with cutter heads having a number of cutters made of very hard steel. The cutter head is rotated at high speed as the cleaner is passed through the tubes and thus the scale is cut away. If the cutter is driven by compressed air a stream of water should be introduced into the tube in order to cool the cutters and to wash away the scale as it is removed from the surfaces. The cleaner should be kept moving through the tube as operating it in one spot, even for a short time, will damage the tube. After mechanical cleaning has been completed the boiler should be washed out once more with a high pressure hose.

Chemical Cleaning - Many of the internal surfaces of modern boilers cannot be cleaned properly by mechanical means. Chemical cleaning has been found to do an adequate job in these cases. In fact this process is now considered to be the quickest, cheapest, and most efficient method of cleaning the internal surfaces of boilers of all sizes and designs. It has the following advantages compared to the mechanical cleaning method:

1. Less time and fewer maintenance personnel are required. Even a large unit can usually be cleaned in less than 36 hours.
2. Inaccessible areas can readily be cleaned and the cleaning is more thorough than mechanical cleaning.
3. With chemical cleaning in mind, boilers can be designed without special provisions for mechanical cleaning accessibility.

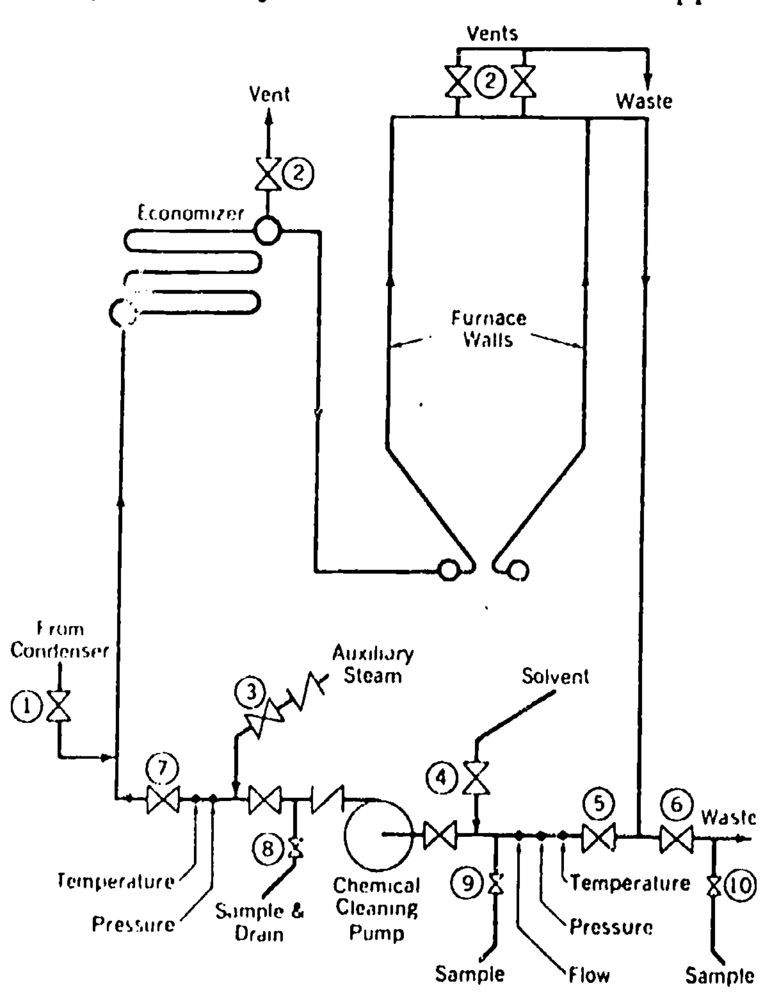
Chemical cleaning involves washing the boiler internal surfaces with an acid solvent and then flushing with clean water. The unit is then treated with a neutralizing solution and then flushed once again with clean water.

The acid solvent may be applied by either circulating it through the unit or by filling the unit with it and leaving it for the prescribed length of time. The latter method is referred to as soaking. The soaking method is usually used for conventional type boilers while the circulation method is preferred for once through boilers.

Before either method can be used, the unit must be prepared by isolating all parts not to be cleaned from the rest of the unit. This can be done by valving, blanking off connections, or filling parts, such as the superheater, with demineralized water. All valves should be steel and all bronze and brass parts should be removed. Gages and meters should be isolated from the unit and enough vents should be provided to remove any acid vapors formed.

The type of acid used will depend upon the type of deposit to be removed. An inhibitor must be added which will prevent the acid selected from reacting with the boiler metal. The inhibitor will lose its effectiveness above a certain temperature and therefore the temperature of the acid solution must be kept below this temperature.

1. <u>Circulation Method</u> - An arrangement for chemical cleaning of a once-through boiler by the circulation method appears in Fig. 2.



Circulation Method
(Babcock and Wilcox)

<u>Fig. 2</u>

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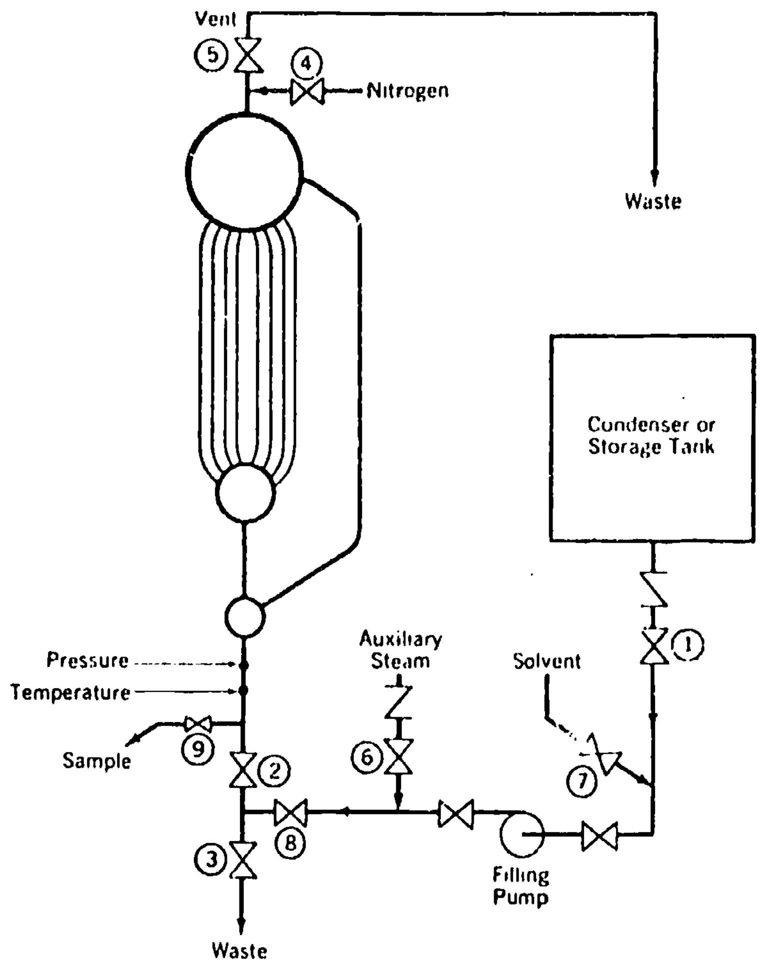
After the unit is removed from service, it is cooled and then drained. The superheater section is filled with demineralized water and pressurized with nitrogen. The boiler proper is then filled with demineralized water through the filling connection 1. While filling is taking place, air is vented through the vents 2. The water is now circulated through the unit by means of the chemical cleaning pump. Low pressure steam is admitted through connection 3 in order to raise the temperature of the circulating water to 95°C. The acid solution with the inhibitor is then admitted through connection 4 to give the desired concentration in the circulating water. During the cleaning the temperature must be maintained at 95°C and the vents must be opened frequently to remove any hydrogen gas accumulations. Samples of the circulating solution should be taken every half hour and analyzed.

When it has been determined by sample analysis that the acid cleaning is complete the chemical cleaning pump is stopped and the cleaning solution is removed from the unit by closing valve 5 and opening valve 6 while demineralized water is admitted through valve 1. When the cleaning solution has been displaced, the demineralized water is circulated by means of the chemical cleaning pump and ammonia and hydrazine are added to provide a neutralizing solution which should be heated to 95°C. This neutralizing solution should be circulated for two hours and all vents, drains, superheater piping and dead-end piping should be flushed out. The neutralizing solution is then displaced by demineralized water.

The final step is to add more ammonia and hydrazine and recirculate the solution for about one hour.

2. Soaking Method - An arrangement for chemical cleaning of a conventional type boiler by the soaking method appears in Fig. 3.

To prepare the unit for soaking, thermocouples should be installed at the steam drum, at the centre of each furnace wall, and at one of the lower furnace wall headers. The unit is then filled with demineralized water and brought up to a temperature of 77 - 82°C by means of pilot burners or light firing. The firing is then stopped and the unit is drained and the superheater backfilled with treated condensate or demineralized water to prevent acid vapors from entering during the cleaning. The drum gage glass is replaced with a plastic tube gage. Then, referring to Fig. 3, the vents 5 and valve 1 are opened and the filling pump started. Heating steam is admitted through valve 6 to keep the water flowing to the unit at 77 - 82°C and the inhibited acid is admitted through valve 7. The amount of acid entering is adjusted to give the desired solution strength as sampled at valve 9. When the unit is filled to the normal operating level, the filling pump, heating steam, and acid feed are stopped. Valves 2 and 8 are closed and the drum vents 5 are left open. The unit is then allowed to soak for the required period of time.



Soaking Method
(Babcock and Wilcox)

Fig. 3

The time required will be determined beforehand by testing a sample of the deposits present in the unit. Usually the time required is from 4 to 8 hours.

After the required period of time the unit is completely drained under nitrogen pressure of about 35 kPa by closing the vents 5 and opening valves 2, 3, and 4.

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After the unit has been drained, valves 3 and 4 are closed and valves 1, 5, and 8 are opened and the unit is filled with demineralized water with the filling pump until a level appears in the water gage. Then more demineralized water is flushed into the unit through the feedwater line until the drum level rises noticeably. This prevents any acid from entering the feedwater system. Similarly, the superheater should be backflushed with demineralized water until a level increase is observed in the drum. Then the unit is completely filled using the filling pump until water overflows through the vents 5. This is to ensure the removal of any acid vapors from the drum.

The unit is now drained under nitrogen pressure and the fill- and -flushing step is repeated. The unit is again drained under nitrogen pressure and the pH of the rinse water is tested. If the pH is below 5, the fill- and -flushing step must be repeated.

If the pH is satisfactory then the next step is to neutralize the surfaces. The temporary gage is replaced by the regular drum level gage and the unit is filled to slightly below operating level with a solution of 10 kg of soda ash to 100 kg water. The unit is then fired and boiled out for 4 to 6 hours. For boilers operating at 1400 kPa or less, the boil-out pressure is operating pressure. For boilers operating at above 1400 kPa, the boil-out pressure is the higher of 1400 kPa or one half the operating pressure although it is not necessary to exceed 4200 kPa.

After the boil-out the unit is shut down and drained without using nitrogen pressure and while the unit is still hot it is filled with demineralized water containing 0.5% sodium nitrite to prevent rusting, until the drum vents overflow. The unit is drained again after one hour. If there is any evidence of loose deposits remaining in the unit then the headers and tubes should be thoroughly flushed out.

Because of the careful chemical control required and because of the potential dangers involved in dealing with corrosive solutions and possible explosive and toxic products of the cleaning process, the chemical cleaning should be supervised by personnel specially qualified in this highly technical field.

Acid cleaning is usually done by a company specializing in this type of operation. During the procedure, smoking or naked lights must not be permitted in the vicinity due to the possibility of hydrogen gas being produced from the acid reactions. Other safety precautions include protective clothing for personnel such as goggles, gloves and aprons. After opening up of the unit for inspection, air should be circulated through to remove any hydrogen gas which may pass off from the metal. This is done before any personnel are allowed to enter the boiler. All solutions whether acid or alkaline must be neutralized before discharging to sewers, rivers, lakes, etc.

BOILER LAYUP

When a boiler is taken out of service, the boiler should be cooled until the water is below the atmospheric boiling point but not below 85^{o}C, and then the boiler should be emptied and flushed out. An inspection should be made to determine what repair work is necessary and what mechanical and chemical cleaning should be done. A decision should then be made on whether to employ dry storage or wet storage.

Dry Storage

This procedure is preferable for boilers out of service for extended periods of time or in locations where freezing temperatures may be expected during stand-by.

The cleaned boiler should be throughly dried, since any moisture left on the metal surface would cause corrosion to occur on long standing. After drying, precautions should be taken to preclude entry of moisture in any form from steam lines, feed lines, or air.

Moisture-absorbing material, such as quicklime at the rate of 1 kg or silica gel at the rate of 3 kg for 1 m^3 of boiler volume, should be placed on trays inside the drums to absorb moisture from the air. The manholes should then be closed and all connections on the boiler should be tightly blanked. The effectiveness of the materials and need for their renewal may be determined through regular internal boiler inspections.

Wet Storage

A wet procedure may be used for a boiler to be placed in stand-by condition. Wet storage is particularly useful if the stand-by boiler may be required for service at short notice or if it is impractical to employ a dry storage procedure. The method is not generally employed for reheaters or for boilers which may be subjected to freezing temperatures.

Three different methods of wet storage are described as follows.

1. Boiler Completely Filled

The clean empty boiler should be closed and filled to the top with water, conditioned chemically to minimize corrosion during stand-by. Water pressure greater than atmospheric should be maintained within the boiler during the storage period. A head tank may be connected to the highest vent of the boiler to maintain pressure above that of the atmosphere.

For a short storage period, condensate or feedwater containing approximately 450 ppm of caustic soda and 200 ppm of sodium sulphite may be used. If the superheater is of the drainable type, it can also be filled with the same treated water by overflowing from the boiler.

If the superheater is non-drainable, it should be filled only with condensate or demineralized water containing a minimum of dissolved solids, not more than 1 ppm. Before introducing the water into the superheater, mix in uniformly about 200 ppm of hydrazine and sufficient volatile alkali, such as ammonia, cyclohexylamine or morpholine to produce a pH of 10. The treated water may be introduced into the superheater through an outlet header drain until the water overflows into the boiler. When the superheater is filled, close the drains and vents.

The boiler can now be filled through the feedwater or other filling line with condensate, feedwater or clean service water treated as described, with hydrazine and additional volatile alkali. If the storage period is expected to exceed three months, the concentration of hydrazine should be doubled.

If preferred, the boiler may be filled using feedwater or condensate treated with caustic soda and sodium sulphite after first filling the superheater with condensate treated with hydrazine and additional volatile alkali.

2. Boiler Partially Filled

As an alternative, the boiler may be stored with water at normal operating level in the drum and nitrogen maintained at greater than atmospheric pressure in all vapor spaces. To prevent in-leakage of air, it is necessary to supply nitrogen at the vents before the boiler pressure falls to zero as the boiler is coming off the line. If boiler pressure falls to zero, the boiler should be fired to reestablish pressure, and superheaters and reheaters thoroughly vented to remove air before nitrogen is admitted. All partly filled steam drums and superheater and reheater headers should be connected in parallel to the nitrogen supply. If nitrogen is supplied only to the steam drum, nitrogen pressure should be greater than the hydrostatic head of the longest vertical column of condensate that could be produced in the superheater.

3. Boiler Empty

Rather than maintain the water in the boiler at normal operating level with a nitrogen cap, it is sometimes preferred to drain the boiler completely, applying nitrogen continuously during the draining operation and maintaining a pressure of nitrogen greater than atmospheric throughout the draining and subsequent storage.

BOILER INSPECTION

Boiler inspections are carried out in order to ascertain the condition of the boiler. This is necessary to ensure the continuing safe and efficient operation of the boiler.

Inspections by authorized inspectors at regular intervals are required by the provincial authorities concerned with boilers and pressure vessels. In addition, steam plant staff should conduct their own inspections at more frequent intervals.

The ASME "Recommended Rules for the Care of Power Boilers" classifies boiler inspections into two categories, namely the external inspection and the internal inspection.

The external inspection is carried out while the boiler is in service and consists of a visual examination of the boiler, its fittings, and its auxiliaries including checking for misalignment, settling, and clearance for expansion.

The internal inspection, on the other hand, is a thorough examination of both the water side and the fire side of the boiler after it has been shut down, cooled, drained, and opened up.

Before the internal inspection, the fire side of the boiler is cleaned of dust, ashes, and soot, but the water side usually is not cleaned of scale, etc., until the inspector has had a look at it.

BEFORE AND DURING THE INSPECTION THE SAFETY PRECAUTIONS AS LISTED BELOW MUST BE ADHERED TO.

1. Non-return and header stop valves, feedwater shut off valves, and blow-off valves must be shut, tagged, and preferably padlocked in the shut position. Any other valves through which steam, water, chemicals, etc., could enter the boiler must be handled in the same way. Drain valves and vent valves must be left open.

2. Similar precautions must be carried out to prevent the entry of fuel, atomizing steam, etc., into the furnace. Oil burners should be disconnected and removed and on gas burning boilers the gas supply lines should be blanked off or a section of pipe removed between the gas shutoff valve and burner.

3. The drum and setting must be cool and well ventilated.
4. Only low voltage lamps of 12 volts or less should be used during the internal inspection. Extension cords must be grounded and properly guarded with waterproof fittings and explosion-proof guarded light bulbs used.
5. Draft fan motor breakers must be locked out and tagged.
6. A responsible person should be delegated to maintain contact with personnel working within the unit.
7. Overhanging slag and other deposits should be dislodged by bars or rods operated from outside the setting before personnel are allowed to enter the setting.
8. Personnel should work in pairs within the boiler and they should be warned of hazards from hot soot, dust, and slag. They should be provided with protective clothing, goggles, and respirators when necessary.

Water Side Inspection

After the inspector has examined the water side surfaces in regard to the amount of scale or sludge present, these surfaces may then be washed down and cleaned. This will leave a clean metal surface which the inspector can easily examine.

When examining the water side surfaces, the inspector will be looking for signs of corrosion, pitting, and cracking of the metal. Cracks may appear in ligaments between tube holes. Stays must be checked for looseness and cracking at the fastened ends. Particular attention is paid to drum connections such as safety valve and steam outlet connections and to manhole and handhole openings. All drum welds are examined closely.

The plugs in the water column connections should be removed to allow inspection for scale or other deposits.

Drum internals should be closely inspected to see that all baffling and other steam separating equipment are positioned correctly and joints are tight. If baffles, plates, or separators are removed for inspection they should be marked to ensure proper reassembly.

In regard to determining the need for cleaning of the internal surfaces, as mentioned in the first paragraph of this section, this can be done by visual inspection in the case of some boiler designs.

However, in the case of the modern high pressure boiler having involved water circulation circuits and all-welded construction, adequate visual inspection may not be possible. In these cases it may be necessary to cut out a representative tube section in order to determine the amount of deposit present. Alternatively, a representative tube can be cleaned with a mechanical cleaner and the amount of deposit so removed can be measured by weighing.

After the water side inspection has been completed, the inspector may wish to have the boiler closed up and a hydrostatic test carried out.

Fire Side Inspection

When inspecting the fire side of the boiler the inspector may require removal of sections of refractory or insulation in order to facilitate inspection of tube or drum surfaces.

Tube surfaces are examined for bulges or blisters which would indicate overheating. Ends of fire tubes are checked for signs of leakage and tube sheet ligaments for cracking. Tubes adjacent to soot blowers are examined for signs of erosion due to direct impingement of steam from blowers. Refractory and brickwork of the burners, baffles, and furnace walls are checked for deterioration.

Corrosion of tubes and support brackets may take place in high temperature sections such as the superheater especially if oil containing vanadium is used as the boiler fuel. Corrosion may also be caused by prolonged contact with ash and areas where ash deposits remain should be cleaned and checked. The alignment of tubes should be checked as misalignment may result from warpage or broken or displaced brackets, hangers, or spacers. If any misalignment is not corrected then erosion of tube surfaces by soot blowers may result.

All dampers and air registers should be checked for warpage and freedom of movement. Burners should be examined for signs of carboning or coking and of overheating. Coal handling equipment such as pulverizers and feeders should be inspected for wear and broken parts.

Safety valves and related piping, connections, drains, and supports should be examined closely. Blow-off connections should be inspected for corrosion and weakness where they connect with the boiler. These connections must be supported and be able to expand and contract without producing excessive stress on the boiler. All other piping connecting to the boiler must be similarly checked.

Pressure gages should be tested and calibrated if necessary.

All other boiler fittings should be examined for plugged connections and for proper operation.

BOILER REPAIR

The amount and the nature of the repairs necessary to the boiler can be established from indications during the operation of the boiler and from the findings made during the inspection.

In the case of repairs to the pressure parts, all materials used must meet ASME Code requirements and these repairs should be made under the guidance of the National Board Inspection Code.

Any repairs to be made by welding must be first approved by an authorized inspector and the welding carried out by a qualified welder. Following weld repairs, stress relieving and inspection procedures must be implemented as required by the code and the inspection authorities.

Tube Section Replacement

A section of failed tube can be replaced by a qualified welder. The defective section, which should be a minimum length of 300 mm can be cut out with an oxyacetylene torch. During the cutting of the tube care must be taken that no slag enters the tube. After cutting, the tube ends are prepared by grinding and the new section of tube is welded into place. Backing rings are usually used except where the tube is located in a high heat input zone of a high pressure boiler. Under these latter conditions the space between the tube ends should be a minimum and the first bead of weld metal should be run with a 2.4 mm electrode. Use of the tungsten-inert-gas process is recommended for the root pass where an inert gas is used to protect the weld zone from the atmosphere. If the tube to be replaced is of alloy material, the boiler manufacturer should be consulted regarding welding procedures.

Seal Welding

Seal welds are used under some conditions for fluid tightness. Structural strength must be secured by some other means such as an expanded joint.

In new construction the ASME Code permits the elimination of the "flare" or "bell" on tubes to be seal welded, provided the throat of the seal weld is not less than 4.8 mm nor more than 10 mm. This applies to a seal weld either inside or outside of the drum or header. For repair work the National Board Inspection Code permits seal welding and differentiates between inside seal welding and outside seal welding as follows:

1. Tubes may be seal welded inside provided no single bead has a throat thickness in excess at 4.8 mm., and the throat thickness of a multipass weld does not exceed 10 mm.

2. Tubes may be seal welded outside provided the tube has been expanded and flared to 3.2 mm over the size of the tube hole, and provided that neither the width nor thickness of the weld exceeds 6 mm.

Both codes require that tubes be re-expanded after seal welding. The re-expanding should be done lightly and the seal weld examined for cracks after the expanding operation is completed.

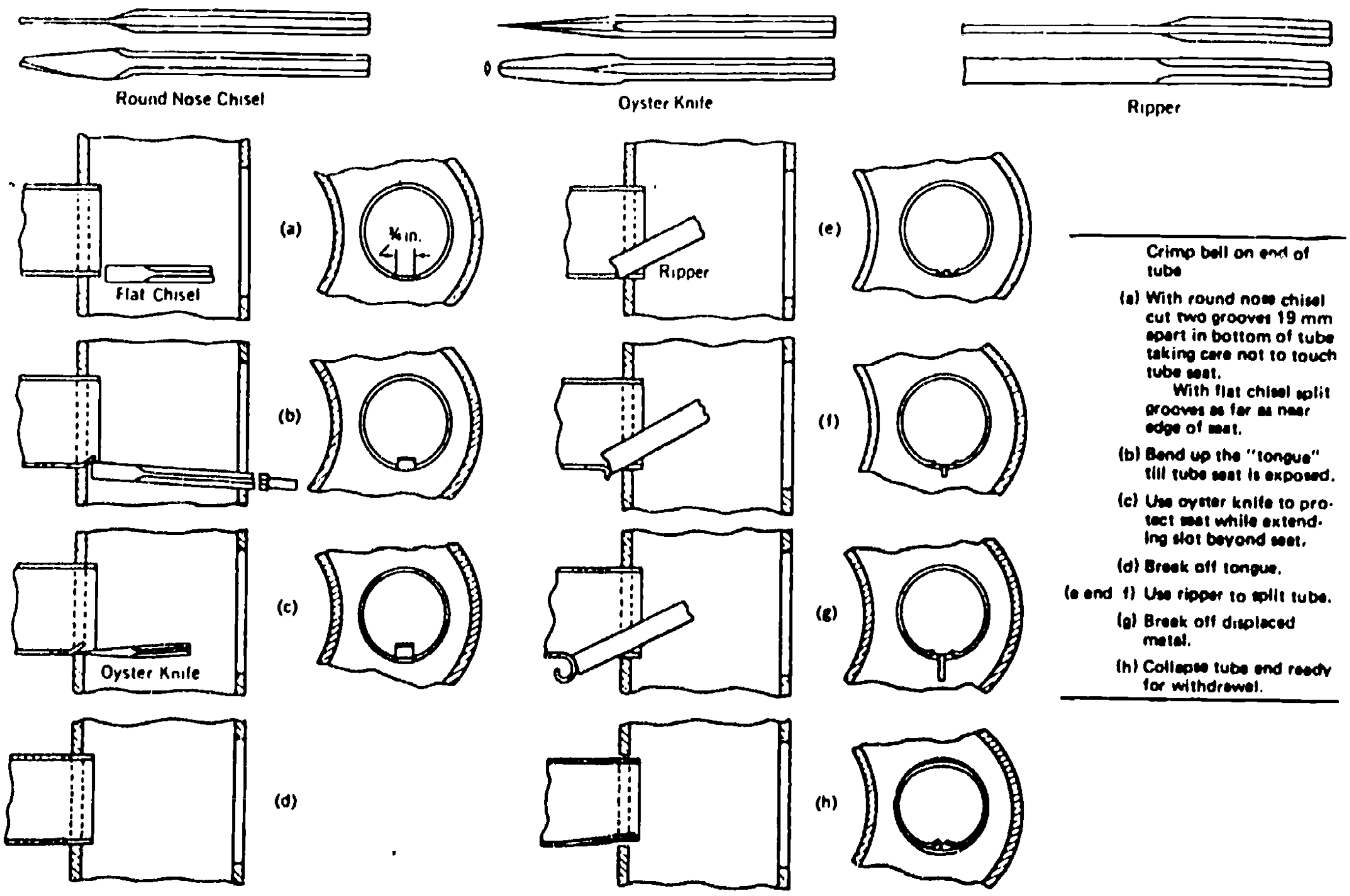
Tube Removal

Occasionally tubes must be removed and replaced because of damage or defects or because the boiler is to be dismantled and relocated. There are a variety of ways for removing tubes, depending on whether the tubes are to be salvaged, wholly or in part, or scrapped.

With light-gage tubes it is often possible to cold-crimp both ends of the tubes to loosen them in the seats and then drive or "jack" the tubes out.

When the tubes are too heavy for cold-crimping, the two-stage heating method may be used. The heat is applied to the inside of the tube end with a torch. Heat is first applied for a short period--not long enough for it to be transferred to the tube sheet. When the tube end cools, the joint will have loosened enough so that the second heat will not be transferred readily to the tube sheet. The tube end can then be heated sufficiently for crimping and the tube can be pushed out of its seat.

If neither of these methods is applicable, the tubes are usually cut off close to the outside of the shell, and the stubs are removed later in a separate operation. To remove light tube stubs, it is advisable to cut grooves about 19 mm apart with a round-nose chisel. When the tongue (the metal between the two grooves) is knocked free, the tubes can be collapsed and removed. Fig. 4 illustrates this method.



Tube Removal
(Babcock and Wilcox)

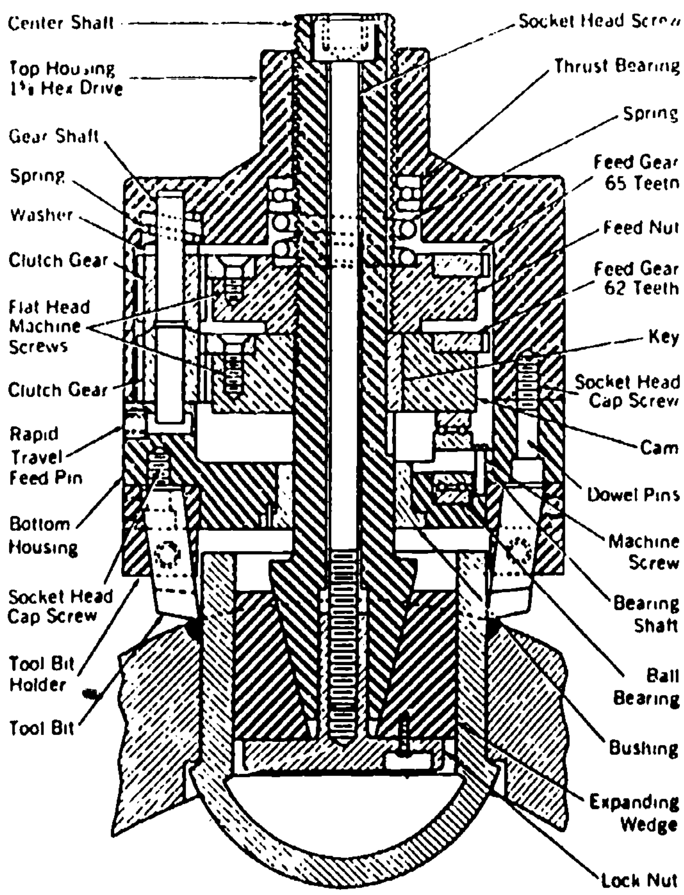
Fig. 4

When a heavy gage tube must be replaced and the expanded end is a good joint, it is better not to disturb the expanded end provided there is outside access to the tube. It is simpler to cut off the tube at a convenient distance from the drum and join the stub end to the new tube with a ring weld. However, if there is no access for such a repair, the cutting can be done from inside the drum by careful use of a cutting torch.

When it is impossible or inadvisable to use a cutting torch then a tube cutting tool which fits inside the tube may be used.

In the case of seal welded tubes, a mechanically driven cutting tool is used to cut away the seal weld and the tube can then be removed as described previously.

Handhole Cover Removal



Handhole Cover Removal
(Babcock and Wilcox)

Fig. 5

In the course of repair and maintenance work it is often necessary to remove one or two handhole fittings that have been seal welded. The most practical way to do this, when no alloy material is involved, is to remove the seal weld with a cutting torch. Considerable care is required to prevent damage to the header i· this process. Alternatively, the seal weld can be removed by grinding or chipping. While these methods are slower, they do not present the hazard involved in the burning process, and alloy materials can be handled without damage.

If a great number of fittings are to be removed from alloy headers, it may be advantageous to use special tools like the one shown in Fig. 5. This type of cutting tool is used outside the header to remove seal welds from 83, 102 and 114 mm expanded-type cup caps and blind nipples, and welded-type handhole plugs.

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 10

1. Discuss briefly the purpose of and the method of carrying out the following procedures:

   (a) hydrostatic test

   (b) drying out

   (c) boiling out.

2. Sketch and describe a method whereby the set point of a safety valve can be tested without causing the valve to open fully.

3. In regard to boiler start up discuss the importance of avoiding thermal stresses and explain where these stresses are liable to occur and how they may be avoided.

4. Summarize the duties of the power engineer in charge of a shift in regard to normal operation. Refer to your own plant if possible.

5. Assume that a furnace tube has ruptured. Summarize the procedure to be followed in shutting down the boiler, repairing it, and returning it to service. Assume that the return to service of the boiler is urgently required.

6. List six precautions to be taken to avoid the occurrence of a furnace explosion.

7. List six precautions to be taken to avoid the occurrence of a pressure explosion.

8. As Chief Engineer you are required to arrange for the chemical cleaning of one of your boilers. Explain how you would arrange for this and describe the general procedure involved.

9. Discuss the safety aspects involved in regard to boiler inspection and repairs.

10. Describe a method used for the laying-up of a boiler. Refer to your own plant if possible.

PE1-2-10-Q

INSTRUCTIONAL LEARNING SYSTEMS

7.6

BOILERS -- CLEANING

Goal:

The apprentice will be able to describe methods for cleaning a boiler.

Performance Indicators:

1. Describe cleaning of aïr.
2. Describe cleaning of feedwater.
3. Describe cleaning of steam.
4. Describe cleaning of soot, ash and scale.
5. Describe cleaning in routine opreations.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Compelte post-assessment.

Vocabulary

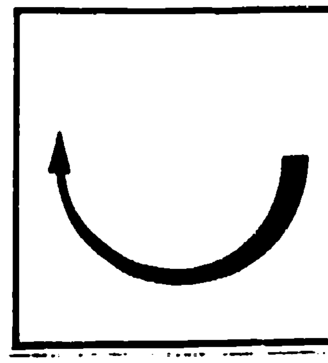
* Air washers
* Alkaline boil out
* Ash hoppers
* Ash separators
* Continuous blow-off
* Dust collectors
* Flyash blowers
* Inhibited acid cleaning
* Precipitators
* Purging
* Retractable nozzles
* Sootblowers
* Steam separators
* Steam washers
* Surface blow-off

Introduction

Efficiency and safety of boiler operation is highly dependent on keeping the boiler parts clean and free of grease, combustible gases, ashes and soot. Purging the boiler with fresh air to rid it of combustible gases is one type of cleaning operation. Ash and soot removal is a cleaning problem in boiler systems. Feedwater must be kept clean of impurities. This requires another cleaning process that involves surface and continuous blow-down systems.

Several packages have dealt with the various cleaning processes. This package will briefly discuss cleaning and cleaning systems. Each of the systems will be discussed in greater detail in other packages that relate to draft control, feedwater and boiler construction and operation.

Information



Cleaning the Air

Draft equipment provides a flow of air through the boiler. At the same time waste gases are moved away from the combustion chamber. An accumulation of combustion gases can be a safety hazard that causes explosion. Purging is a strict requirement for all boiler startups. Clean air flows through the boiler and removes all combustible gases before firing the boiler. The purging operation must become a habit with boiler operators. Draft equipment must function properly during operation. The furnace needs air for combustion. Waste gases must be removed continuously to eliminate hazards of explosion. Forced draft and induced draft fans are used to move new air into the boiler and combustion gases out.

Cleaning the Feedwater

Feedwater is cleaned by mechanical and chemical methods. Controlling the quality of feedwater that enters the boiler is most important. The water may be treated with chemicals such as softeners and anti-foam materials. Blow-down connections are designed to help keep the feedwater clean. Surface blow-off removes impurities of the water line. Continuous blow-off removes water from well below the surface. The continuous blow-off is located at a point where heavy accumulations of solids occur. This continuous removal of feedwater that is heavy with solids is a cleaning method. Blow-off is used to remove sludge and scale from the boiler.

Cleaning the Steam

A number of devices are used to clean steam before it enters the turbine. If the steam contains water, it causes fouling of the turbine blades. The water is actually cleaned from the steam by such devices as steam separators and steam washers. These devices are part of the drum internals.

Cleaning Out Soot, Ash and Scale

Soot and ash tend to cover the heating surfaces of the boiler. Excess soot and ash reduce the transfer of heat and efficiency of steam production. Soot blowers are used to remove soot and ash from the furnace, superheater and reheater walls. These soot blowers operate on steam, water or air pressure that is delivered through retractable nozzles. The operator determines the need for soot blowing and follows prescribed safety procedures in operation of the blowers. With some fuels, especially coal burning plants, ash handling equipment becomes very important in boiler operation. Ash handling equipment

Information

includes waterfilled ash hoppers, blowers for handling flyash, ash separators, air washers, dust collectors and precipitators.

Scale deposits are a major problem in boilers. The control of feedwater quality determines the amount of scale deposit in the boiler. Scale deposits are removed by mechanical or chemical cleaning methods. Mechanical cleaning involves cleaning tools with cutter heads of hard surfaced material. These tools are powered by steam or air and rotate at high speeds. The tools actually cut the scale deposits from tubing and drum surfaces. Chemical cleaning is used to reach surfaces that cannot be cleaned by mechanical methods.

Two methods of chemical cleaning are used. The alkaline boil-out is used to remove grease and oil. Inhibited acid cleaning uses acid to dissolve scale. A test should be made of the scale deposit and a chemical strength selected for each type of deposit. Chemical cleaning is usually accomplished with a low strength acid (inhibited hydrochloric) that will remove the deposit without damage to the metal. Experts are usually contracted to do chemical cleaning.

Cleaning in Routine Operations

Most cleaning oeprations require that the boiler be shut-down and cooled for internal inspection. The following steps are basic to the cleaning operation.

1. Reduce load on boiler.
2. At about 50% load, operate all sootblowers to clean fireside surfaces.
3. Open drum vents after boiler pressure reduces to 30 kPa.
4. Isolate boiler by closing and tagging valves and opening circuit breakers.
5. Open blowdown valves and drain boiler when it has cooled down to 90 C.
6. Remove steam drum manhole cover.
7. Remove lower drum manhole cover. This step must be done after step 6 to avoid steam burns.
8. Open blowdown valves and flush boiler with high pressure hose.
9. After draining, close and tag blowdown valve.
10. Open fireside access door.
11. Inspect drums, drum internals, burners, dampers, sootblowers, tubes and connections.
12. Record condition of parts in the inspection log.
13. Make recommendations on cleaning methods to be used. Outside help may be needed in analyzing scale deposits and recommending chemical cleaning method to be used.
14. Perform additional cleaning as determined by inspection.

Assignment

* Read manufacturer instructions on methods for cleaning a specific boiler.

* Complete the job sheet.

* Complete the self-assessment and check your own answers with the answer sheet.

* Complete the post-assessment and ask the instructor to check your answers.

Job Sheet

CONDUCT INTERNAL INSPECTION OF BOILER

* Review safety rules for entering a boiler that is shut down.
* Obtain permission from operator to inspect interior or assist operator in making routine inspection.
* Keep log on condition of all parts inspected.
* Inspect drum, tubes, drum internals, dampers, sootblowers, burners, connections and other parts for deposits, erosion, wear, etc.
* Complete inspection log and show it to instructor for comments.
* Make recommendations for cleaning of the boiler. If possible have instructor to verify your recommendations.

Self Assessment

Mark each of the following pieces of equipment or process accoridng to the following code.

(A) -- used in cleaning air
(F) -- used in cleaning feedwater
(S) -- used in cleaning steam
(Q) -- used in cleaning ash, soot and scale

1. Mechanical cleaning ______________
2. Steam separator ______________
3. Induced draft fans ______________
4. Inhibited acid cleaning ______________
5. Surface blow-off ______________
6. Retractable nozzles ______________
7. Dust collector ______________
8. Ash hoppers ______________
9. Purging ______________
10. Alkaline boil-out ______________

Self Assessment Answers

1. Q
2. S
3. A
4. Q
5. F
6. Q
7. Q
8. Q
9. A
10. Q

Post Assessment

1. List two main methods for cleaning a boiler.

2. List two devices used in cleaning steam.

3. How does soot deposits on heating surfaces reduce the efficiency of steam production?

4. Which method of chemical cleaning is used for removal of grease and oil from boiler.

5. What are two types of blow-off?

6. What device uses retractable nozzles?

7. How is sludge normally removed from the boiler?

8. What is the purpose of purging?

9. List two types of fans used in draft control systems.

10. Which type of chemical cleaning is used to dissolve scale deposits?

Instructor Post Assessment Answers

1. Mechanical and chemical
2. Steam separator and steam washer
3. Reduces heat transfer
4. Alkaline boil-out
5. Surface and continuous
6. Sootblowers
7. By blow-off procedures
8. Removes combustible gases from boiler or to ignition. Purging prevents explosions from these gases.
9. Forced draft and induced draft
10. Inhibited acid cleaning

Supplementary References

* Manufacturer's Instruction Manual on boiler cleaning procedures.

7.7

BOILERS -- HEAT RECOVERY SYSTEMS

Goal:

The apprentice will be able to describe heat recovery systems.

Performance Indicators:

1. Describe types of superheaters and reheaters.
2. Describe methods of steam tempterature control.
3. Describe types of economizers.
4. Describe types of air heaters.

Study Guide

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* Read the vocabulary list to find new words that will be used in package.
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* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Attemperation
* Combination superheaters
* Combustion gas by-pass
* Combustion gas recirculation
* Continuous tube
* Convection superheaters
* Desuperheating
* Dry steam
* Economizer
* Extended surface tubes
* Integral economizer
* Integral type
* Plate air heaters
* Radiant superheaters
* Recuperative air heaters
* Regenerative air heaters
* Reheaters
* Rotary regenerative air heater
* Saturated steam
* Separate economizer
* Separately fired type
* Superheaters
* Tilting burners
* Tubular air heaters
* Twin furnace
* U-bend tubes

Introduction

Heat recovery systems improve the efficiency of steam generation. The heat that is normally lost as combustion gases pass up the smokestack are conserved as heat for making steam.

This package describes the various types of heat recovery systems. With this basic understanding, the apprentice can learn more about heat recovery through on-the-job experience.

Information

The boiler has several components that are designed for recovery of heat from combustion gases. The more heat that can be recovered, the more efficient the steam generation process becomes.

Heat recovery includes superheaters that remove water from steam to make it more efficient. Reheaters serve as superheaters for steam that is returned from the turbine. Economizers absorb heat from the combustion gases into tubes filled with feedwater. Air heaters absorb the combustion gas heat into the air that will be returned to the furnace. All of these components are designed to improve the efficiency of modern boilers.

Superheaters and Reheaters

The superheater and reheater are designed to increase the temperature of steam. Both are made up of tubes over which the furnace gases can pass. Regular boiler steam contains moisture and is called saturated steam. If this steam has the moisture removed by passing it over a superheater, it becomes dry steam with increased temperature. Dry steam produces more energy than saturated steam. After steam enters the turbine and expands, it cools and the temperature drops. The steam is returned to the boiler for reheating. A reheater is actually a type of superheater.

Superheaters are of two types:

1. Integral type
2. Separately fired type

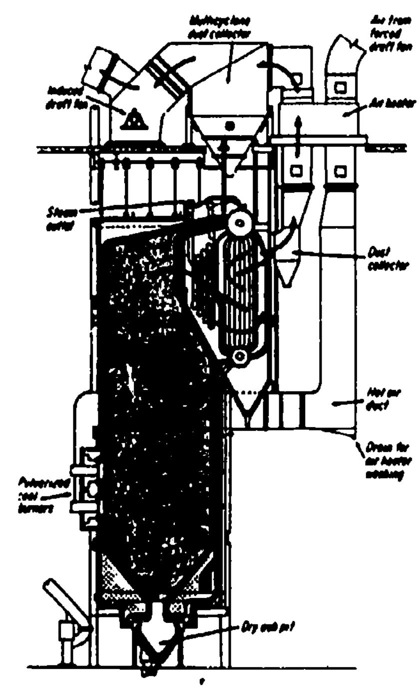
ntegral Type Superheaters

Integral type superheaters may be further classified into:

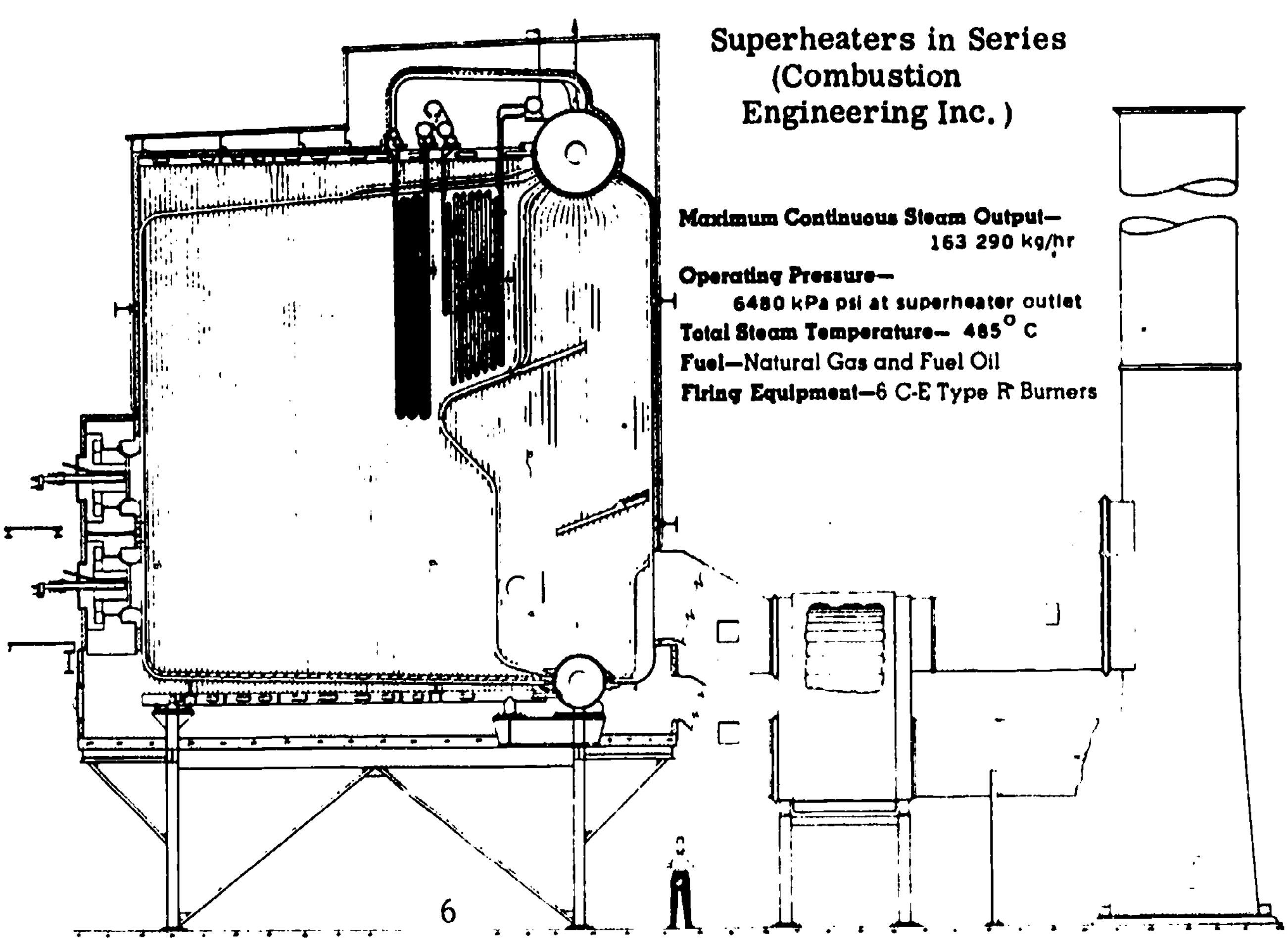
1. Convection superheater that is shielded from the radiant heat of the furnace.
2. Radiant superheater that is exposed to the radiant heat of the furnace.
3. Combination superheater that is partly exposed and partly shielded.

Information

A convection type superheater is shown below.



A combination superheater is shown in the following illustration.

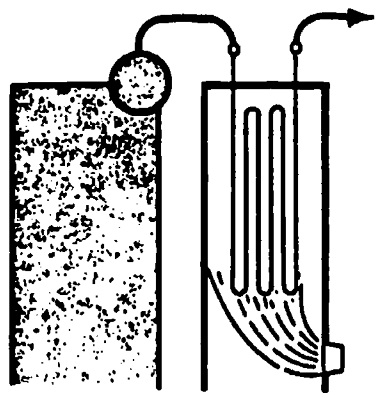


Superheaters in Series (Combustion Engineering Inc.)

Information

Separately Fired Superheaters

A separately fired superheater has its own furnace. It is housed separately from the steam furnace. It may be supplied with steam from several units. The greatest disadvantage to this type of superheater is the cost. The principle of a separately fired superheater is shown in this diagram.

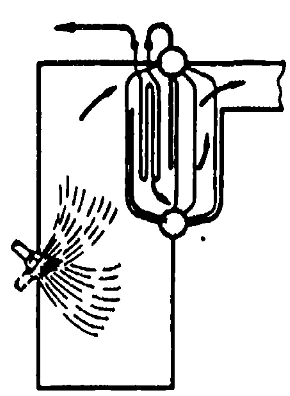


One adaptation of the separately fired superheater is the twin furnace. It consists of two furnaces in one unit. Superheater tubes are placed in one furnace and the steam from both pass through it.

Steam Temperature Control

Several methods are used to control the temperature of steam leaving the superheater. For efficient turbine operation, the temperature of its steam supply must remain constant.

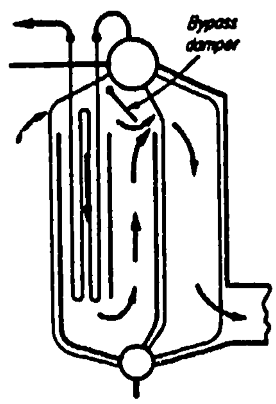
- Tilting Burners have burners that can be tilted up or down. If temperature is too high, the burners are tilted downward. If too low, they are tilted upward.



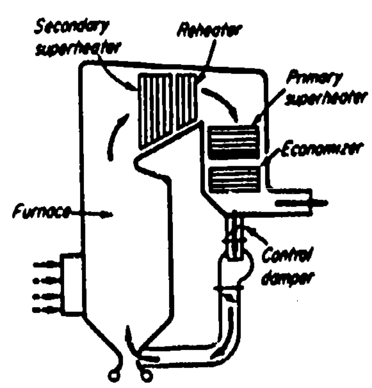
Information

- Twin Furnace used on separately fired superheaters.

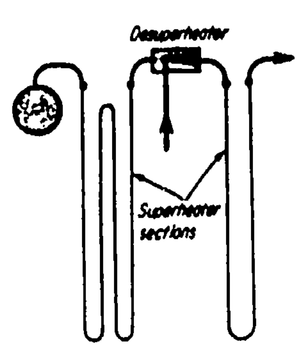
- Combustion Gas Bypass routes some of the combustion gases around the superheater to avoid overly high temperatures.



- Combustion Gas Recirculation recirculates combustion gas over the superheater tubes to raise temperature.

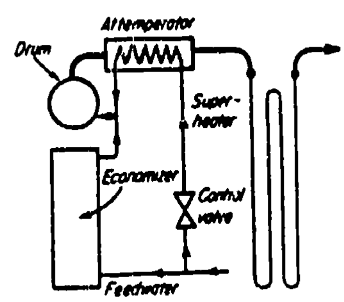


- Desuperheating lowers temperature by spraying feedwater into the superheated steam.



Information

- Attemperation lowers the steam temperature by condensing it as it passes over the attemperator tubes which are filled with feedwater.



Economizers

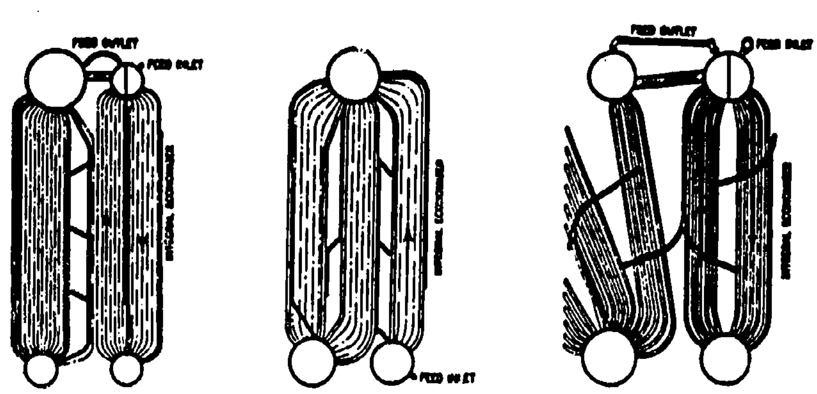
Economizers are also a series of tubes. They are designed to absorb heat from combustion gases. This savings of heat will improve the economics of steam generation. Economizers are of two basic types:

1. Integral economizer is one that forms an integral part of the boiler.

2. Separate economizer is located outside of the boiler. This type is the most commonly used economizer.

Integral Economizer

The integral economizer is a tube and drum arrangement. The tubes may attach to the drum of the boiler or may have two drums of its own. Some typical integral economizer arrangements are shown.



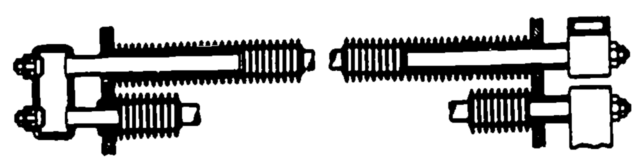
(A) (B) (C)

Information

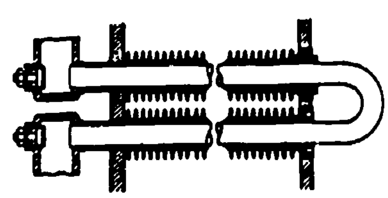
Separate Economizer

Separate economizers are located outside the boiler. They consist of rows of tubes placed horizontally. The tubes are filled with feedwater. As combustion gases flow over the tubes, the feedwater collects heat from the gases. Economizers are available in different configurations.

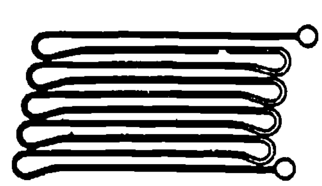
- Extended surface tubes have straight tubes with cast iron fins that provides more surface for heat collection.



- U-bend tubes has extended surface u-bend tubes.



- Continuous tube has a continuous tube that loops between headers.



Air Heaters

Air heaters are used to collect heat from the flue gases. It can be used in addition to the economizer. The air heater is a heat exchange surface that is

Information

located in the flow of combustion gases. The air absorbs the heat where in an economizer the heat was absorbed by feedwater in the tubes. Heated air is then used in the combustion process. Combustion efficiency is improved with increases in the temperature of the air that enters the furnace. Air heaters are of two basic types:

1. Recuperative heaters
2. Regenerative heaters

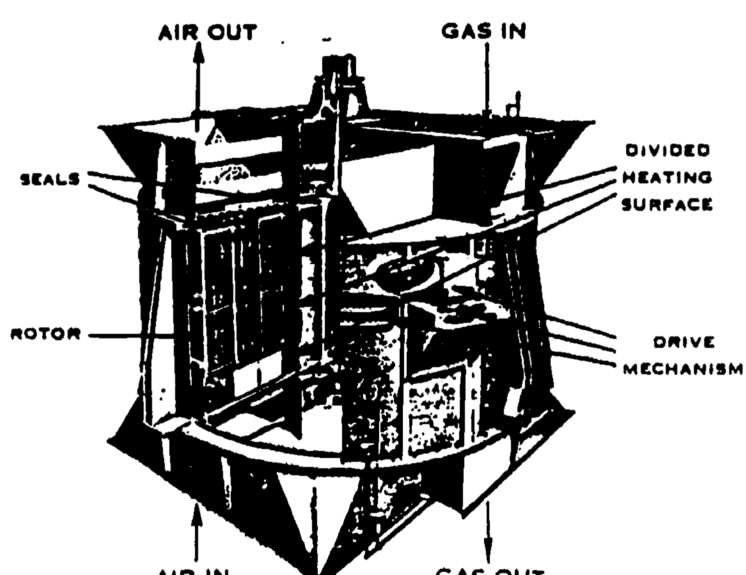
Recuperative Air Heaters

The heat from the gases is transferred through the wall of a tube or plate to the air on the other side. Recuperative air heaters may be further classified into two types.

1. Plate air heaters consist of a series of thin plates with passagewayus between them. Flue gases pass through every other passage and air passes in the alternate spaces. The gases and air flow in opposite directions. Heat is passed through the plates.
2. Tubular air heaters have a series of tubes that carry air to the combustion chamber. Flue gases pass over the tubes and heat is transferred through the tube wall to the air inside. Tubular heaters may be arranged horizontally or vertically.

Regenerative Air Heaters

In regenerative air heaters, metal sheets are heated by the gases and then moved to heat the air at another location. It becomes a second hand heating process as compared to recuperative type heaters. The most common type is the rotary regenerative air heater. The rotor turns slowly and the metal plates are heated by the gases. As it continues to turn, it passes through the air section and gives up its heat. A rotary regenerative air heater is pictured below.



11

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Assignment

* Read pages 18-38 in the supplementary reference.
* Complete job sheet.
* Complete self-assessment and check answers.
* Complete post-assessment and ask the instructor to check your answers.

Job Sheet

INSPECT A HEAT RECOVERY SYSTEM

* Locate a steam generation plant that has a modern heat recovery system.

* Ask permission to visit the facility.

* Observe the heat recovery system and ask questions of operator.

  - Does it have a superheater?

  - Is the superheater of the integral type or separately fired?

  - Is it a convection, radiant or combination type superheater?

  - Does it use tilting burners, twin furnaces, combustion gas bypass, combustion gas recirculation, desuperheating, attemperation or other methods of temperature control?

  - Is the economizer of the integral or separate type? How is it made?

  - Are the air heaters recuperative or regenerative types?

Self Assessment

Match the following terms with the phrases by writing the proper letters into the blanks beside the numbers.

____ 1. Economizers

____ 2. Reheaters

____ 3. Convection type superheater

____ 4. Saturated steam

____ 5. Separately fired superheater

____ 6. Dry steam

____ 7. Radiant superheater

____ 8. Tilting burners

____ 9. Combination superheater

____ 10. Recuperative

A. Exposed to the radiant heat of the furnace.

B. Steam with moisture removed by superheating.

C. Partially exposed and partially shielded from the radiant heat of the furnace.

D. Reheats steam that is returned from the turbine.

E. Absorbs heat from combustion gases into feedwater filled tubes.

F. Shielded from radiant heat of the furnace.

G. Type of air heater.

H. Steam that contains moisture.

I. Method for controlling temperature of steam that leaves the superheater.

J. Superheater has its own furnace separate from the steam generation furnace.

Self Assessment Answers

E 1.

D 2.

F 3.

H 4.

J 5.

B 6.

A 7.

I 8.

C 9.

G 10.

Post Assessment

1. U-bend tubes are often found in ______________________.

2. An ______________________ economizer is formed as a part of the boiler.

3. ______________________ air heaters transfer heat through the walls of a plate or tube.

4. ______________________ air heaters move metal sheets through combustion gases for collecting heat and then rotate to a fresh air stream to deposit heat.

5. A rotary air heater is an example of a ________________ air heater.

6. ______________________ superheaters are shielded from the radiant heat of the furnace.

7. ____________________ superheaters are exposed to the radiant heat of the furnace.

8. One adaptation of the separately fired superheater is the ______________ ____________________.

9. ____________________ is the spraying of feedwater into superheated steam to lower its temperature.

10. Extended surface tubes are a type of tube that is found in ______________.

Instructor Post Assessment Answers

1. Economizers

2. Integral

3. Recuperative

4. Regenerative

5. Regenerative

6. Convection

7. Radiant

8. Twin furnace

9. Desuperheating

10. Economizers

Supplementary References

* Correspondence Study. Lecture 3, Section 3, Third Class. Steam Generation. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 3

STEAM GENERATION

Third Class
Lecture 3

BOILER DETAILS

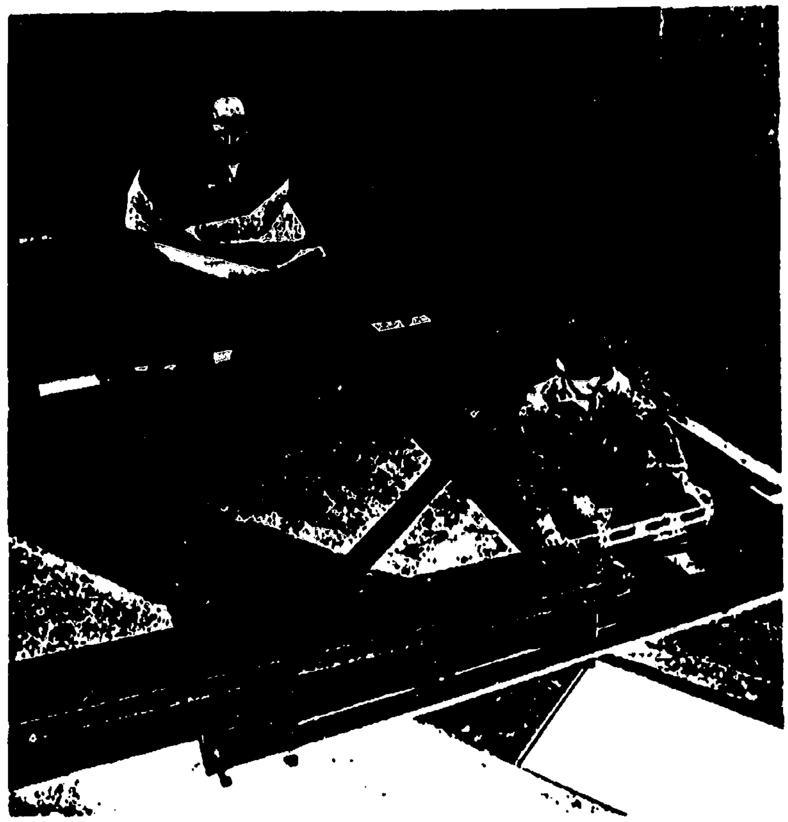
FOUNDATIONS AND SUPPORTS

Every boiler must be supported by a good foundation in order to avoid any movement due to settling which would result in extra stress in the connecting pipework. In addition, if the boiler is of the type which requires a brick setting, then any movement usually results in cracking of the brickwork. Another undesirable result of boiler settlement is that the gage glass will not give an accurate indication of water level within the boiler.

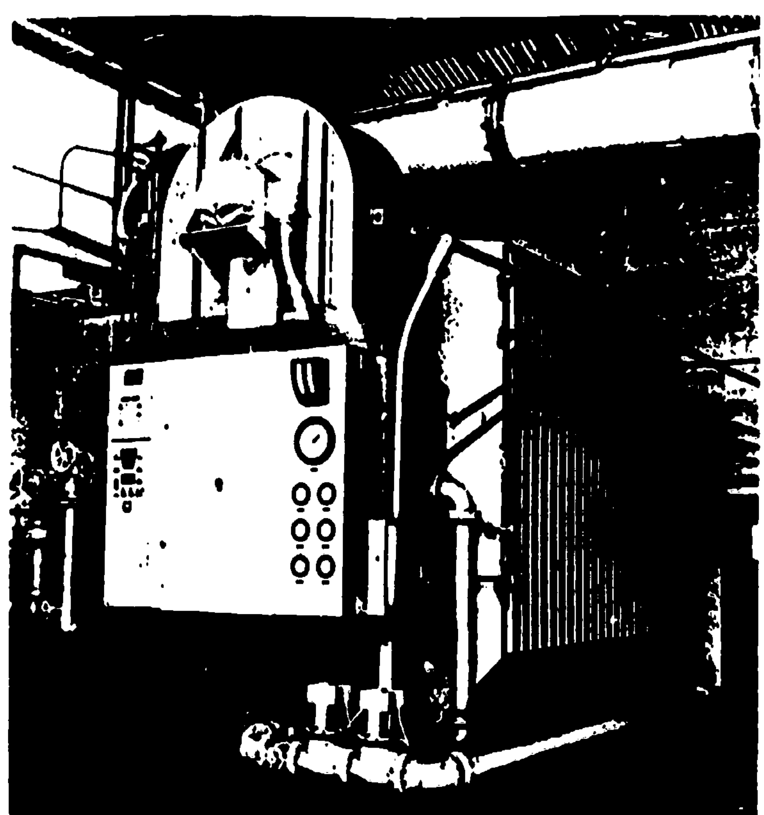
In the case of a small boiler of the packaged type, the boiler room floor is usually strong enough to serve as the boiler foundation. The packaged boiler is supplied already mounted on a steel base which supports the entire mass of the unit. This steel base is usually grouted into place on the boiler room floor. The term "grouted" refers to the practice of pouring a thin mixture of concrete around and within the base of the unit.

Fig. 1 shows the structural steel base of a "D" type packaged watertube boiler being assembled in the manufacturer's shop.

Fig. 2 shows a complete packaged boiler installed in a plant with the steel base grouted into place.



Base for Packaged Boiler
Fig. 1

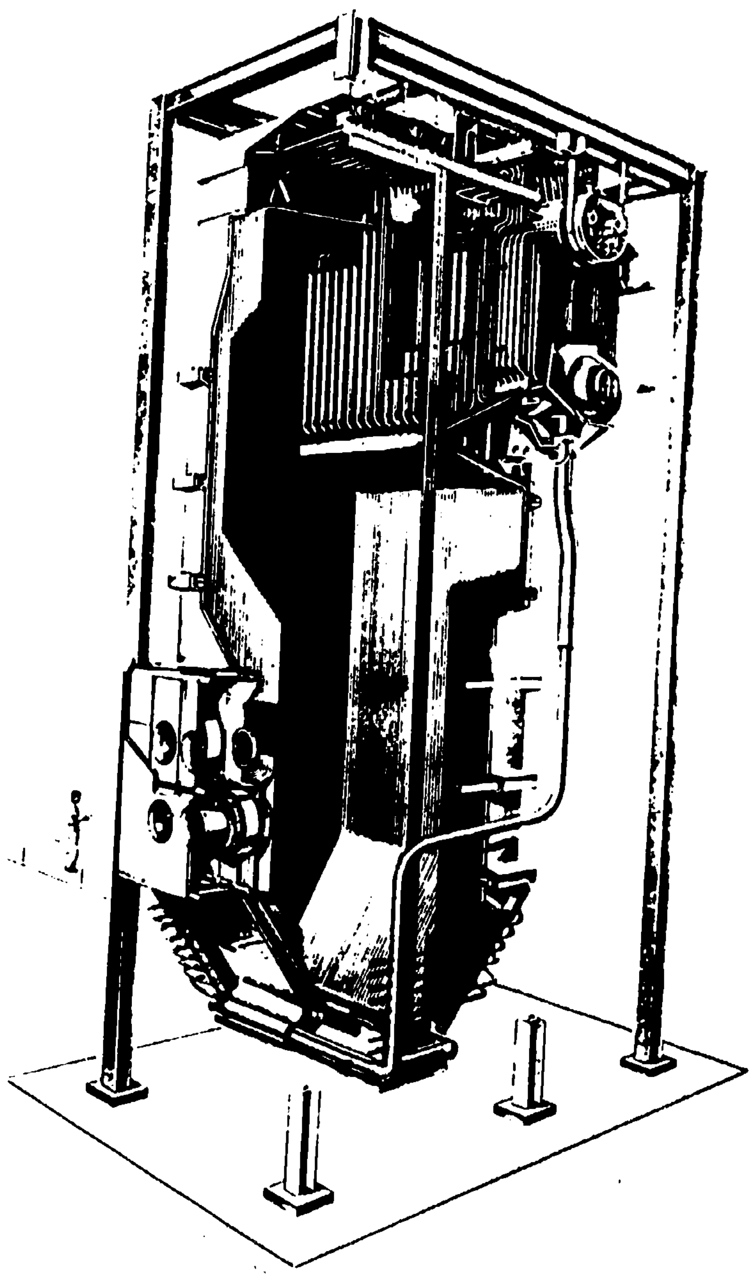


Installed Packaged Boiler
Fig. 2

PE3-3-3-2

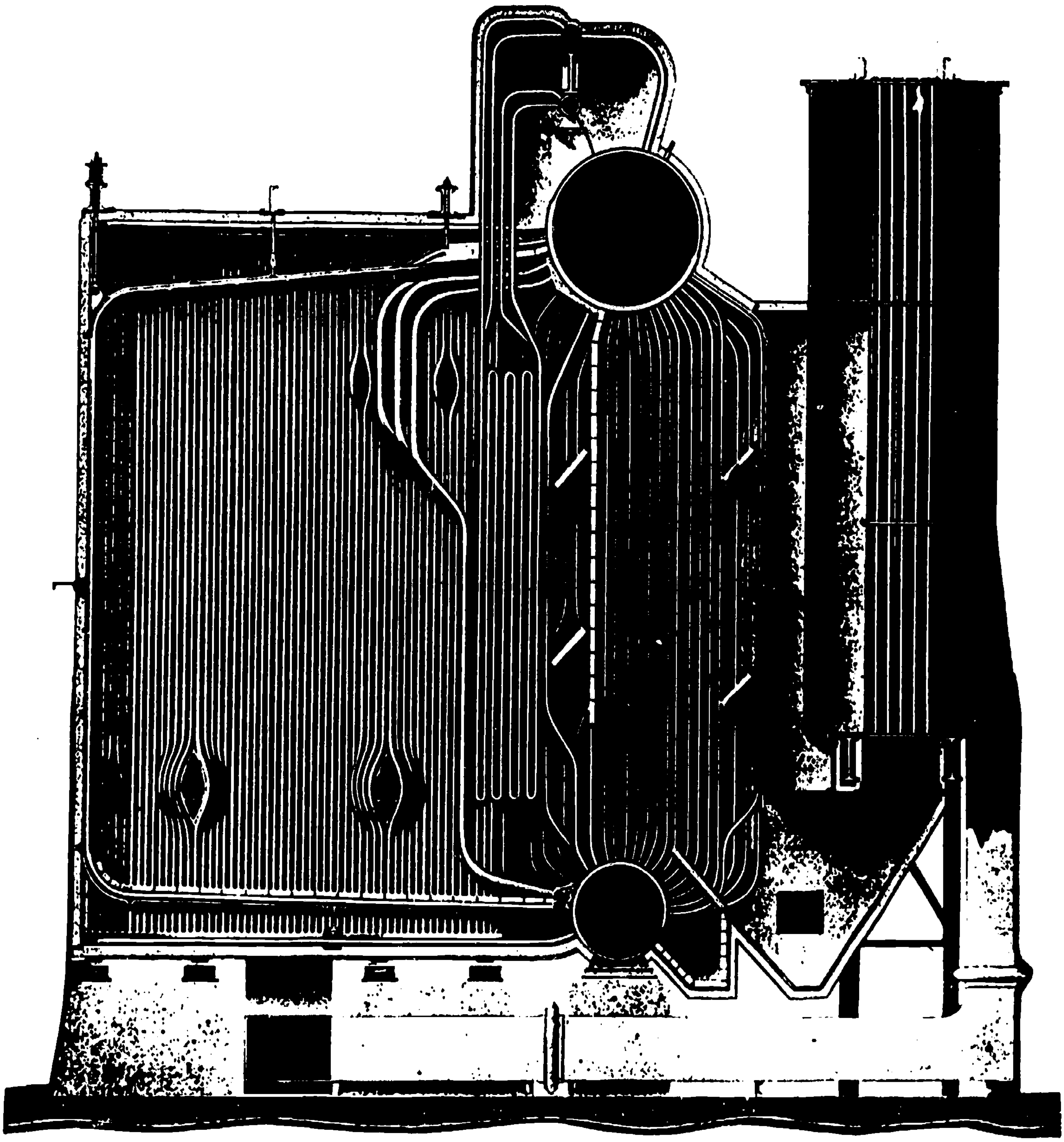
For boilers other than the packaged type it is usually necessary to provide special foundations. These consist of substantial concrete footings or piers upon which the supporting columns for top-supported boilers and the supporting saddles for bottom-supported boilers are placed.

Fig. 3 illustrates the supporting columns and overhead steelwork used for a top-supported boiler. The concrete foundations upon which the columns are placed are not visible but the method of supporting the top drum and headers is shown.



Top-supported Boiler
Fig. 3

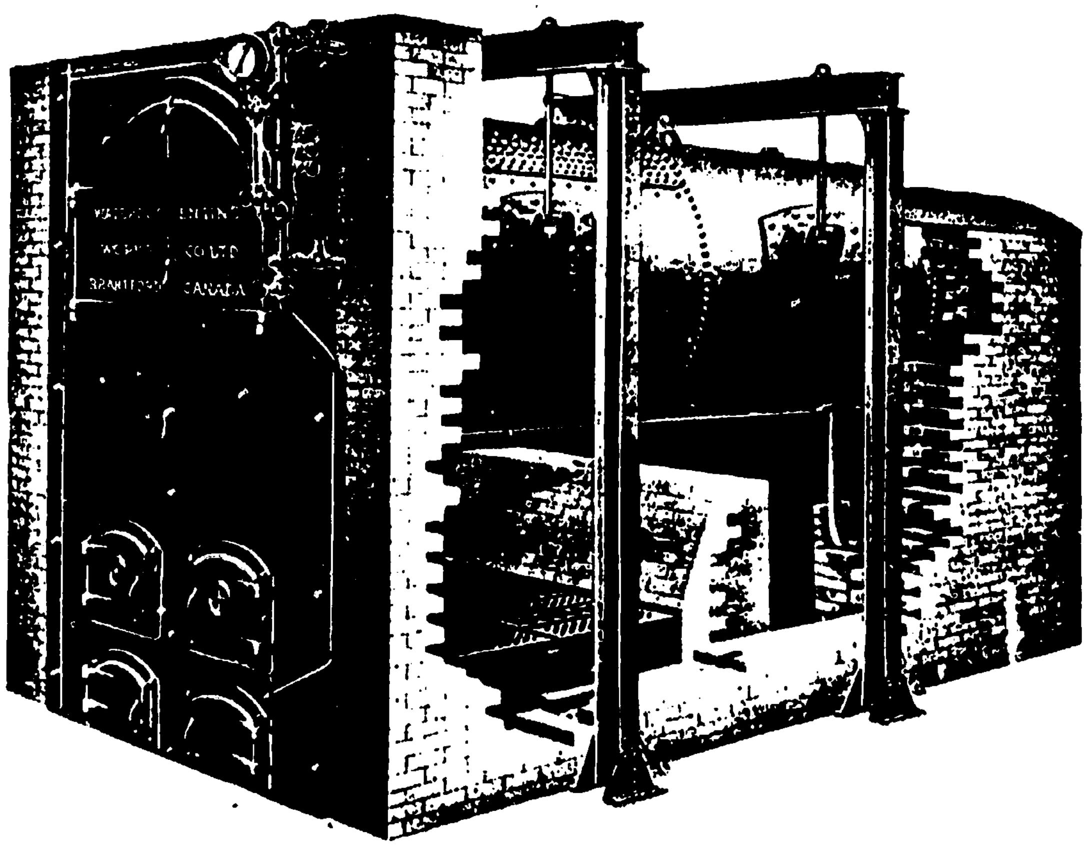
The boiler in Fig. 4 is bottom-supported with the bottom drum and furnace walls resting upon concrete piers.



Bottom-supported Boiler
Fig. 4

PE3-3-3-4

Although most firetube boilers built today are of the packaged design and are bottom-supported, an example of a top-supported firetube boiler is the H.R.T. type shown in Fig. 5. The shell is hung from overhead crossbeams which are supported by vertical columns. Paragraph PFT-46 A.S.M.E. Code lists the requirements for this method of support for horizontal return tubular boilers.



Suspension Method for H.R.T. Boiler

Fig. 5

Whether a boiler is top-supported or bottom-supported it must be able to expand freely when heated to operating temperature. With top-supported boilers, the bottom drums and headers must be free to move downwardly as the tubes expand. This movement may amount to several cm in the case of large units operating at high temperatures. The bottom-supported boiler has one end of the lower drum free to slide horizontally on rollers as it expands, while the top drum moves upwardly as the tubes expand.

SETTINGS

The term setting usually is taken to mean the brickwork structure that encloses the furnace and pressure parts of the boiler and which forms a passage through which the combustion gases flow. It must be able to withstand high temperatures and prevent the escape of heat from the furnace to the boiler room. In addition it must prevent the leakage of gas from, and air into, the furnace. As mentioned in the previous section, it occasionally serves to support some types of boilers.

Internally fired firetube boilers such as the packaged types, locomotive type, and firebox type, have the furnace contained within the shell or surrounded by a water-leg extension of the shell. As a result they do not require a brickwork setting.

An externally-fired firetube boiler, such as the H.R.T., has the furnace external to the shell and therefore requires furnace walls of brickwork.

Watertube boilers also require some type of setting around the furnace. Usually these furnace walls are the waterwall type wherein the boiler tubes are arranged to form the enclosure. Sometimes a brick and tube wall is used consisting of brickwork lined with tubes spaced a few inches apart. Some small watertube boilers use only brickwork to form the furnace enclosure.

Brickwork Settings

Brickwork settings are of either of two types, namely, the solid wall type or the sectionally-supported wall type.

The solid wall type may be constructed entirely of firebrick, see Fig. 5, or in some cases with only the inner lining of firebrick and the outer part of red brick. Firebrick is made from clays which have the property of resisting high temperatures without fusing. These special clays are known as fire clays and the products from these clays are known by the general term refractories. The constituents of fire clay are mainly silica and alumina with small amounts of various oxides and alkalies.

Frequently, instead of using individual firebricks to make up the inner lining of the setting wall, a plastic form of fireclay is used. This is a soft putty-like substance and is hammered into place to make a continuous lining without joints. Another form of refractory is the castable type which is supplied as a dry powder that can be mixed with water and poured into place like concrete.

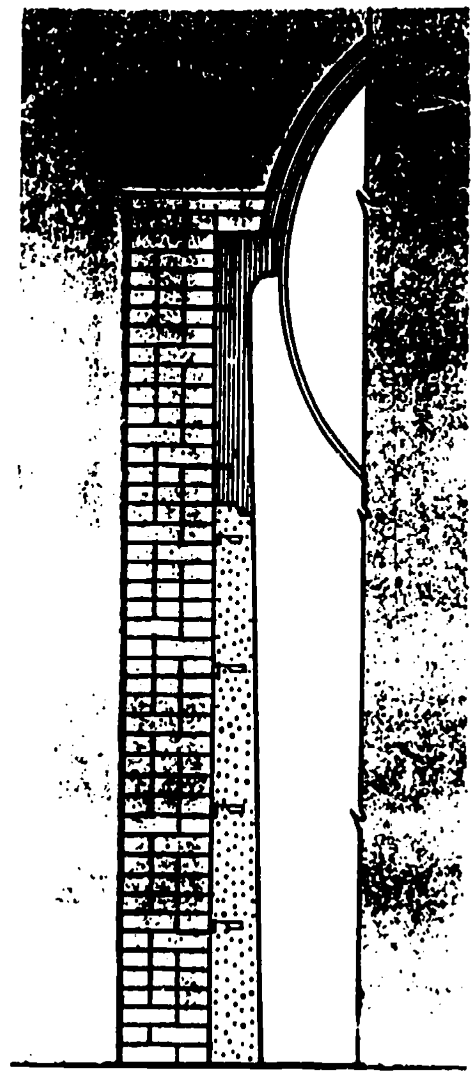
Fig. 6 shows a solid wall type of brickwork setting with the lower part of the inner lining made of plastic refractory (the dotted section). The lining above the plastic refractory is made of castable refractory.

Solid wall settings should be entirely independent of the boiler, and expansion of the boiler and the setting should be able to take place without one interfering with the other.

Spaces or expansion joints should be left at intervals throughout the brickwork to allow for expansion of the setting walls. These spaces should be sealed with asbestos rope to prevent leakage of air into the setting.

With the solid wall setting the entire mass of the wall acts upon the lowest section and tends to deform this section. In order to avoid this condition, the sectionally-supported wall is often used.

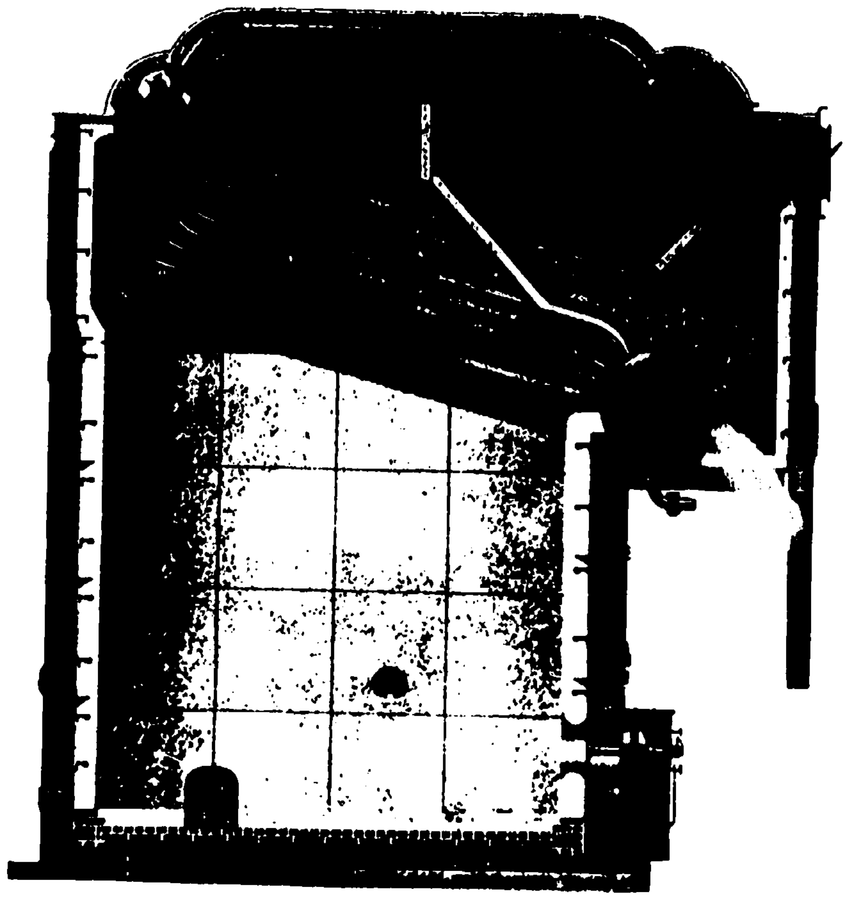
In this type the wall is anchored and supported in sections by external steelwork. This means that the load of the furnace wall is not carried by the lower wall sections. Brick and tube walls are frequently sectionally-supported.



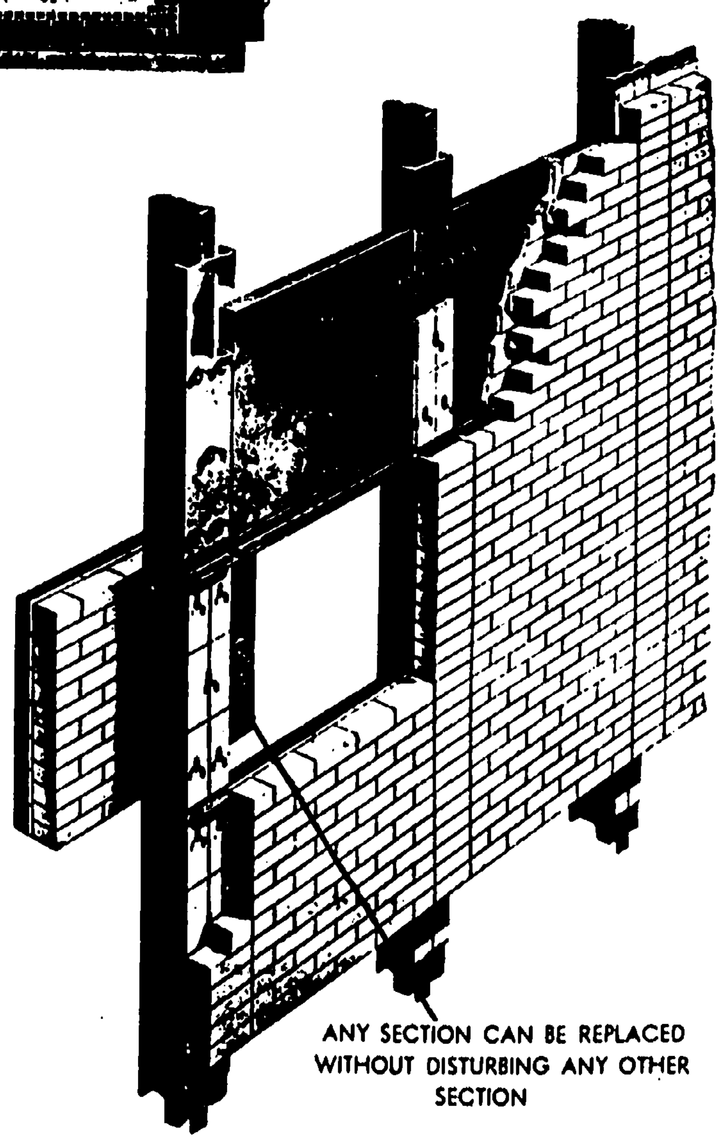
Sidewall of H.R.T. Setting
Fig. 6

Fig. 7 shows a sectionally-supported setting for a three-drum watertube boiler. The walls are air-cooled having a space between the inner and outer sections through which air is circulated before being used for combustion.

The construction details of a sectionally-supported wall that is not air-cooled are shown in Fig. 8.



Sectionally-Supported
Setting
Fig. 7



Sectionally-Supported
Wall Construction
(The Babcock and Wilcox Co)
Fig. 8

PE3-3-3-8

Water-Cooled Settings

Water-cooled settings, wherein the furnace walls are lined with tubes, are more suitable for large steam generators than are brickwork settings, due to the following reasons:

1. Because of the great height of the large steam generator, the mass on the lower portions of a solid brick setting would be excessive.

2. Furnace temperatures are too high for the brickwork to endure.

3. The brickwork will not stand up to erosion from ash particles and slagging encountered in pulverized fuel furnaces.

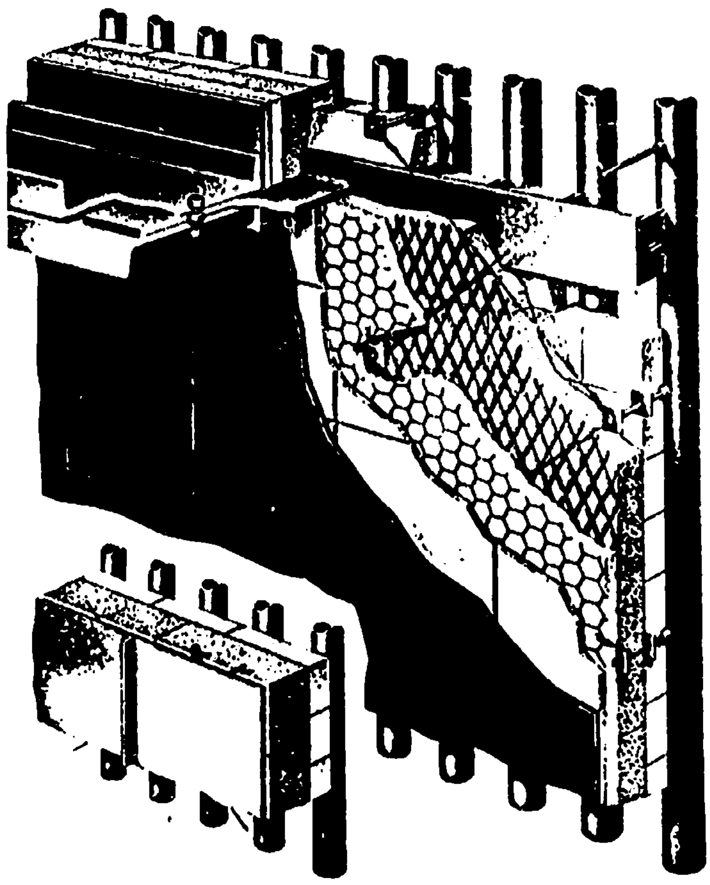
4. Greater heat absorption is obtained by circulating boiler water through the furnace wall tubes which are exposed to the high temperature of the furnace.

5. Relative movement of boiler and setting due to expansion is a serious problem with a brickwork setting.

Water-cooling of the furnace is obtained in firetube boilers of the internally-fired type. In the Scotch type packaged boiler the furnace is contained within the shell and the firebox type of boiler frequently has the furnace surrounded by a water leg.

In the watertube boiler, water-cooling of the furnace is achieved by arranging tubes to form all or part of the furnace walls. Various types of construction are used and some of these are illustrated and described as follows.

Fig. 9 illustrates a tube and brick wall consisting of tubes spaced apart and backed by firebrick which is shaped to fit the contour of the tubes. A thick layer of block insulation held in place by metal lath is applied against the firebrick and that is followed by plastic insulation reinforced with chicken wire. Another layer of thinner block insulation and a coating of sealing compound completes the wall.

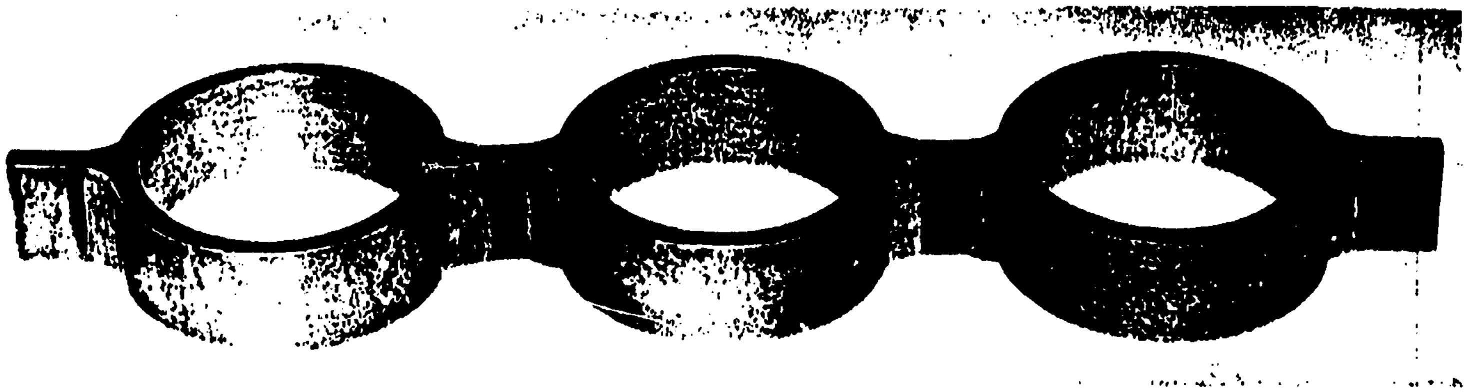


Tube and Brick Wall
(The Babcock and Wilcox Co.)
Fig. 9

Fin-welded Wall
Fig. 10

In the wall shown in Fig. 10, metal fin bars are welded to adjacent tubes forming a continuous surface. This surface is backed by block insulation and an outer steel casing. A pressure-tight wall results from this type of construction.

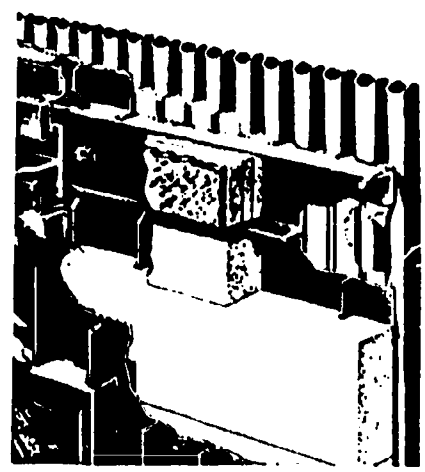
Fig. 11 shows details of the welded fins and tubes.



Fin-welded Tubes
Fig. 11

A tangent-tube wall is shown in Fig. 12. In this design the tubes are installed side by side and touching each other to form a continuous steel envelope around the furnace.

The tubes are backed with plastic or castable refractory and a steel casing. Then block insulation is used and finally an outer steel casing.



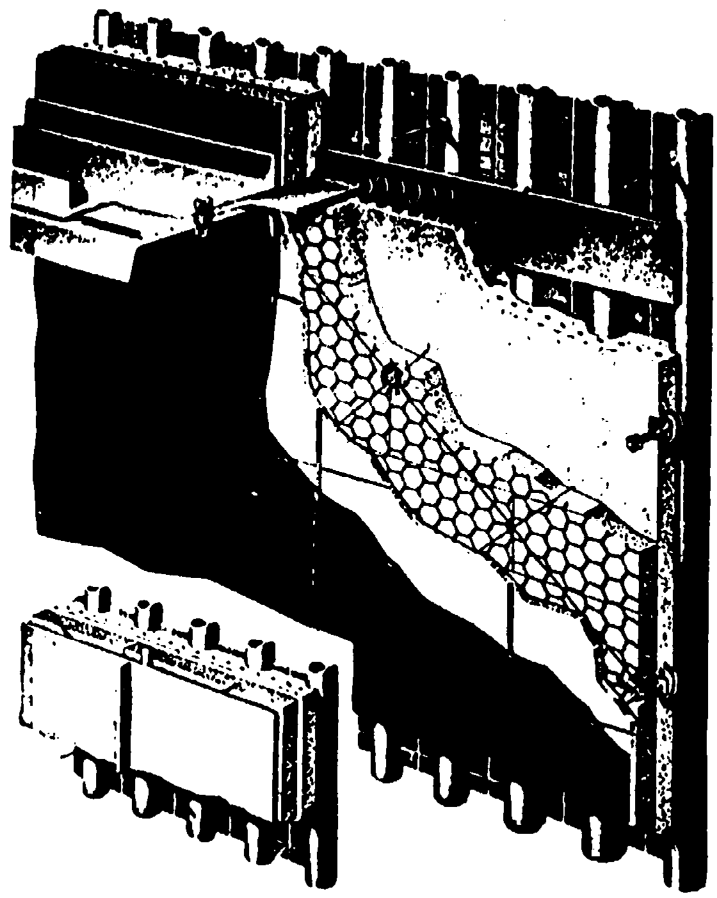
Tangent-tube Wall
Fig. 12

Fig. 13 shows the arrangement of a flat-stud tube wall. Flat plates or studs are welded to each side of the tubes and when the tubes are installed these studs fill the space between the tubes.

In this way an almost continuous metal surface is provided. The tubes are backed with castable refractory with metal lath. Then a layer of block insulation held in place by chicken wire is added.

On top of this is a layer of plastic insulation and then a finish layer of sealing compound.

Fig. 14 illustrates the furnace side of this wall showing the almost continuous metal surface and Fig. 15 shows the flat studs being welded to a tube during the manufacturing process.



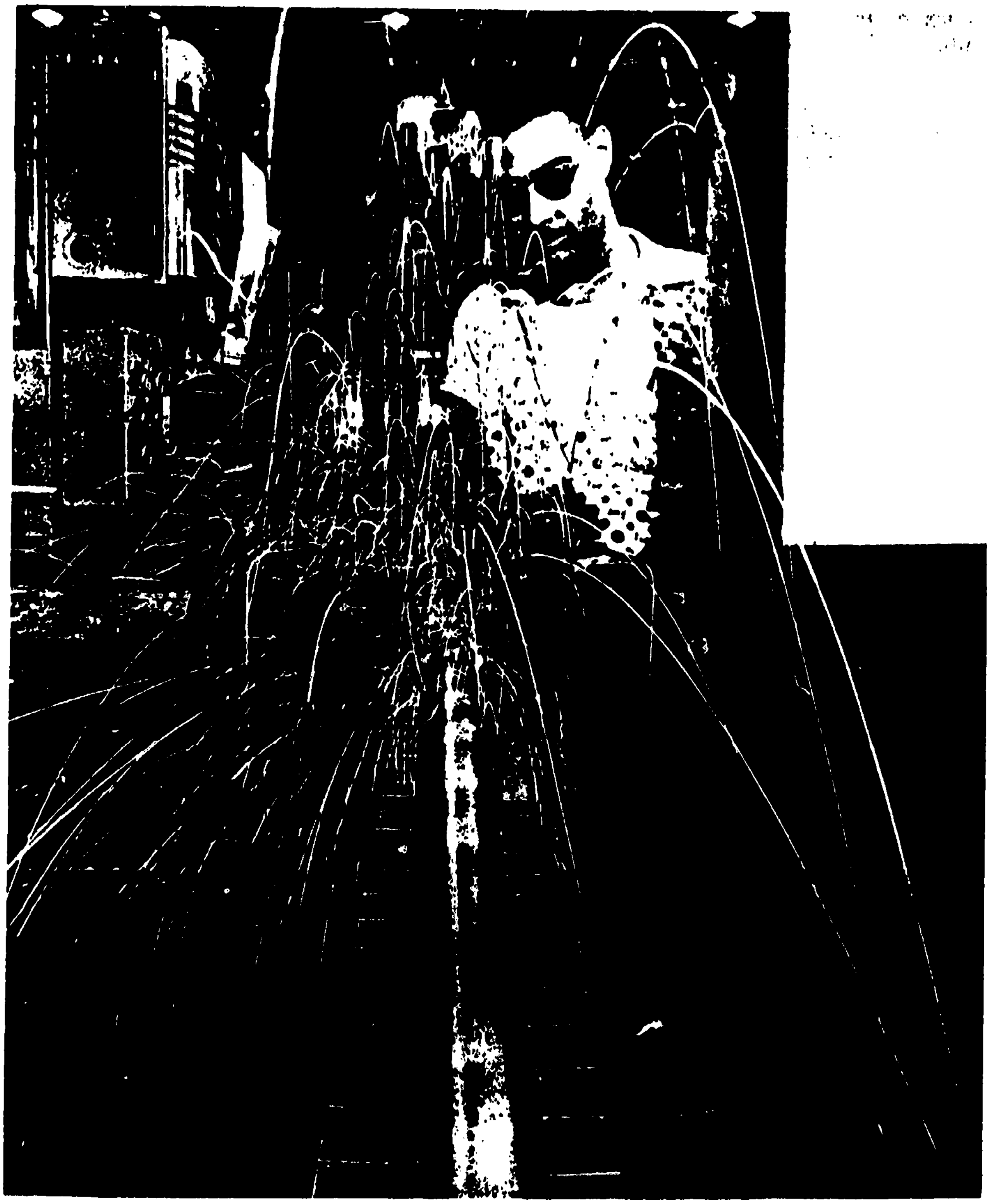
Flat-Stud Tube Wall
(The Babcock
and Wilcox Co.)

Fig. 13

Flat-Stud Tube Wall
(Furnace Side)
(The Babcock
and Wilcox Co.)

Fig. 14

PE3-3-3-12



Welding Studs to Tubes
(The Babcock and Wilcox Co.)

Fig. 15

PE3-3-3-13

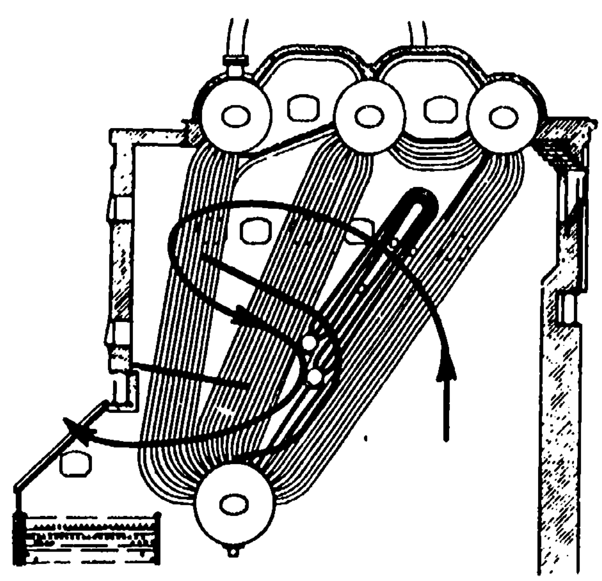
Furnace Baffles

In order to direct the flow of combustion gas over the tubes in a water-tube boiler it is necessary to use baffles. These baffles are arranged to provide the required number of gas passes through the boiler. They may be placed so as to cause the gases to flow at right angles to the tube length, in which case they are called cross baffles, or they may be placed so as to cause the gases to flow parallel to the tubes, in which case they are called longitudinal baffles.

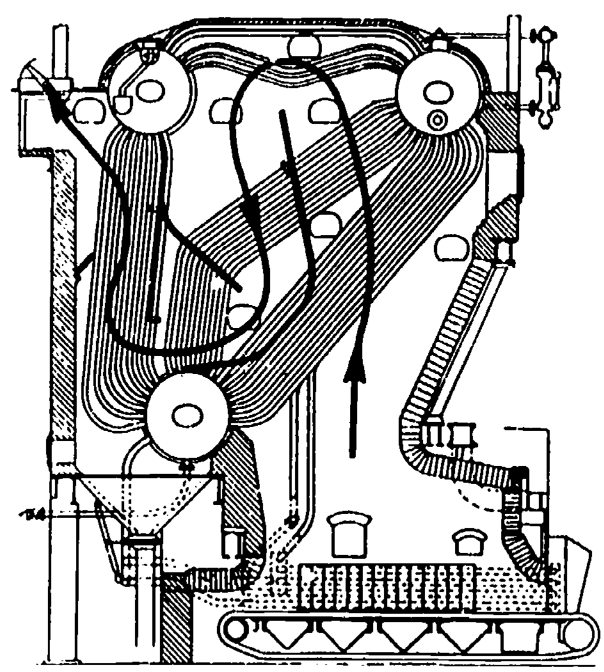
Baffles are usually constructed of refractory material and may be made up of individual bricks or tiles fitted into place around the tubes. An alternative method is to use castable refractory and form the baffle as one continuous piece.

Curved or streamlined baffles have the advantage of having no sharp turns which cause eddy currents and increased friction and which form pockets for ash accumulation.

The baffle arrangement in a four-drum boiler is shown in Fig. 16 while Fig. 17 illustrates the arrangement in a three-drum boiler.



Four-drum Boiler Baffling
Arrangement
Fig. 16

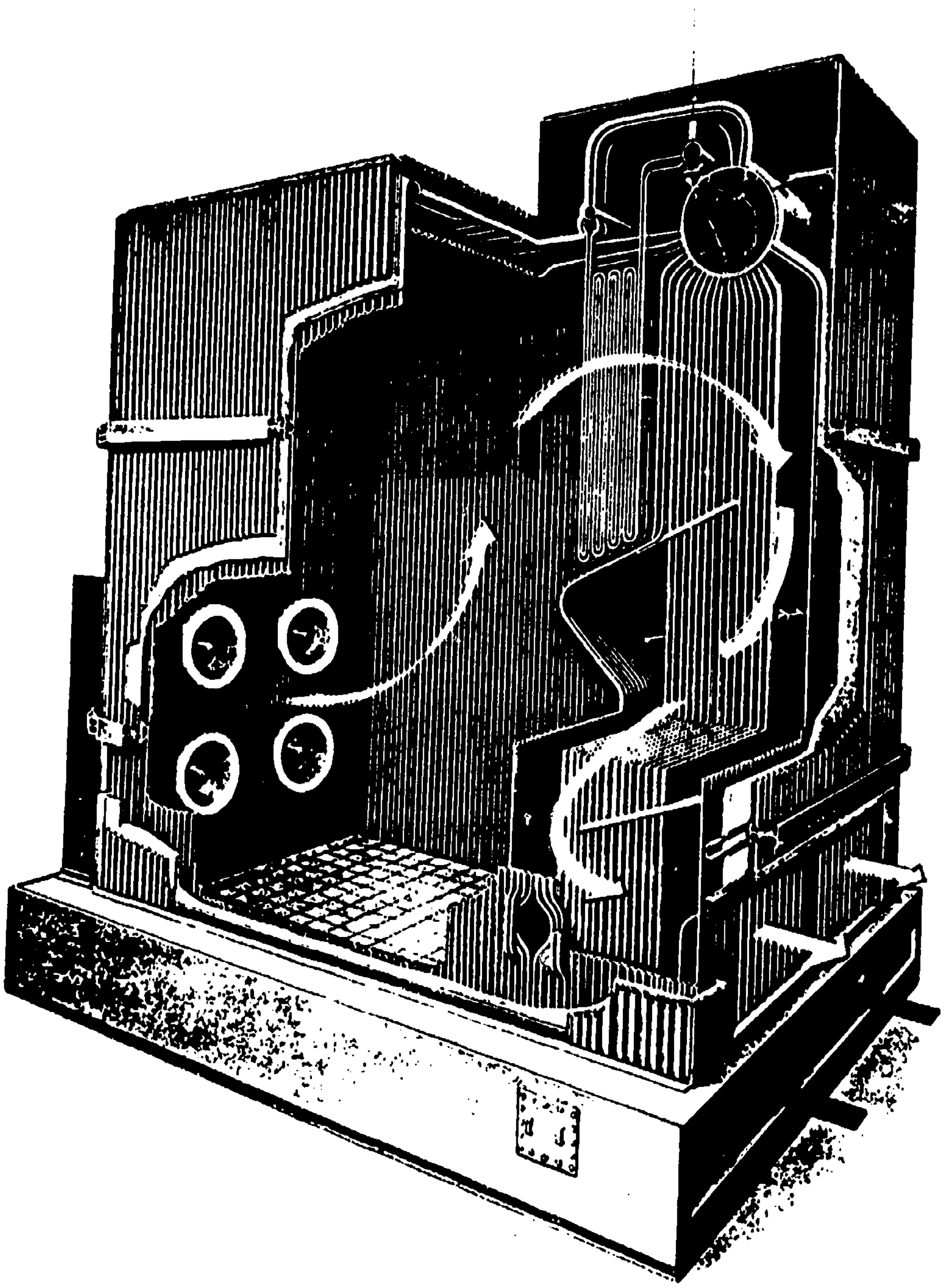


Three-drum Boiler Baffling
Arrangement
Fig. 17

Fig. 18 shows the path of the combustion gases through the tube banks and around the baffles in a two-drum integral furnace unit. As can be seen, the furnace walls feature tangent-tube construction as described in the previous section on water-cooled settings.

Note that the air inlet duct runs beneath the furnace floor.

PE3-3-3-14



Two-drum Integral Furnace Boiler
Fig. 18

PE3-3-3-15

Boiler Casings

Boiler furnaces usually operate at a pressure less than atmospheric and as a result there is a tendency for air to infiltrate to the furnace. This has an adverse affect on the boiler operation and may be eliminated to a large extent by means of an airtight boiler casing. These casings are usually made of steel although aluminum is occasionally used. In order to be airtight the panels making up the casing must be welded together or flanged and bolted together.

In some instances, the casing serves only to protect the wall insulation and is not airtight in itself. When this is so, the wall refractory and insulation must provide the air sealing necessary.

A fairly recent design of boiler has the furnace pressure considerably above atmospheric. In this design the casing must be absolutely airtight and is therefore entirely welded. In order that the casing and the wall tubes expand at the same rate the casing may be welded directly against the tubes and insulation applied to the outside of the casing.

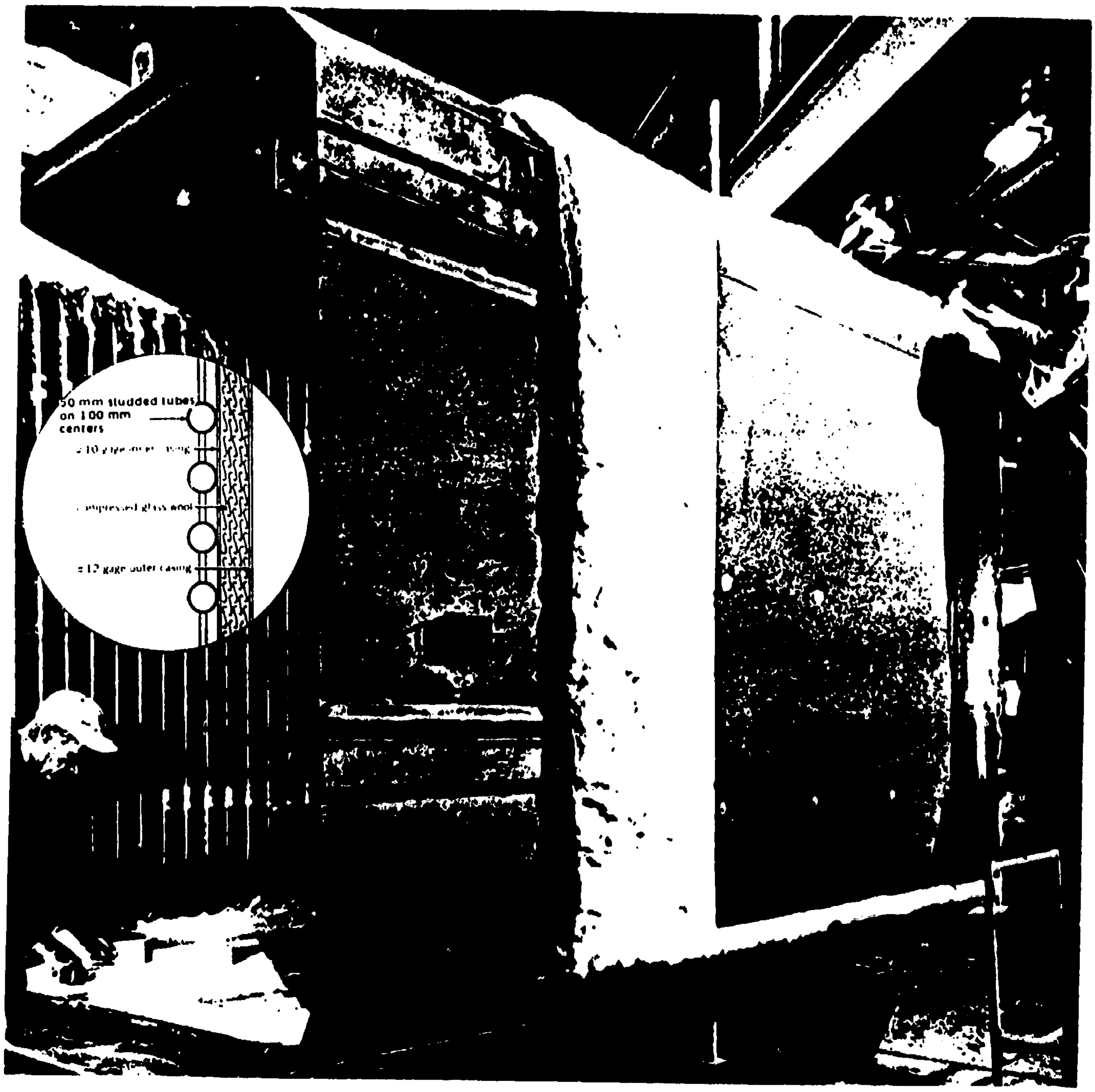
In this way, the casing and the wall tube temperatures remain very nearly equal and expansion problems are greatly reduced. This type of construction for a small boiler is shown in Fig. 19. The insert shows that the wall consists of an inner steel casing placed against the flat-stud tubes and then a layer of glass-wool insulation between the inner casing and an outer casing.

Drying out the Setting

After construction of the setting, the refractories which will contain a considerable amount of moisture should be dried out slowly. It is usually convenient to dry out the setting and at the same time to clean the boiler by boiling it out.

The boiler is filled with water to slightly below normal water level and the boil-out chemicals added to the water. The burners are then set to give a firing rate sufficient to produce a slight vapor from the drum vent. It may be possible to use the pilot burners rather than the main burners to obtain this firing rate. The dry-out may take from two days to a week to complete after which time more chemicals may be added to the boiler water and the pressure raised to give a thorough boil-out.

The A.S.M.E. Code Section VII "Recommended Rules for the Care of Power Boilers" Paragraph C1.208 lists the rules for drying out of settings.



Pressure Casing Construction

Fig. 19

SUPERHEATERS AND REHEATERS

Superheaters and reheaters are similar both in their general construction and in their purpose. They both are made up of numerous tubes through which steam is passed. Combustion gases from the furnace pass over the outside of these tubes and the temperature of the steam is thus increased. This increase in steam temperature is the purpose of both the superheater and the reheater.

Steam produced from water in a boiler is at saturation temperature and usually contains a certain amount of moisture (see Lecture 6, Section 1). If this steam is passed through a superheater, any moisture present will be evaporated and then the temperature of the now dry steam will be increased.

The increased temperature of the steam means increased energy per kg of steam and therefore the ability to do more work per kg. In addition, the increase in steam temperature means the steam will not condense as readily and therefore the amount of moisture contained in the steam after expanding through a turbine is greatly reduced. This is a great advantage as moisture in the steam rapidly erodes turbine blades and also reduces turbine efficiency.

In a steam generating unit having both a superheater and a reheater, the steam is first superheated in the superheater. The steam is then led to a turbine where it expands through the high pressure stages and in so doing drops in temperature. It is then brought back to the reheater section of the steam generating unit and superheated once again. Then it is led back to the turbine and expanded through the remaining turbine stages.

The reheater can be considered as essentially a superheater and therefore will not be discussed separately in detail in this lecture.

Superheaters may be classed as either the integral type or the separately-fired type. The integral superheater is so called because it is contained within the boiler setting and is an integral part of the boiler or steam generator. The separately-fired superheater is located in a furnace separate from the main steam generator and is independent of the steam generator operating conditions.

Integral Superheaters

Integral superheaters are classed according to their location within the boiler setting.

If the superheater is shielded from the radiant heat of the furnace and is located within the path of the hot combustion gases from the furnace then it is classed as a convection superheater.

If the superheater is exposed to the radiant heat of the furnace then it is classed as a radiant superheater.

A combination superheater has a section exposed to the radiant heat of the furnace, and a section located away from the radiant heat but in the hot combustion gas path.

The convection superheater has a rising steam temperature characteristic which means that the superheated steam temperature will rise as the firing rate or boiler output increases. At low loads the steam temperature will be low and at high loads the steam temperature will be high. The reason for this is that at high loads, although there is an increase in steam flow through the superheater, there is also an increase in combustion gas flow and combustion gas temperature due to the higher firing rate and this causes a rise in the steam temperature.

The radiant superheater, on the other hand, has a falling steam temperature characteristic which means that the superheated steam temperature will be high at low loads and will drop as the load increases. This is because the furnace temperature does not increase as rapidly as the steam flow does on a load increase.

superheater combines the characteristics of the

The steam gener
23 has a pendent typ
section located in th
combustion gases an
the radiant heat of t
superheater tubes.

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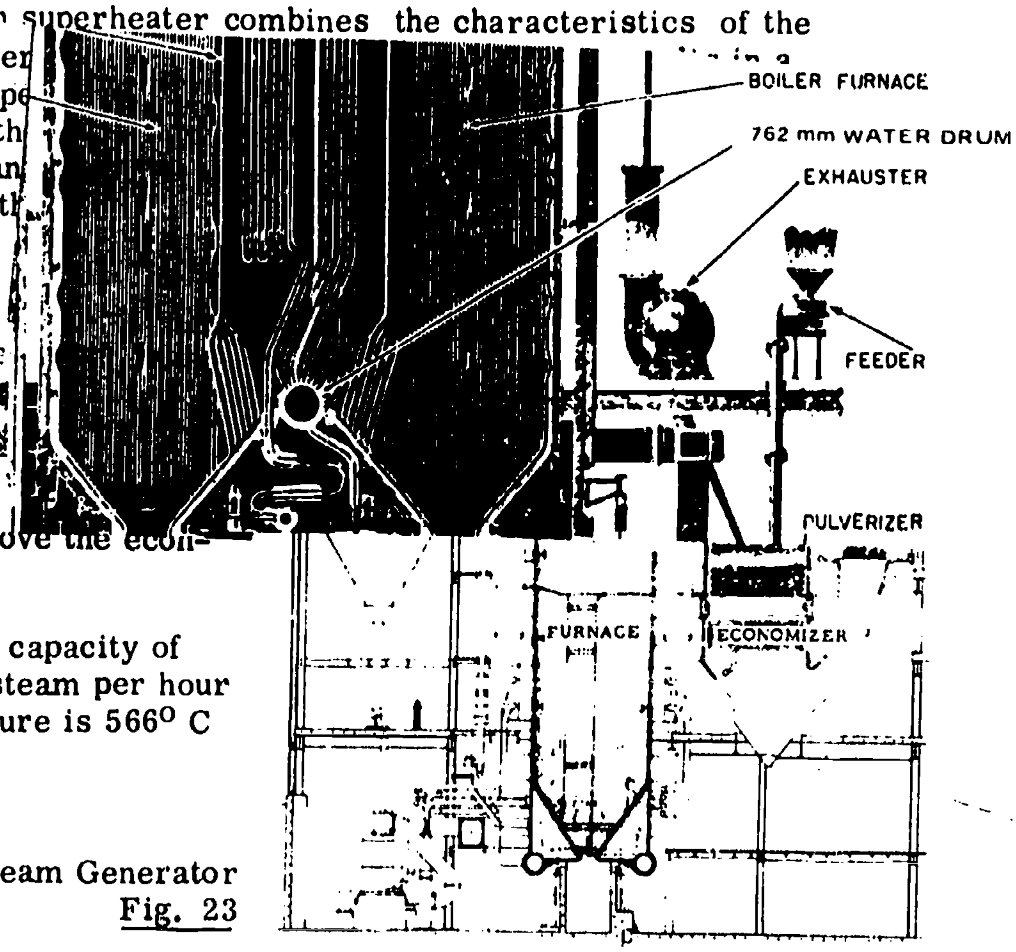
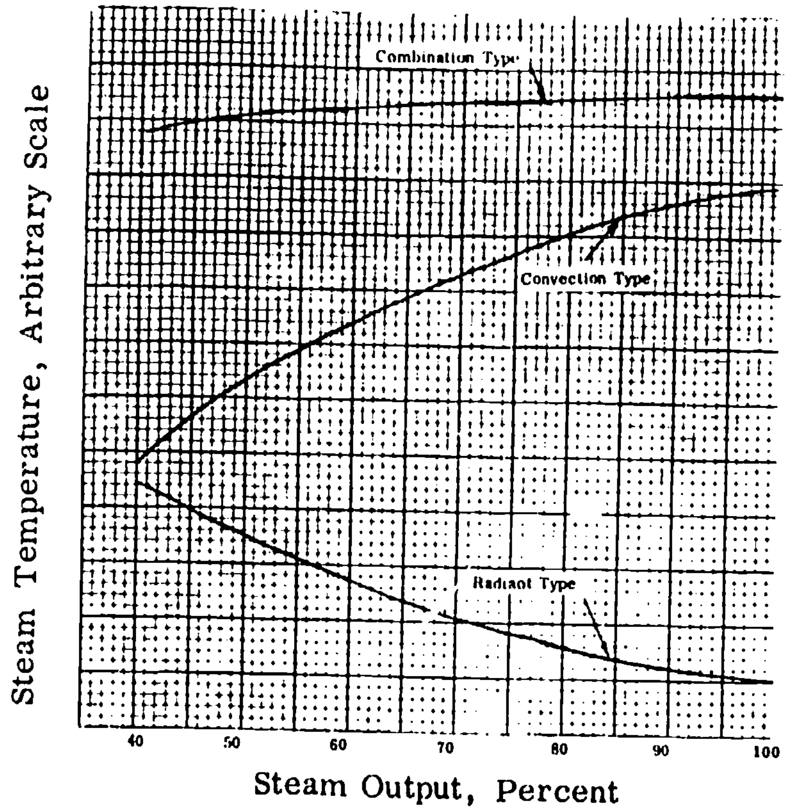


This unit has a capacity of over 454 000 kg of steam per hour and steam temperature is 566^{o} C reheated to 538^{o} C.

Reheat Steam Generator
Fig. 23

PE3-3-3-21



Superheater Characteristic Curves
Fig. 20

✕

The steam generator shown in Fig. 22 uses a convection superheater only. The superheater tubes are suspended (pendent type) in the gas path from inlet and outlet headers.

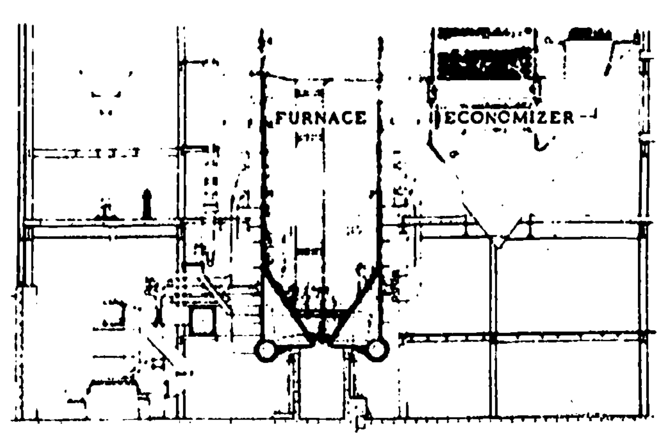
With this arrangement the steam temperature will tend to be high at high loads and some means of reducing this temperature must be employed. Various methods may be used and these will be mentioned in a later section.

A steam generator employing a reheater may have the reheater section located in the furnace proper where it will receive radiant heat or it may be located away from the radiant heat of the furnace in which case it receives it^ heat by convection.

The steam gener
23 has a pendent typ
section located in th
combustion gases an
the radiant heat of th
superheater tubes.

The superheat
divided into two se
adjacent to the reh
radiant pendent typ
section a horizonta
type located just above the economizer.

This unit has a capacity of over 454 000 kg of steam per hour and steam temperature is 566° C reheated to 538° C.



Reheat Steam Generator
Fig. 23

PE3-3-3-21

BEST COPY AVAILABLE

perheater section is contained within
ı the steam generating furnace. The
)urners and its firing rate may be varied,
nds without affecting the steam generating
ely fired superheater may be supplied
am generating units.

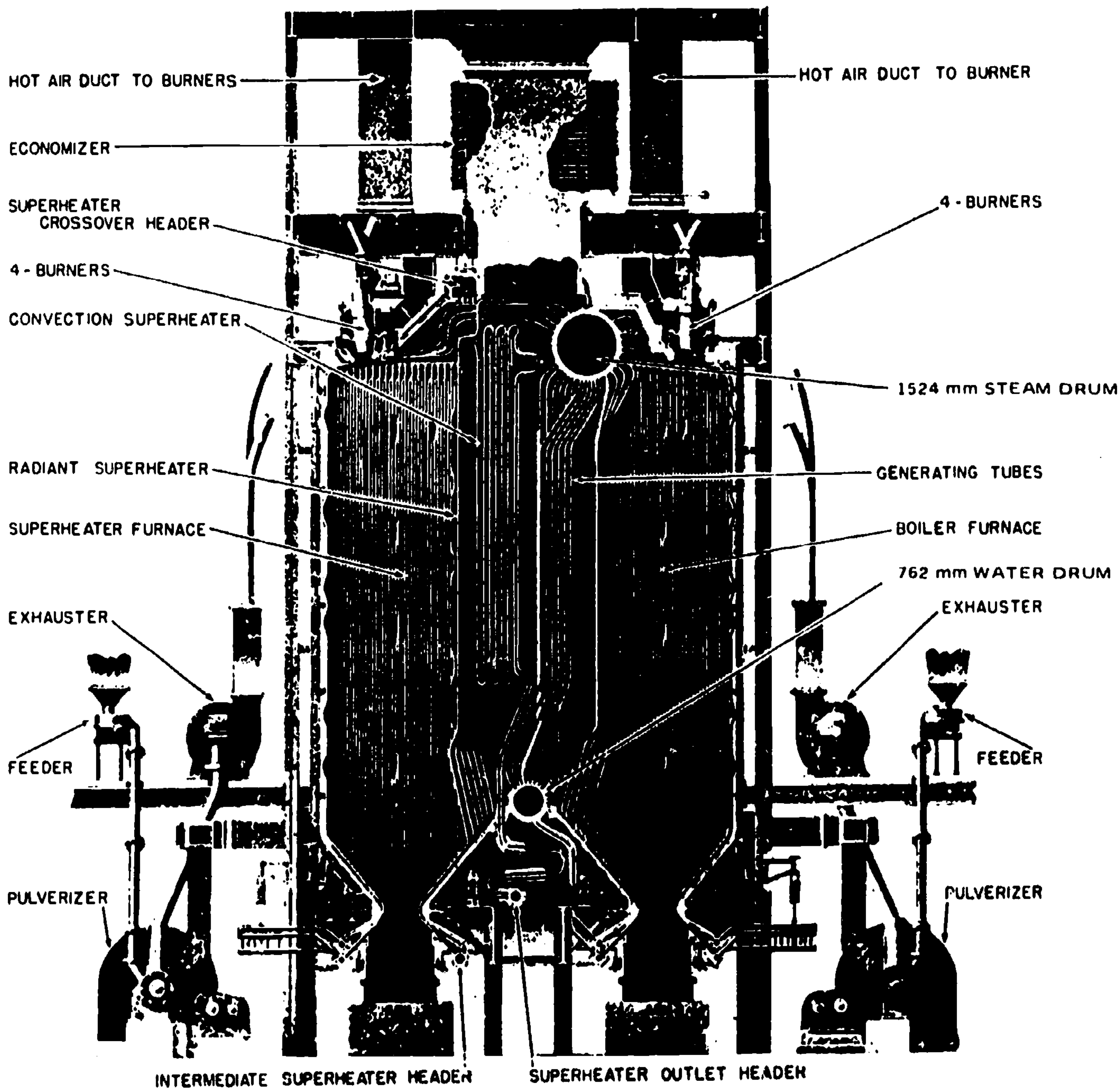
is usually limited to special industrial
rolled and very high steam tempera-

)erheater the separately-fired arrange-
These are higher first cost, lower
space requirements. It does, however,
ature control than the integral type.

rately-fired superheater arrangement

An adaptation of the separately-fired superheater is shown in Fig. 25. This is called a twin furnace unit, differentially fired. It consists of two steam generating furnaces incorporated into one unit. One of these furnaces contains superheater tubes in addition to steam generating tubes while the other furnace has only steam generating tubes.

By varying the firing rate of each individual furnace the steam temperature may be controlled independently of the saturated steam generated. The unit shown has four pulverized coal burners located in the roof of each furnace. Each furnace has water-cooled walls made up of steam generating tubes.



Twin Furnace - Differentially Fired

(Foster Wheeler Ltd.)

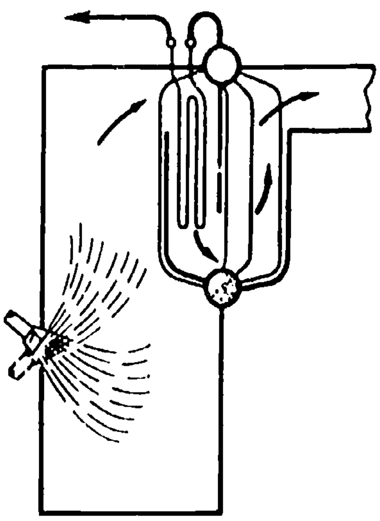
Fig. 25

PE3-3-3-23

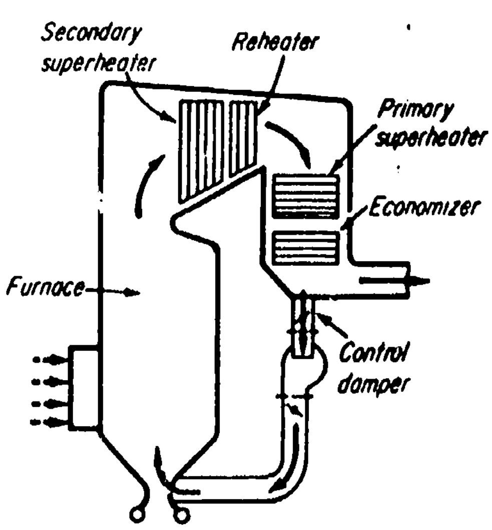
Steam Temperature Control

When superheated steam is produced, for use in a steam turbine for example, it is necessary that the final steam temperature be maintained at a constant value. Various methods may be used to control the temperature of the steam leaving the superheater and some of these methods are briefly described and illustrated as follows:

1. Tilting Burners - Fig. 26
If steam temperature begins to drop then the burners are tilted upwardly and if steam temperature is high then the burners are directed downwardly.



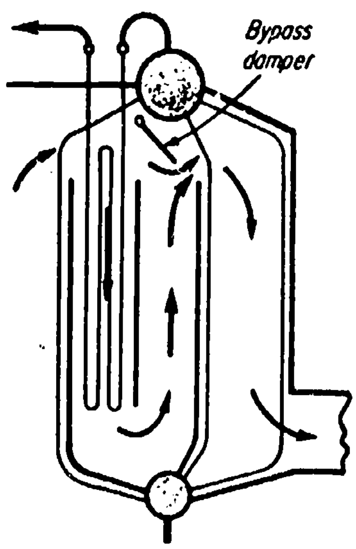
Tilting Burners
Fig. 26



Combustion Gas Recirculation
Fig. 28

2. Twin Furnace - Differentially Fired
This method was discussed previously in the section on separately-fired superheaters and is illustrated in Fig. 25.

3. Combustion Gas Bypass - Fig. 27
A portion of the combustion gas is bypassed around the superheater section to prevent steam temperature from becoming too high during high steaming periods.

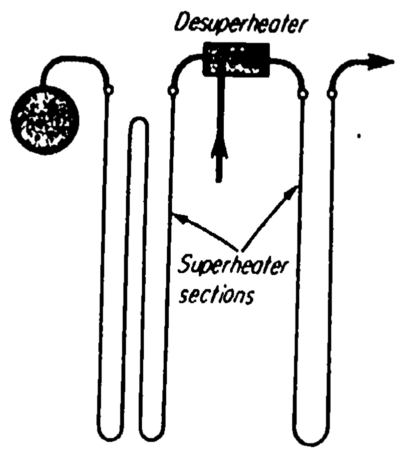


Combustion Gas Bypass
Fig. 27

4. Combustion Gas Recirculation - Fig. 28
At low loads a portion of the combustion gas is recirculated back to the furnace thus increasing the mass of gas flowing over the super-heater tubes and in this way increasing the steam temperature.

5. Desuperheating - Fig. 29

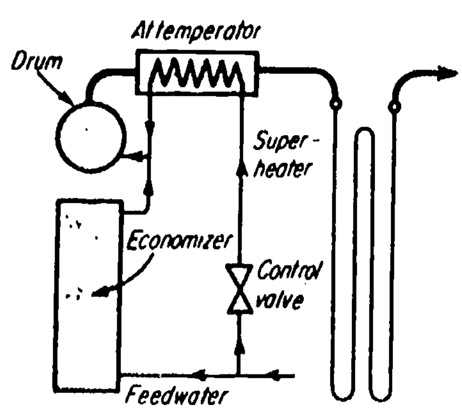
Pure feedwater is sprayed into the superheated steam. This water is converted to steam by absorbing heat from the superheated steam thus lowering the superheated steam temperature.



Desuperheating
Fig. 29

6. Attemperation - Fig. 30

A portion of the steam leaving the drum is condensed by coming in contact with attemperator tubes through which feedwater is passing. This will lower the superheated steam temperature as the condensed portion will require extra heat in superheater in order to vaporize once again.



Attemperation
Fig. 30

ECONOMIZERS

In order to obtain maximum economy in steam generator operation it is necessary to absorb the maximum amount of heat from the combustion gases. The amount of heat that can be absorbed by the steam generating tubes is limited by the temperature of the water within these tubes.

For example, the temperature of the boiler water in the tubes of a steam generator operating at 6000 kPa abs. is approximately 276° C (saturation temperature for 6000 kPa abs). Therefore these tubes will absorb heat from the combustion gas only as long as the combustion gas temperature is above 276° C (heat only travels from the higher temperature substance). This means that the combustion gas leaving the steam generator will be at a temperature greater than 276° C and as a result will still contain a great deal of heat.

In order to recover a portion of this heat, the combustion gases may be passed over a series of tubes through which feedwater travelling to the boiler is passing. This arrangement of tubes is called an economizer. As the temperature of the feedwater entering the economizer is comparatively low (possibly around 90° C) there will be good heat absorption from the combustion gases which may be at a temperature of 288° C or more.

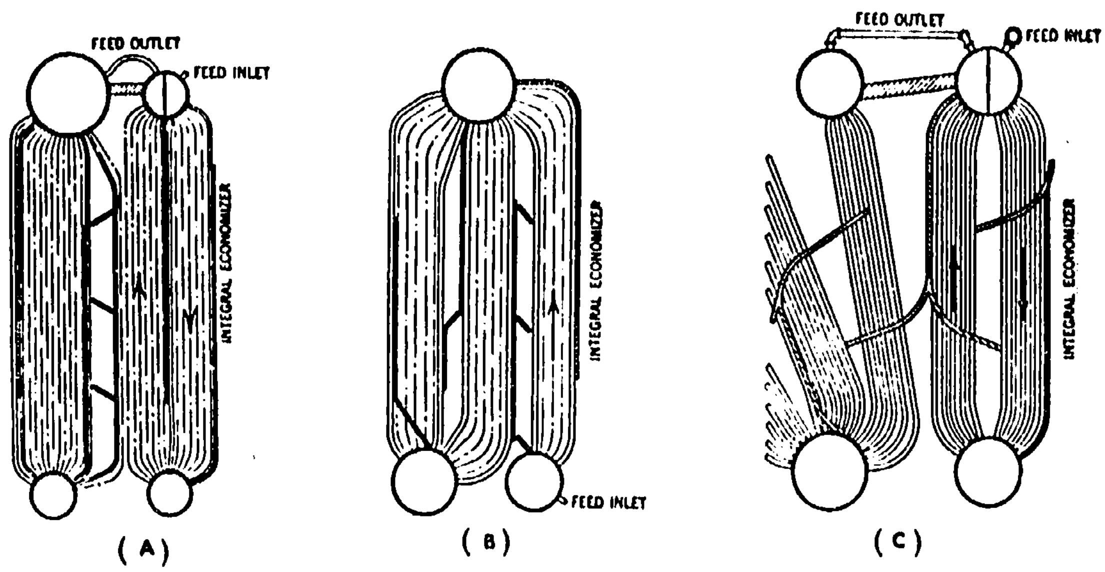
Integral Economizers

The integral type is so-called because the economizer forms an integral part of the boiler. It consists of vertical banks of tubes which run either between the boiler steam drum and an economizer water drum or between two economizer water drums. These tubes are usually located in the last combustion gas pass of the boiler.

Fig. 31(A) shows an integral economizer having two drums. Feedwater enters one side of the top divided drum and flows downwardly through one-half of the economizer tubes to the bottom drum. It then rises up the other half of the tubes to the top drum again and from there to the boiler steam drum.

In the economizer in Fig. 31(B) the water enters a bottom economizer drum and flows upwardly through the economizer tubes to the boiler steam drum.

Another two-drum integral economizer with a divided top drum is shown in Fig. 31(C). The feedwater flow in this type is similar to that in Fig. 31(A).

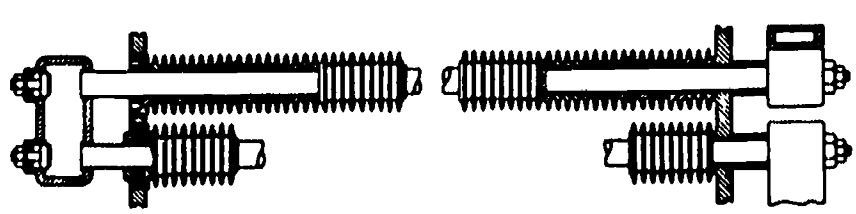


Integral Economizer Types
Fig. 31

Separate Economizers

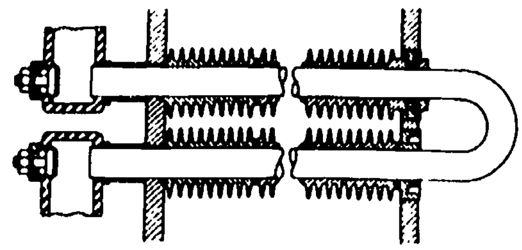
The type of economizer most commonly used today is the separate economizer. This type uses rows of horizontal tubes located outside of the boiler proper. The combustion gases after leaving the furnace are directed over the surface of the economizer tubes and give up some of their heat to the feedwater flowing inside the tubes. Various types of tubes and various methods of connecting tubes may be used.

The arrangement in Fig. 32 consists of straight tubes upon which are shrunk cast-iron fins giving an extended heat transfer surface. The tubes are expanded into headers at each end and the headers have hand-hole openings opposite each tube end for installation, repair and inspection purposes.



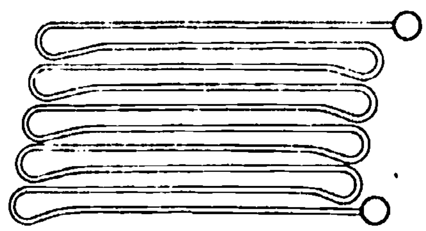
Extended Surface Economizer Tubes
Fig. 32

Fig. 33 illustrates another type of economizer which has extended surface U-bend tubes expanded into headers which have handholes provided for tube installation and maintenance.



U-bend Economizer Tubes
Fig. 33

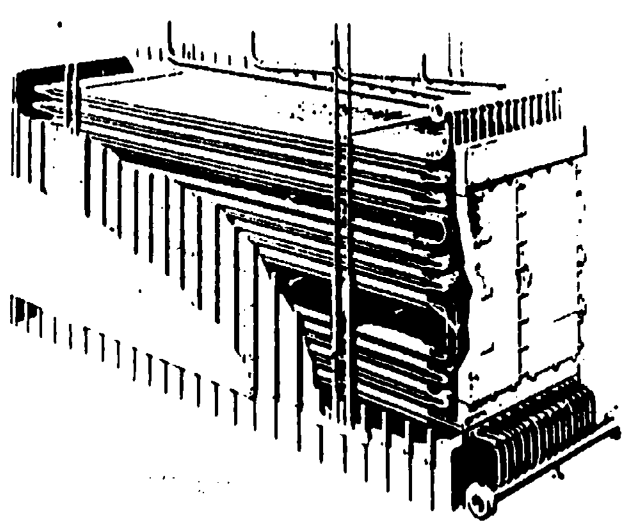
An economizer made up of continuous tubes looped between headers is shown in Fig. 34. Plain tubes without extended surfaces are used here.



Continuous Tube Economizer
Fig. 34

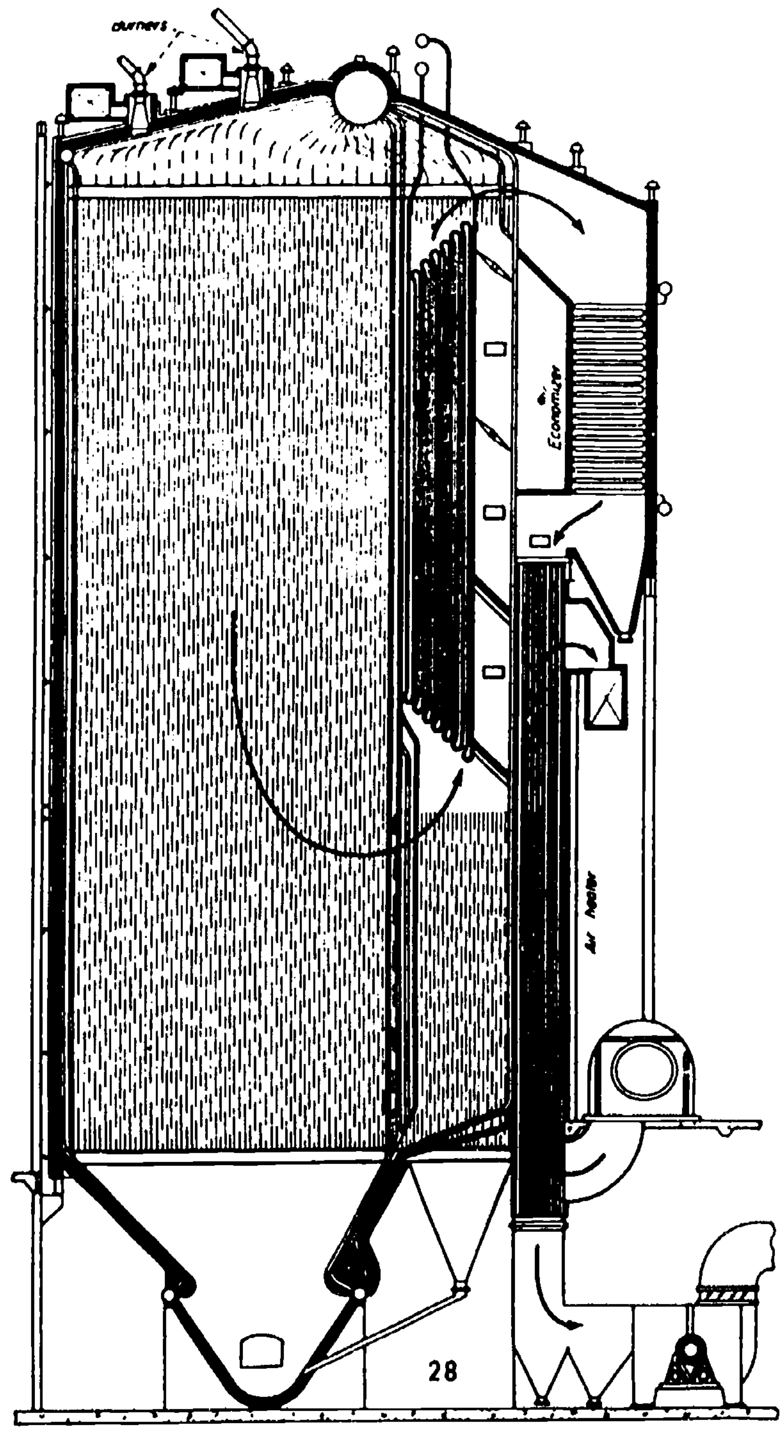
Fig. 35 shows another continuous tube economizer showing use of finned tubes.

Most modern economizers feature horizontal continuous tube design.



Fin Tube Economizer
Fig. 35

The steam generator in Fig. 36 features a continuous tube separate economizer.



Single Drum Steam Generator

Fig. 36

Economizer Advantages and Disadvantages

The greatest advantage of the economizer is increased boiler efficiency due to the fact that heat is recovered from the flue gases that would otherwise be lost up the stack or chimney. Another advantage of using an economizer is that there is less thermal shock to the boiler drum if the entering feedwater has been heated than if cold feedwater was admitted to the drum.

The disadvantages of an economizer are as follows:

1. It provides increased resistance to flue-gas flow and therefore increased fan power is required with an economizer.

2. Greater feedwater pumping is required as the economizer provides increased resistance to feedwater flow.

3. Corrosion of both internal and external surfaces of the economizer may be a problem.

4. Both internal and external surfaces of the economizer must be kept clean to provide the increased efficiency.

AIR HEATERS

Another method of recovering heat from the flue gases, in addition to using an economizer, is by the use of an air heater. The air heater, often called an air preheater, consists of a heat exchange surface located in the path of the combustion gases usually between the economizer and the stack. In the air heater, the flue gases travelling to the stack heat the air required for combustion on its way to the burners. In this way not only is heat recovered from the flue gases but combustion efficiency is improved due to the heated air.

Air heaters may be divided into two general classes: the recuperative type, and the regenerative type.

Recuperative Air Heaters

In the recuperative type of air preheater the heat from the flue gases passes through a plate or a tube wall to the air on the other side.

1. Plate Air Heater

This type of recuperative air heater consists of a series of flat thin parallel plates which form a number of narrow passages. The flue gas and the air pass through alternate passages in opposite directions (counterflow) and the heat from the flue gas passes through the plate metal to the air in contact with the other surface of the plate.

Due to the difficulty in cleaning the plates and replacing them when they become corroded, this type is not generally used in modern plants.

The general construction of the plate air heater is shown in Fig. 37.

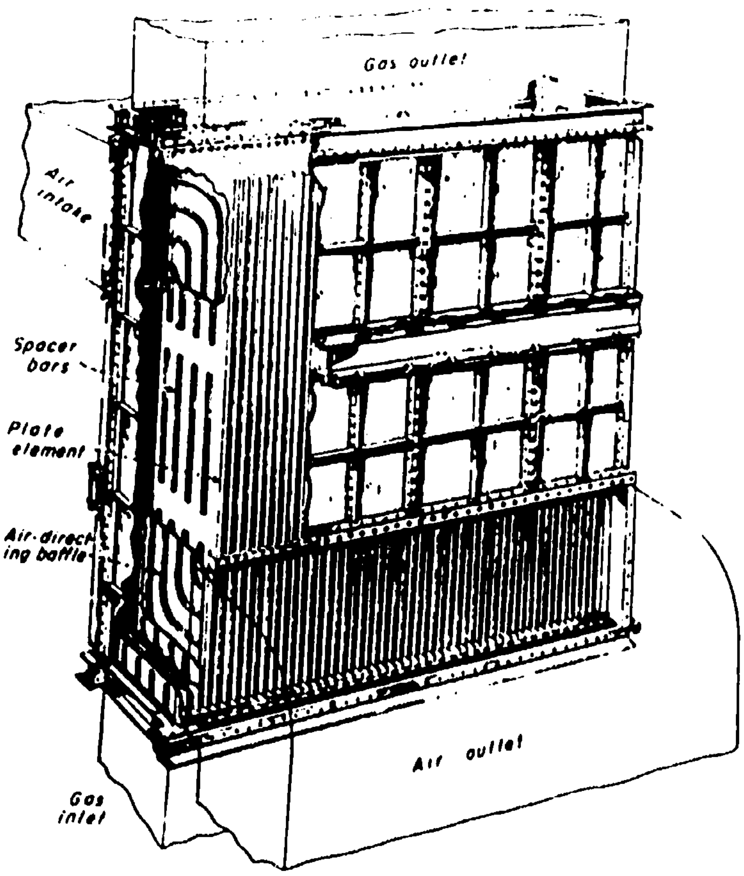


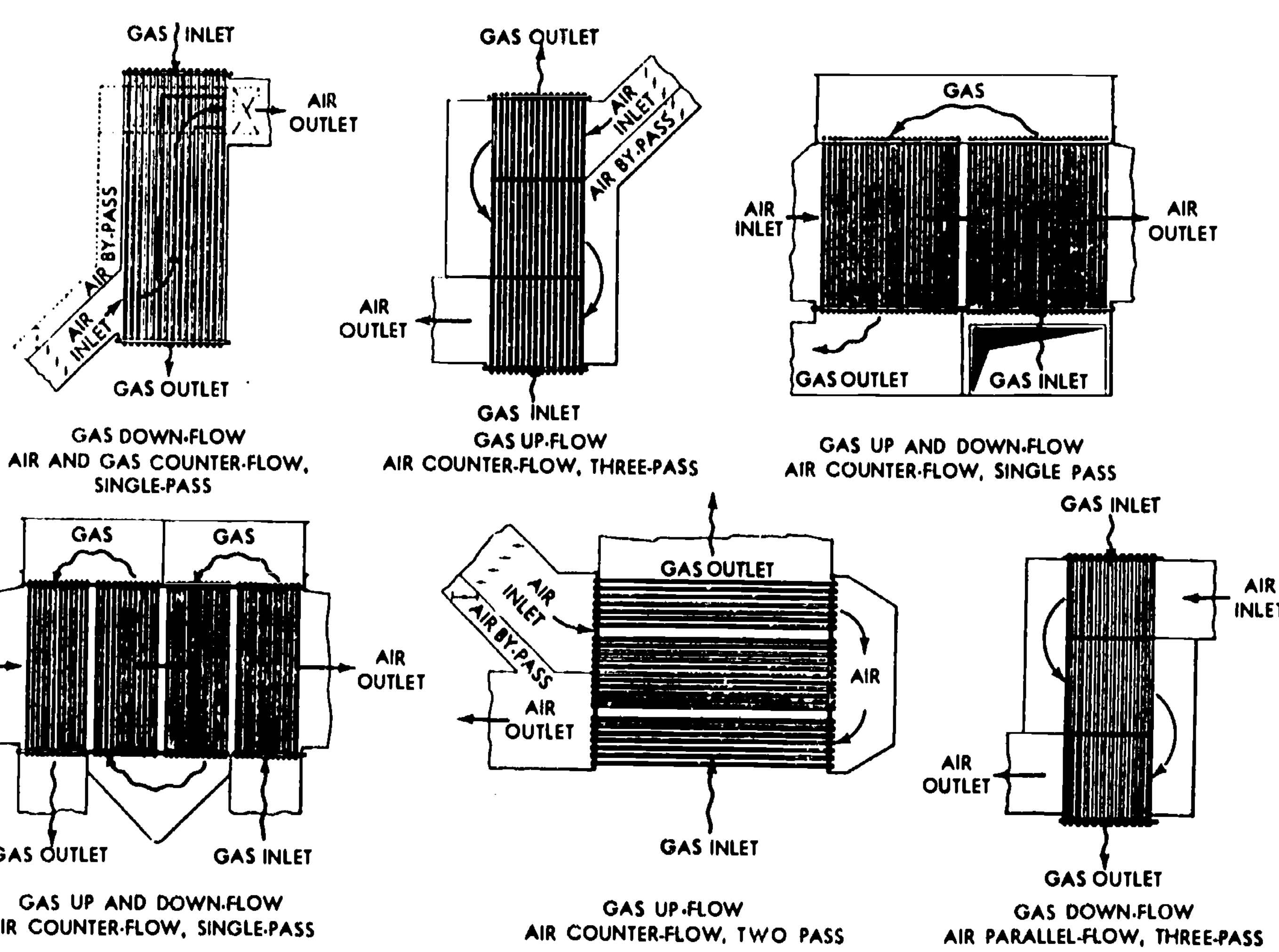
Plate Type Air Heater
Fig. 37

2. Tubular Air Heater

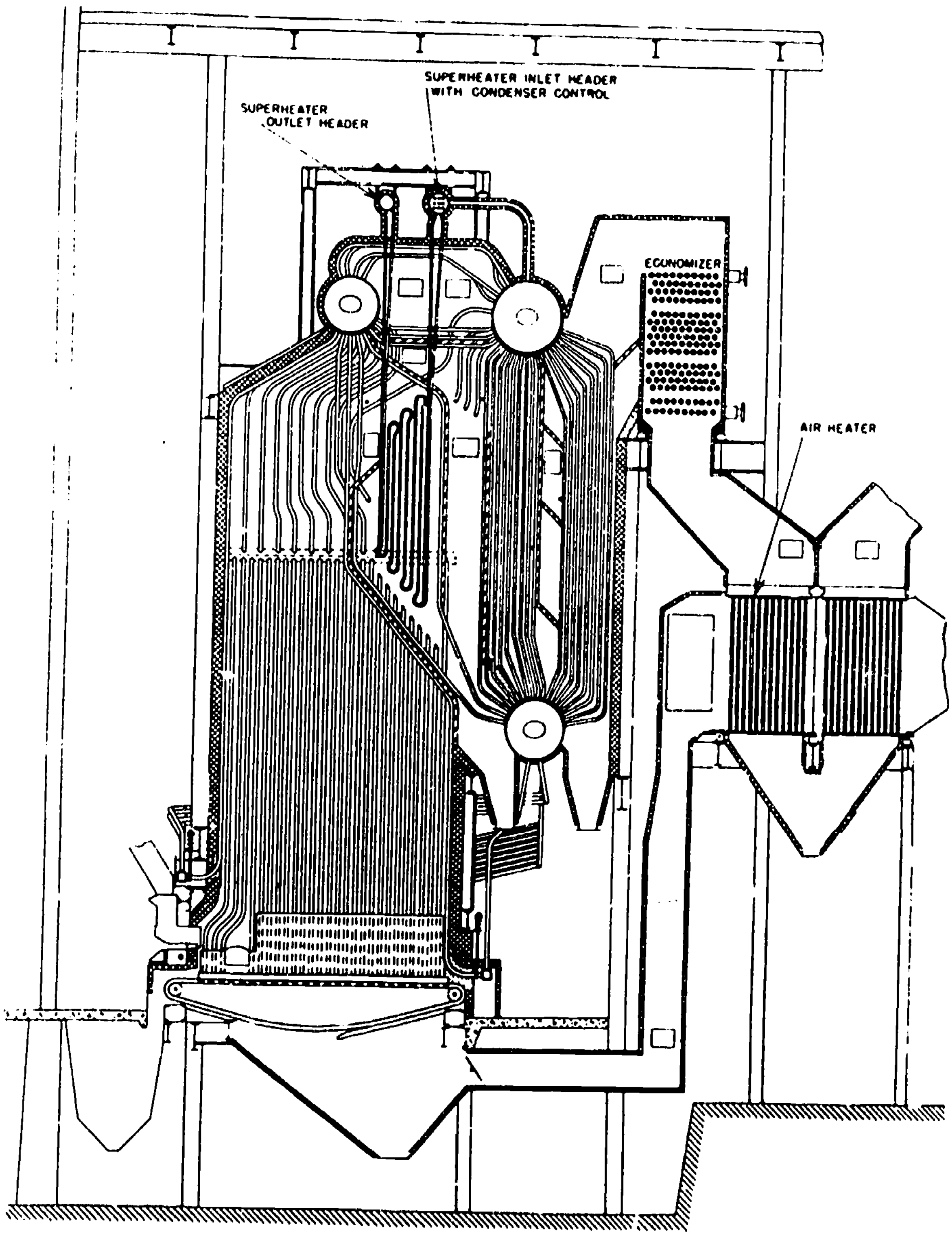
This recuperative air heater is made up of long straight steel or cast-iron tubes which may be arranged either horizontally or vertically within the heater casing. The horizontal tube design has the air required for combustion passing through the tubes while the hot flue gases pass over the outside of the tubes. In the vertical tube design, it is usual to have the hot gas passing through the tubes with the air passing over the outside surfaces of the tubes. Baffles are placed within the air heater to direct the air across the tubes in a number of passes.

Fig. 38 shows several designs of tubular air heaters having various arrangements of gas and air flows.

The steam generator illustrated in Fig. 39 has a tubular air heater with flue gases passing through vertical tubes. This air heater features a two-pass arrangement for the flue gases, with them leaving the economizer and passing downwardly through one set of air heater tubes and then reversing and passing upwardly through another set of tubes. The air travels in a horizontal direction across the surface of the tubes.



Tubular Air Heater Arrangements
<u>Fig. 38</u>



Steam Generator with Economizer and Tubular Air Heater

Fig. 39

Regenerative Air Heaters

In a regenerative air heater, a mass of metal or other material is first heated by coming in contact with hot gases. The mass, which usually consists of a number of metal sheets called heating elements, is then removed from contact with the hot gases and brought in contact with the air to be heated. In this way heat is transmitted from the mass to the air.

The type of regenerative air heater used in power plants is a rotary heater and is described in the following section.

Rotary Regenerative Air Heater

This air heater is made up of a casing within which rotates a rotor. The rotor consists of a number of baskets containing thin corrugated metal sheets placed closely together. The casing above and below the rotor is divided into two sections. The hot flue gas travels through one section in one direction and the air to be heated travels through the other section in the opposite direction.

As the rotor slowly turns, the baskets containing the corrugated heating elements pass through the hot gas stream and then through the cold air stream alternately. In this way the elements absorb heat from the gas and then give up this heat to the air. The elements are arranged to be edge-on to the flow of both gas and air which allows the flow to take place between the closely spaced elements. Leakage of gas and air is largely prevented by means of radial and circumferential seals mounted on the rotor.

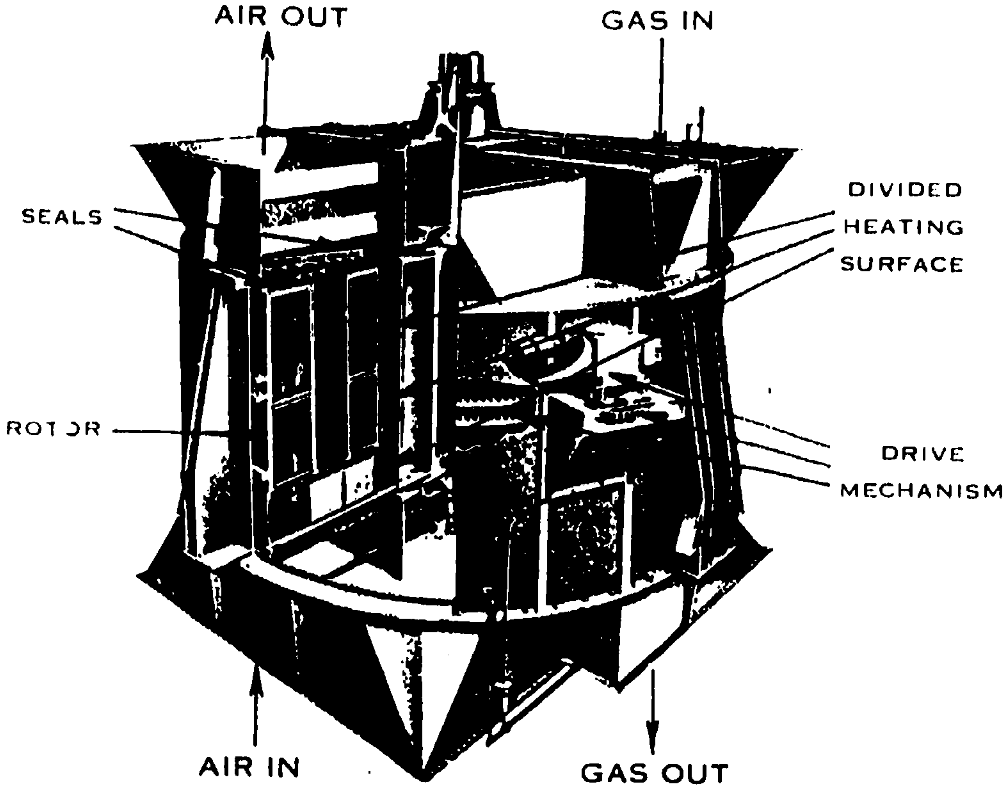
The rotor is driven at about 3 rpm by a small electric motor through a gearing arrangement. The power required will not usually exceed 3 hp.

Fig. 40 shows a rotary air heater with the gas and air flows indicated.

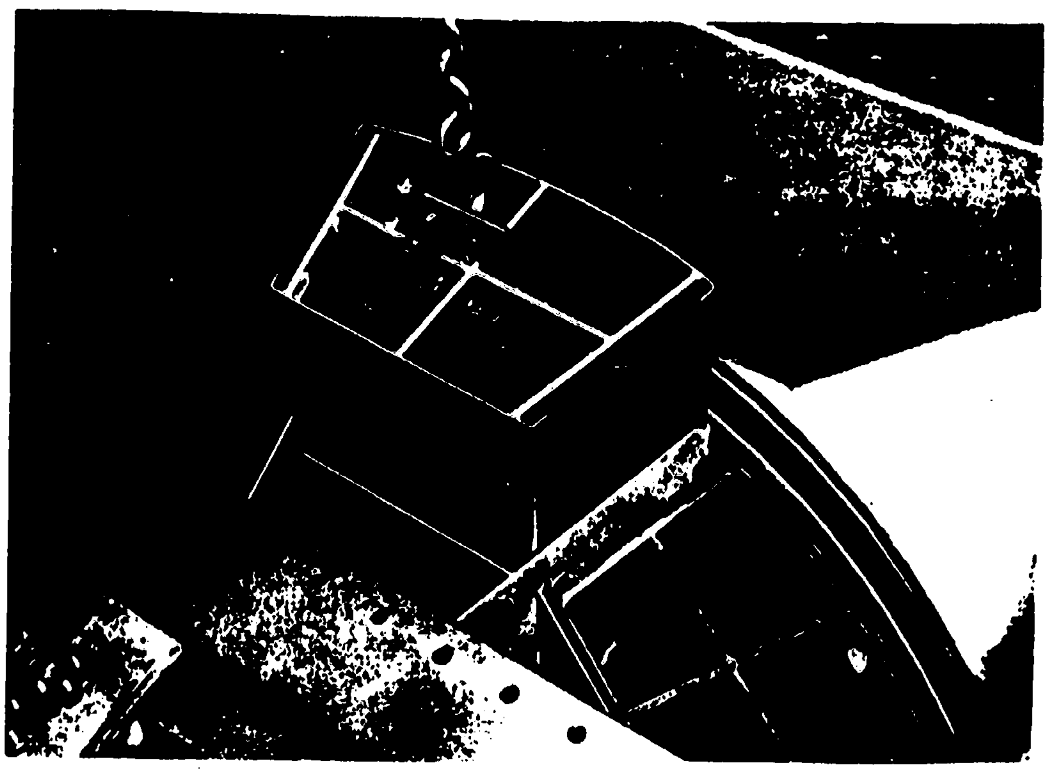
In Fig. 41 the insertion of a heating element basket is illustrated and the closely spaced elements within the basket can be clearly seen.

The rotary regenerative air heater may be arranged in either a vertical or horizontal manner. Fig. 42 shows a steam generator with the air heater arranged so that the flow of gas and air is in a vertical direction.

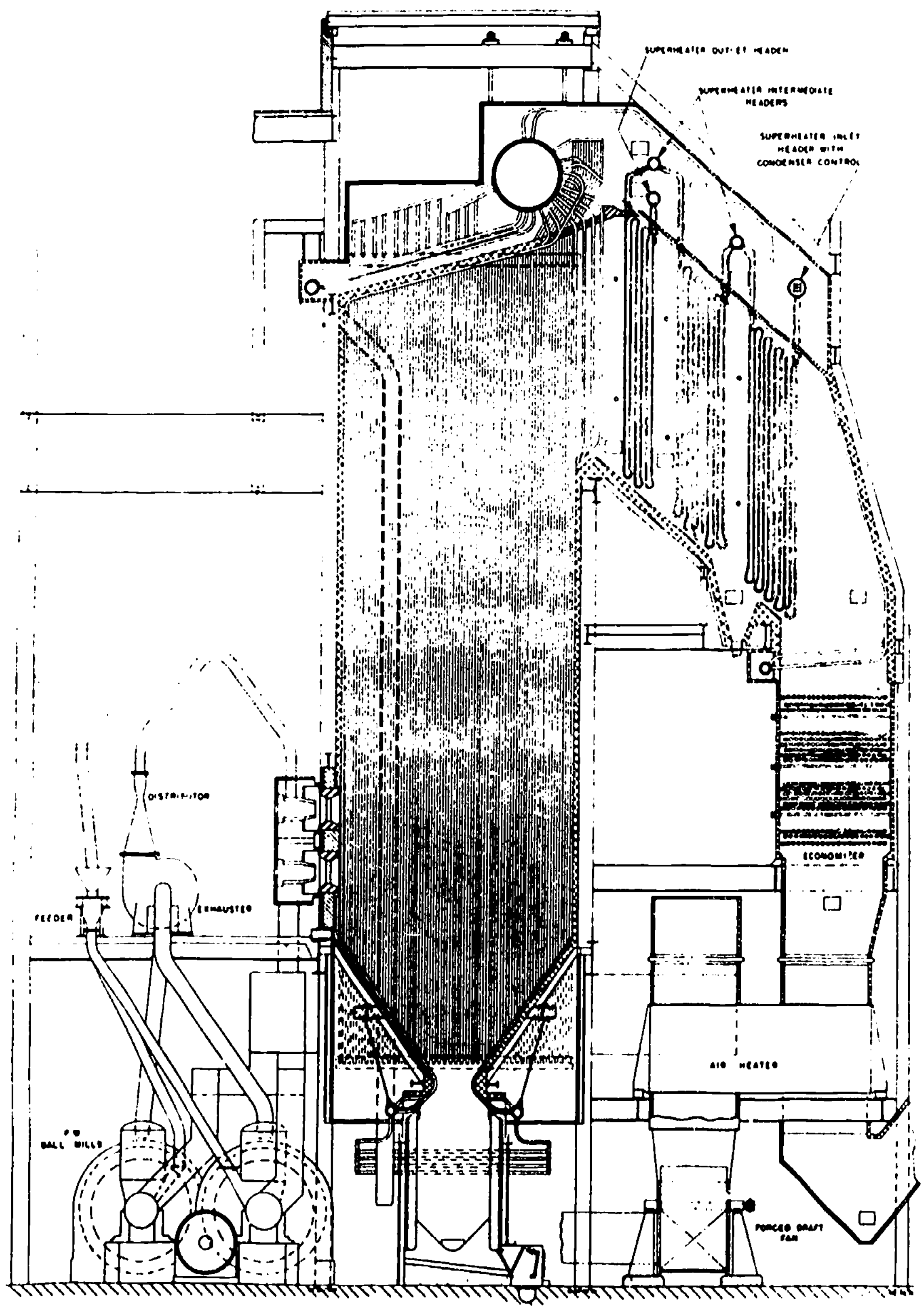
The steam generator in Fig. 43 has the air heater arranged so that the gas flows are in a horizontal direction.



Rotary Regenerative Air Heater
Fig. 40

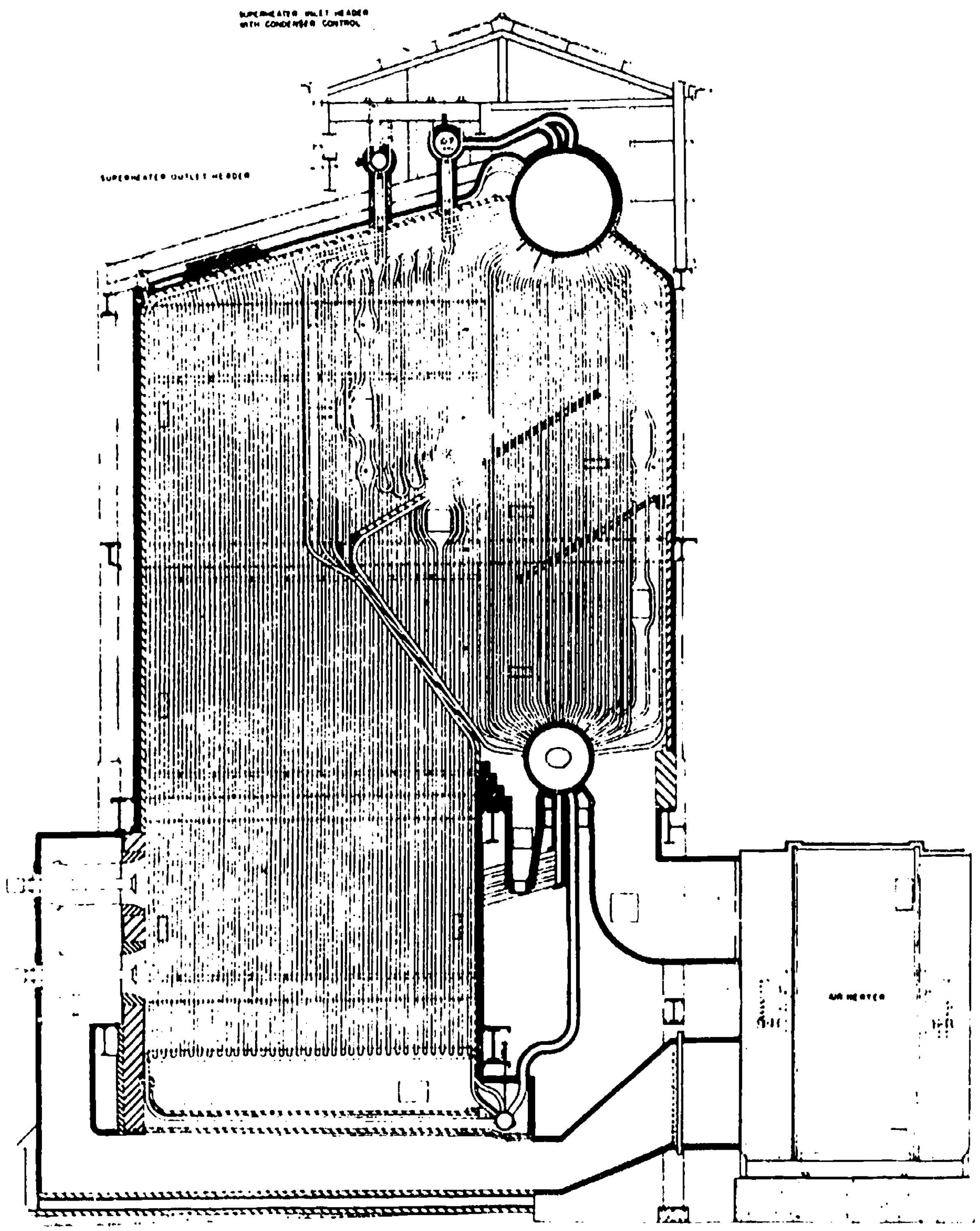


Heating Elements for Rotary Heater
Fig. 41



Steam Generator with Vertically Arranged Air Heater

Fig. 42



Steam Generator with Horizontally Arranged Air Heater

Fig. 43

Air Heater Corrosion

Boiler fuels usually contain some amount of sulphur and therefore the flue gases will contain sulphur compounds. If the temperature of the flue gas is reduced to a certain point (dew point) then sulphuric acid will condense and form on the air heater surfaces resulting in corrosion of these surfaces. This corrosion will occur at the cold end of the air heater, that is, the gas outlet - air inlet end in a counterflow unit.

Various methods are used to eliminate or reduce this corrosion and these methods usually involve keeping the temperature of the gas leaving the heater above the dew point. A method sometimes used is to recirculate heated air from the heater outlet to the heater inlet. Another method is to bypass a portion of the cool inlet air around the air heater with the bypassed air mixing with the heated air at the heater outlet. Several of the arrangements in Fig. 38 feature this methcd A less common method is to increase the temperature of the air by means of steam coils before the air enters the heater.

The rotary regenerative air heater is so designed that the heating element baskets in the cold end region of the heater may be quickly and easily replaced as it is these baskets that are subject to the most corrosion.

Air Heater Advantages and Disadvantages

As mentioned previously the advantages of using an air heater are increased boiler efficiency due to heat recovered from flue gases and increased combustion efficiency due to the use of heated air.

The air heater, however, has certain disadvantages as well. Fans must be used to assist the flow of both air and flue gas through the heater and power is necessary to drive these fans. Maintaining the air heater may also be a problem due to ash deposits within the passages and corrosion of the heat transfer surfaces.

QUESTION SHEET

1. Describe the method of support used for any boiler in your plant or for any boiler with which you are familiar.

2. Describe two different types of construction used for brick-work settings.

3. List the advantages of a water-cooled setting as compared to a brickwork setting.

4. Sketch and describe one type of tube wall used in a water-cooled setting.

5. (a) Explain the purpose of a superheater and why it is used.

   (b) Explain the purpose of a reheater and why it is used.

6. (a) What is meant by the terms radiant superheater, convection superheater and combination superheater?

   (b) Describe the steam temperature characteristics of the types in (a).

7. What are the advantages and disadvantages of separately fired superheaters?

8. Describe three different methods of controlling superheated steam temperature.

9. A factor which limits the amount of heat that can be absorbed by steam generating tubes is the temperature of the water within the tubes. Explain how this affects the efficiency of a boiler and describe a method used to increase the amount of heat absorbed by the boiler water.

10. List the advantages and disadvantages of:
    (a) economizers,
    (b) air heaters.

7.8

BOILERS -- INSTRUMENTS AND CONTROLS

Goal:

The student will be able to describe the instruments and controls for boiler operation.

Performance Indicators:

1. Describe measuring devices.
2. Describe controllers, transmitters and actuators.
3. Describe feedwater control systems.
4. Describe combustion control systems.
5. Describe steam temperature control systems.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheet.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Actuator
* Bellows gauge
* Bi-metallic thermometer
* Bourdon tube
* Controller
* Diaphragm pressure gauge
* Float cage
* loat manometer
* Float weight device
* Flow nozzle
* Flow transmitter
* On-off controller
* Orifice plate
* Positioner
* Pressure transmitter
* Proportional controller
* Proportional plus integral (reset) controller
* Proportional plus reset plus derivative controller
* Remote indicating bulb thermometer
* Single element control
* Temperature transmitter
* Thermocouple
* Thermo-electric pyrometer
* Thermo-hydraulic system
* Thermo-expansion regulator
* Transmitter
* Two element control
* Three element control
* Venturi tube

Introduction

The safe and efficient operation of a steam generation plant is dependent upon the proper control of temperature, pressure, levels and flow of air, fuel, water and steam. This can only be accomplished with the help of control equipment that shows the operator what is happening inside the boiler.

These vairables must be measured and that measurement must be shown in a dial or gauge that is visible to the operator. This package is designed to acquaint apprentices with the measuring instruments and how the measurements reach the dials and gauges.

Information

The instrumentation and control devices must measure such things as temperature, pressure, fluid flow and fluid levels. Other control devices monitor feedwater, combustion and steam temperature.

Measurement Devices

Temperature Measurement Devices

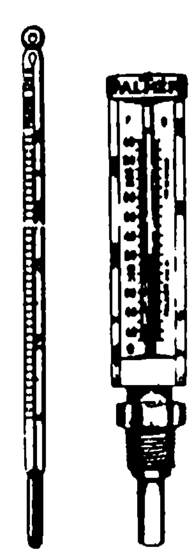
Heat transfer involves changes in temperature. The following items must have temperature control and thus must be measured regularly.

1. Steam
2. Feedwater
3. Oil
4. Cooling water
5. Flue gas

There are many types of instruments for measuring temperature. These include:

1. Glass stem thermometers
2. Remote indicating bulb thermometers
3. Bi-Metallic thermometers
4. Thermo-electric pyrometer

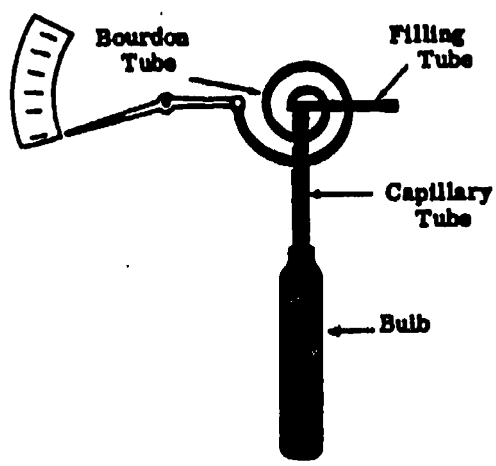
The glass stem thermometer operates with a column of mercury or alcohol in a glass tube. Mercury filled thermometers are suitable for high temperatures. Alcohol filled thermometers are best suited to low temperatures.



Glass-stem Thermometers

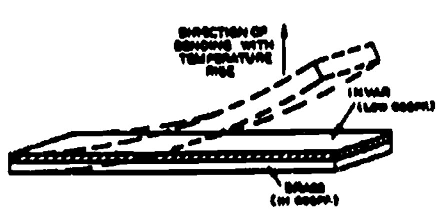
Information

A remote-indicating bulb thermometer is used to record temperatures away from the site of measurement. This thermometer is made of a Bourdon tube, a capillary tube and a bulb. Changes inside the tube cause the Bourdon tube to expand or contract. The Bourdon tube is attached to an indicator arm.



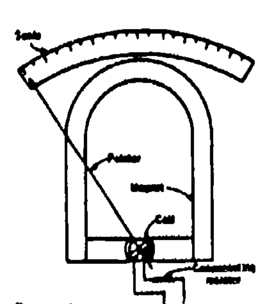
Remote Bulb Thermometer

Bi-metallic thermometers are made of thin metal strips of different metals. The metals expand at different rates because of differences in metallurgical properties of the two metals. As the metals are welded together, expansion causes a bending action which moves the indicator. Brass and an iron nickel alloy are commonly used as metal strips.



Bimetal Strip

A thermo-electric pyrometer is actuated by a thermo-couple which responds to temperature change by increasing or decreasing its voltage output.



Thermoelectric Pyrometer

Information

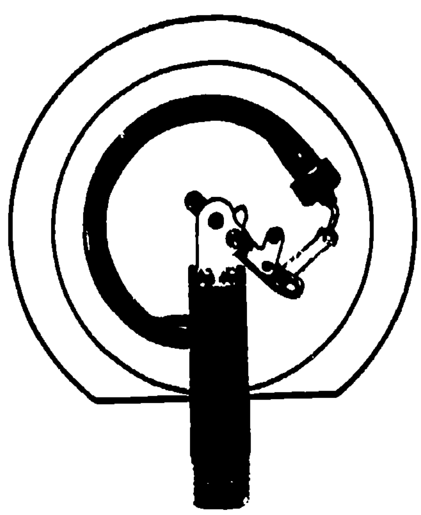
Some of the common pressure measurements are:

1. Steam
2. Feedwater
3. Furnace
4. Condenser
5. Oil

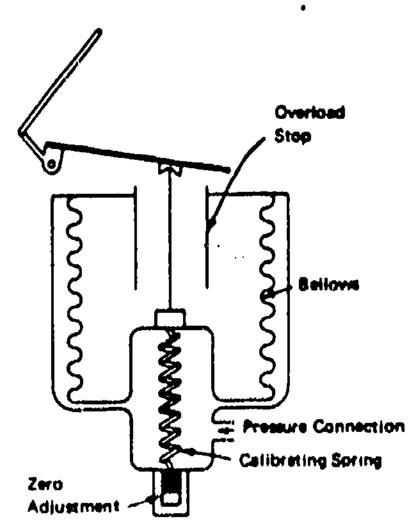
The devices used to measure pressure include:

1. Bourdon tubes
2. Bellows pressure gauge
3. Diaphragm pressure gauge

The Bourdon tube is shaped in the form of a C, spiral or helix. The open end of a Bourdon tube is attached by a linkage mechanism that moves an indicator. Increases in pressure cause the tube to straighten and move the indicator.



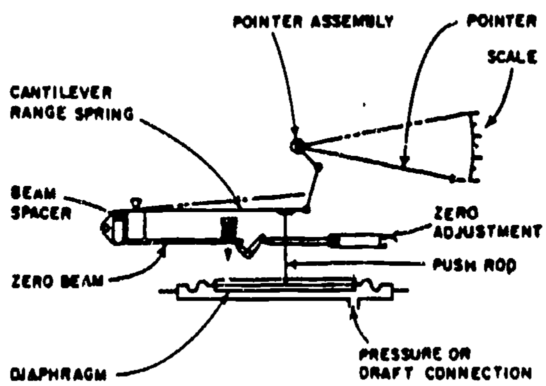
A bellows pressure gauge is a corrugated chamber that expands along its length. Pressure on the bellows causes expansion. This expansion moves a linkage to the indicator which registers change in pressure.



Bellows Pressure Gage

Information

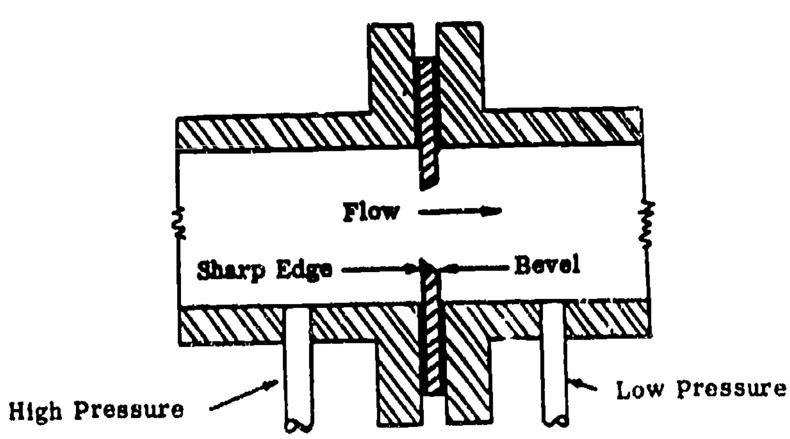
The diaphragm pressure gauge utilizes a liquid filled u-tube that is connected to the pressure sources at one end. The other end of the u-tube is connected to the atmosphere. The difference in pressure at the two ends of the u-tube is measured. Pressure on the diaphragm moves one side of the u-tube which, in turn, moves the indicator arm.



Diaphragm Pressure Gage

Flow Measurement Devices

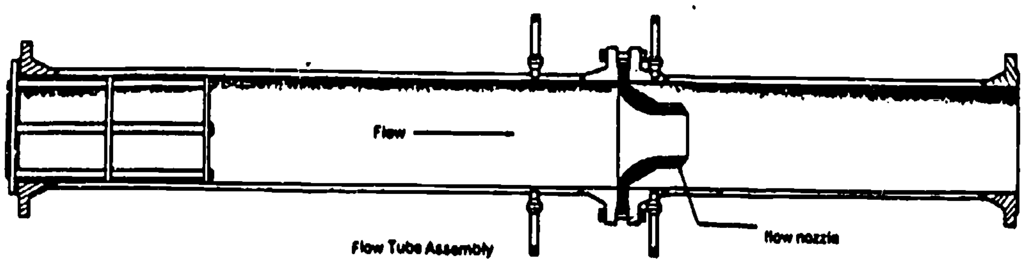
The rate of flow must be measured for steam, feedwater, fuel and air. Flow is measured by measuring pressure drops across a constriction within the pipe. A constriction increases velocity and decreases pressure of the substance flowing through a pipe. In measuring the flow of steam an orifice plate is used as a means to constrict flow.



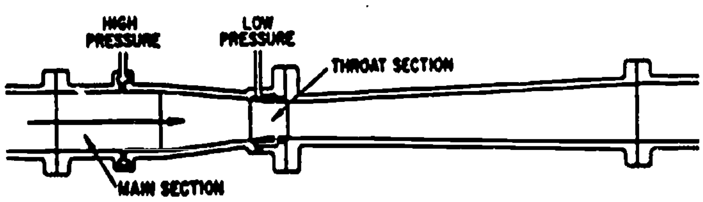
Orifice Plate with Pressure Taps

Information

Liquid flow uses a flow nozzle or venturi tube to constrict the flow for measurement.



Flow Nozzle



Venturi Tube

The actual measurements are made with pressure measuring devices. The flow is proportional to the square root of the pressure drop at the constriction.

Level Measurement Devices

Devices are needed to measure the levels of liquids such as:

1. Boiler water
2. Storage tanks
3. Fuel tanks
4. Condenser hot well

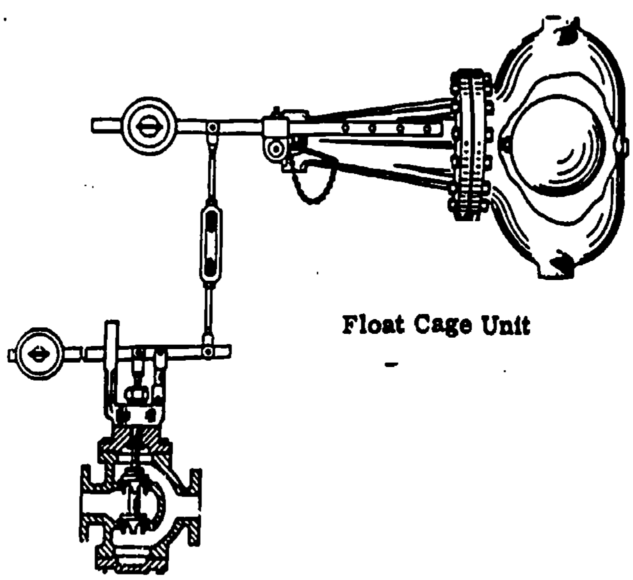
The devices most commonly used to measure levels include:

1. Gauge glasses
2. Float weight device
3. Float cage
4. Differential pressure gauge

Information

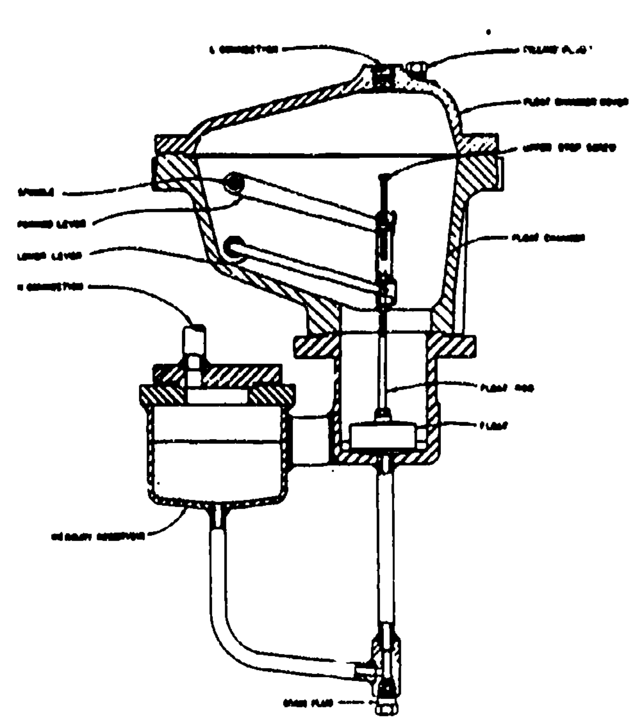
The gauge glass has been discussed in detail in other packages. Float weight devices use floats inside the tank which are attached to a scale device outside. The float moves up and down with the water level and changes the measurements on the scale.

Float cage units are attached to a container on the outside. It is connected to the liquid near the bottom of the tank and to the vapor space above the liquid. As the levels change, the float moves up and down. The level is measured on an indicator scale.



Float Cage Unit

The float manometer is a differential pressure gauge. The manometer is attached to the top of the vessel. A mercury reservoir responds to the rise and fall of liquid in the vessel. The movement of the mercury moves a float which actuates the indicator.



Float Type Manometer

Information

Controllers, Transmitters and Actuators

A control system consists of three main parts:

1. Controller
2. Transmitter
3. Actuator

Controllers

Controllers sense changes in such things as pressure, temperature and levels and send the signal on to an actuator which can charge dials and open valves. The controller must have a sensing device and a signalling device. The signal device may be operated by electrical signal or by pneumatics. Some common controllers are:

1. On-off controller are set to measure above or below a set point. A flapper is held against a nozzle for maximum settings and away from the nozzle for minimum settings.

2. Proportional controllers measures how much a measurement is above or below the set points. These controllers have some problems with offset. Offset is the difference between new corrected valves and the set point valves.

3. Proportional plus integral (reset) controller offset problems can be avoided by adding an adjustable restriction and positive feedback bellows to the controller. The feedback bellows serves as a reset that brings measurements back to set point.

4. Proportional plus reset plus derivative controller has, in addition to the reset feature, a controller with a rate action or derivative feature. This feature consists of a restriction in the airline to the feedback bellows. A rate action feature causes a quick return to the set point and the final controls move further in the required direction.

Transmitters

A transmitter measures the signal produced by the controller and converts the signal into transmission signals. The transmission signals are sent to the controller and indicators. Some transmitters contain sensing devices rather than the controller. Transmitters operate on pneumatic or electronic signals.

Information

Transmitters may be classified as:

1. <u>Pressure transmitters</u>
2. <u>Flow transmitters</u>
3. <u>Level transmitter</u>
4. <u>Temperature transmitter</u>

The pressure transmitter uses a sensor of the Bourdon, bellows or diaphragm types. The transmitter is arranged in a flapper-nozzle assembly. They operate on pneumatic or electronic signals.

Flow transmitters use the orifice plate to restrict the flow and produce a pressure drop. A bellows type sensor measures the pressure drop.

A level transmitter uses a float device to move the flapper. A feedback bellows is used to keep the signal output proportional.

Temperature transmitters use a Bourdon tube to move the flapper in relation to the nozzle.

<u>Actuators</u>

Actuators receive signals from the controller and change them into mechanical motion. The pneumatic or electronic signals are changed into mechanical energy for opening valves, dampers, etc. Actuators may be classified according to the signals that they receive--pneumatic or electronic. Another way to classify actuators is by the type of motion they produce--rotary or linear. A <u>positioner</u> may be used to amplify the control signal at low pressures and using high pressure air to move the actuator.

<u>Control Systems</u>

<u>Feedwater Controls</u>

Feedwater control systems may be classified as:

1. Thermo-hydraulic
2. Thermo-expansion
3. Single element
4. Two element
5. Three element

Information

The thermo-hydraulic system has a feedwater regulating valve which is actuated by a generator. An outer tube of the generator is connected to the feedwater regulating valve and the bottom. At the top, both inner and outer tubes are connected to the steam and water. Heat from steam in the inner tube cause the water in the outer tube to flash into steam. This forces water into the bellows which controls the opening and closing of the feedwater valve.

Thermo-expansion regulators are a tube mounted on a beam and attached to the steam and water space. As water level drops in tube, its temperature is raised by the steam on its outside. The increased heat expands the tube and actuates the feedwater regulating valve.

Single element control has a drum level transmitter signal differences between drum levels and the set point. This system is used where slow changes are made in the feedwater load. Single element control only responds to teh drum level variable.

Two element controls use a system that responds to both drum level and steam flow. The drum level measurement balances water input with steam output. Steam flow measurements proportions water according to the steam flow.

Three element controls measure steam flow, feedwater flow and drum level.

Combustion Control Systems

The flow of fuel and air must be regulated to get good combustion. The ratio of fuel to air must be maintained for combustion efficiency. There are three types of combustion controls:

1. On-off controls
2. Positioning controls
3. Metering controls

The on-off control system consists of a bellows operated switch which is activated by boiler pressure. A drop in pressure will start the fans and burner. This system is inefficient because of the variation of boiler pressure between "cut in" and "cut out" points.

Positioning control involves actuators that position the draft dampers and fuel valve according to the boiler load. A positioning control is operated by a master controller that signals the actuators for dampers and full valve.

Information

Metering control use a master controller to signal the damper and fuel valve actuators. In this case, the signals are based on measured or metered amounts of fuel and air.

Steam Temperature Control

The temperature of superheated steam must be constant for turbine efficiency. Several methods of steam temperature control are discussed in other packages in more detail. These methods of temperature control are:

1. Combustion gas bypass which routes combustion gases around the superheater to avoid overly high temperatures.

2. Combustion gas recirculation which recirculates combustion gases over the superheater tubes to rais temperatures.

3. Desuperheating by spraying feedwater into the superheated steam to lower temperature.

4. Tilting burners to vary temperature by tilting burners upward or downward.

5. Twin furnaces used on separately fired superheaters that allows temperature control.

6. Attemperation lowers steam temperature by passing it over attemperator tubes and condensing it.

A three element control for steam temperature uses an attemparator with signals from three sources. The signals come from the steam or air flow meter, the thermal element in the attemperator nozzle and a thermal element in the second stage superheater. The final steam temperature is determined by the thermal element in the second stage superheater.

Assignment

* Read pages 1 - 43 in supplementary reference. Study diagrams and illutrations.

* Complete the Job Sheet.

* Complete the self-assessment and check answers.

* Complete the post-assessment and ask the instructor to check your answers.

Job Sheet

ANALYZE MEASUREMENT DEVICES

* Obtain devices for measuring temperature, pressure, levels and flow.

* Carefully inspect them one at a time.

* Do the measuring instruments fit the classificaitons given in this learning package?

* Do you understand the principle of their operation?

* Read manufacturers specifications and diagrams to enhance your understanding of these devices.

Self Assessment

Indicate what the following devices are used to measure. Show by placing a code letter in the space at the front of the device. Pressure (P), Temperature (T), Flow (F), Level (L)

_____ 1. Venturi tube

_____ 2. Bourdon tube

_____ 3. Gauge glass

_____ 4. Glass stem

_____ 5. Float cage

_____ 6. Orifice plate

_____ 7. Remote indicating bulb

_____ 8. Bellows gauge

_____ 9. Thermo-electric pyrometer

_____ 10. Diaphragm gauge

Self Assessment Answers

F 1.

P 2.

L 3.

T 4.

L 5.

F 6.

T 7.

P 8.

T 9.

P 10.

Post Assessment

Please show these devices as controllers, transmitters or actuators by placing (C) for controller, (T) for transmitter or (A) for actuator in the blank space.

____ 1. On-off type

____ 2. Level

____ 3. Proportional plus integral reset

____ 4. Flow

____ 5. Temperature

____ 6. Pressure

____ 7. Rotary

____ 8. Linear

____ 9. Pneumatic

____ 10. Electronic

Instructor Post Assessment Answers

___C___ 1.

___T___ 2.

___C___ 3.

___T___ 4.

___T___ 5.

___T___ 6.

___A___ 7.

___A___ 8.

___A___ 9.

___A___ 10.

Supplementary References

* Correspondence Course. Lecture 11, Section 2, First Class. Steam Generator Controls. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

14.3

12.8

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 2

STEAM GENERATION

First Class
Lecture 11

STEAM GENERATOR CONTROLS

In order to ensure safe, economical, and reliable operation of the steam generator, instruments and controls are necessary. The boiler outlet conditions such as steam flow, pressure, and temperature must be measured and the quantities of fuel, air, and water must be adjusted to maintain the desired values of the outlet steam conditions. This measuring and adjusting must be done continuously during the time the boiler is in operation. The subject of the instrumentation and control necessary to perform the measurement and adjustment is of necessity quite complex and extensive and its coverage in this course must be limited to not much more than basic concepts.

METHODS OF MEASUREMENT

In measuring the values of the variables involved in the power plant operation, many different types of instruments may be used, not only to indicate the measured value, but also to record the value, usually continuously, on a chart. The instruments are also often used to send signals to control certain flows.

The measuring instruments may be located directly at the point where the measurement is being taken or they may be located remote from the measurement point, for example, in a central control room.

Some of the more commonly used designs of measuring instruments are described in the following sections.

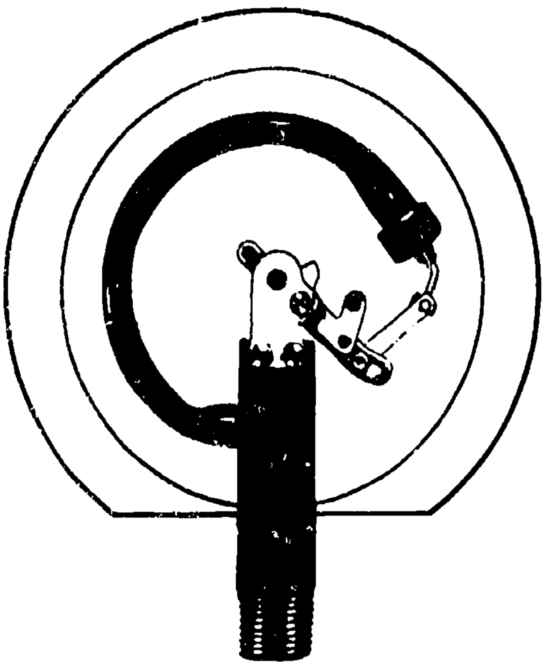
1. PRESSURE MEASUREMENT

Pressure is one of the most commonly measured variables in power plant operation. These pressure measurements include steam pressure, feedwater pressure, furnace pressure, condenser pressure, lubricating oil pressure and many others.

The Bourdon tube, the bellows, and the diaphragm are three devices commonly used to measure pressure. Another device which is sometimes used is the liquid or mercury filled U-tube used for low pressure work.

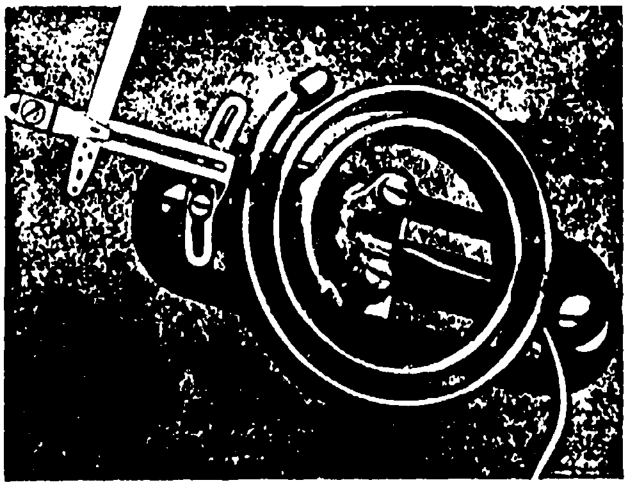
The Bourdon tube may be in the form of a C, a spiral, or a helix. In each case a hollow flattened or oval shaped tube is used sealed at one end. The open end is fixed and is connected to the source of pressure while the sealed end is free to move. Pressure tends to straighten the tube and the movement of the free end is a measure of the pressure.

The Bourdon tube types are illustrated in Figs. 1 to 3 inclusive.



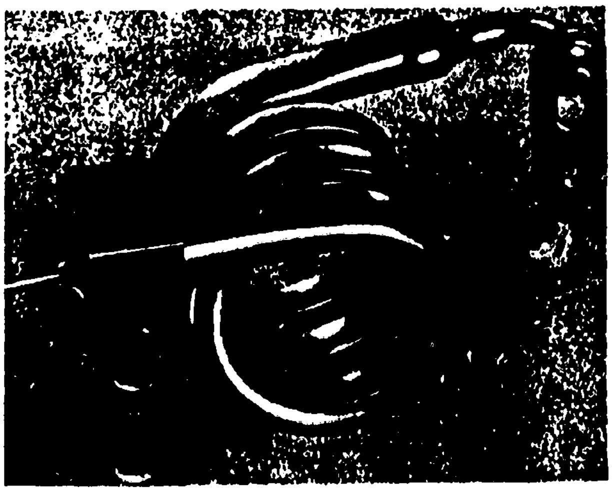
C Bourdon Tube

Fig. 1



Spiral Bourdon Tube

Fig. 2



Helix Bourdon Tube

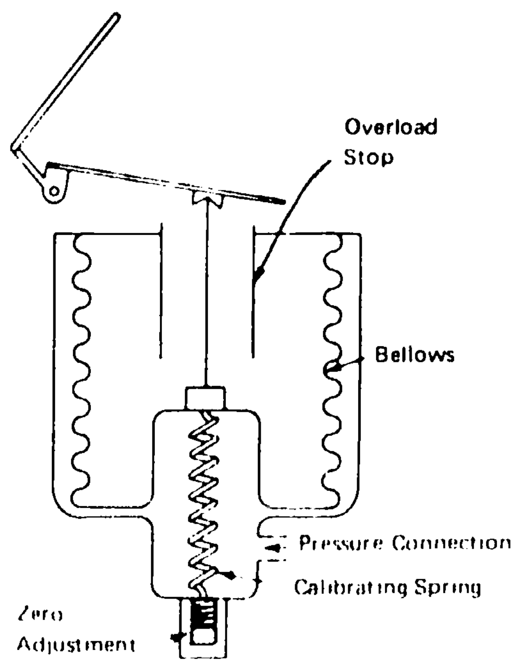
Fig. 3

(PE1-2-11-2)

The bellows consists of a chamber which is corrugated in such a way that it will expand or contract in the direction of its length rather than in the direction of its side walls.

The pressure to be measured may be applied to the inside of the bellows, in which case it will expand or elongate. Conversely the pressure may be applied to the outside of the bellows causing it to contract or shorten. The bellows may also be used to measure the difference between two pressures by applying one pressure to the inside of the bellows and applying the other pressure to the outside of the bellows.

Fig. 4 is a sketch of a bellows type pressure gage in which the pressure to be measured is between the bellows and the case.

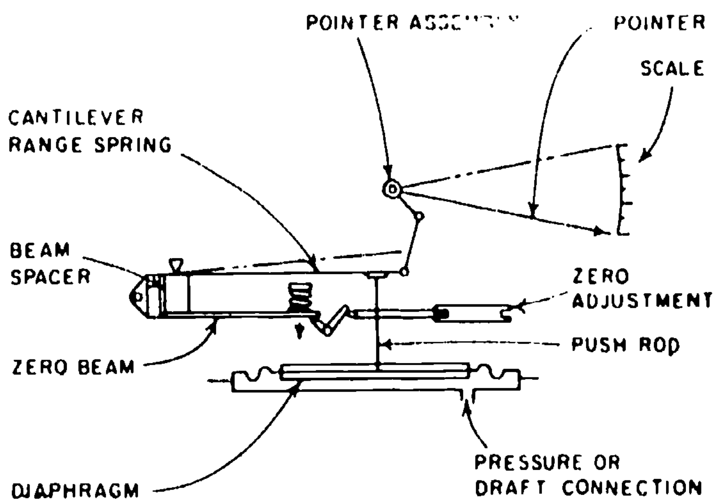


Bellows Pressure Gage

Fig. 4

The diaphragm type of pressure gage is used primarily to measure low pressures such as draft in a boiler furnace and is normally calibrated in inches of water. It consists essentially of a non-metallic diaphragm, sometimes called a limp diaphragm, which, when pressure is applied to it, will distort and either stretch, compress, or deflect a spring.

The principle of operation of this type is shown schematically in Fig. 5.



Diaphragm Pressure Gage

Fig. 5

For low pressures and drafts (suction), liquid or mercury U-tubes or variations thereof are sometimes used. Depending on the pressure (or suction) either mercury or a colored oil is used. One end of the U-tube is connected to the source of pressure or suction, the other to atmosphere. The difference in the levels of the two legs represents the pressure of the suction head in linear units of the medium being used. If pressure is measured, the connected leg is depressed; if suction, the leg to atmosphere is depressed. Inclined draft gages are of this variety.

Connecting one side of the U-tube to one point of pressure or suction in a system and the other side to a different point in the same system gives a drop or differential pressure between the two points. The instrument thus becomes a differential pressure gage and is used for various readings, such as draft loss across an air heater.

2. TEMPERATURE MEASUREMENT

Most power plant operations involve the transfer of heat and resulting temperature changes. Therefore, temperature is another of the most commonly measured variables in the plant. Examples include steam temperature, feedwater temperature, flue gas temperature, oil temperature, cooling water temperature and many others.

(PE1-2-11-4)

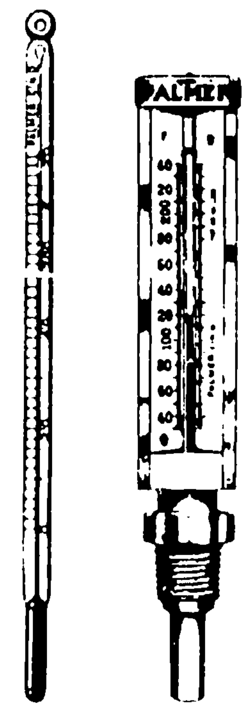
Temperature measuring instruments used in power plants include glass-stem thermometers, remote-indicating bulb thermometers, bimetallic thermometers, and thermoelectric pyrometers.

Glass-stem Thermometers

The principle of operation of this type involves the expansion and contraction of a column of mercury or alcohol due to temperature changes. The thermometer consists of a thick-walled glass tube with a small bore and formed into a bulb at one end. The bulb contains the mercury or alcohol which expands or contracts with temperature changes and so rises or falls in the small bore tube. The reference scale numbers are either etched on the outside of the glass tube or secured adjacent to it.

The mercury filled type is more stable at high temperatures than the alcohol filled type and is used for temperatures up to about 300^{o}C and in some cases up to about 500^{o}C. The alcohol type is better suited for low temperatures due to its very low freezing point.

Fig. 6 shows two types of glass-stem thermometers.

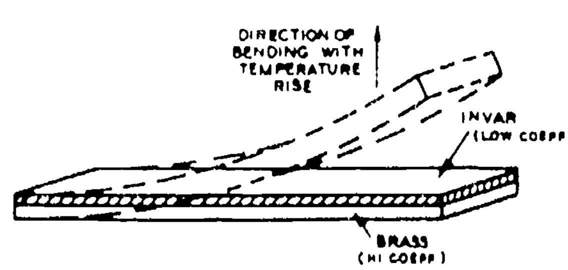


Glass-stem Thermometers

Fig. 6

Bimetallic Thermometers

The operation of this type depends upon the fact that dissimilar metals when heated will expand at different rates. The thermometer is made up of two thin strips of different metals welded together face to face. When heated, the strips expand at different rates causing the assembly to bend as shown in Fig. 7.



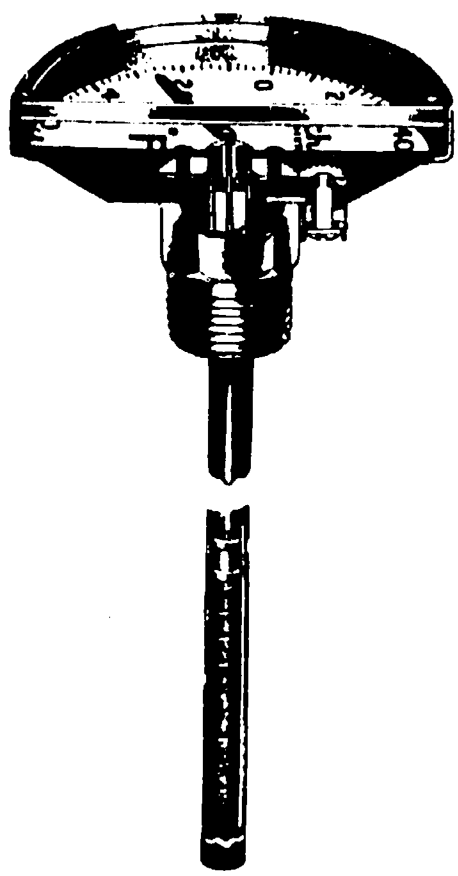
Bimetal Strip

Fig. 7

(PE 1-2-11-5)

This bending movement is used to move a pointer thus indicating a temperature change.

Brass and invar, which is an iron nickel alloy, are often used as the metals as they have a wide difference in expansion coefficients, brass expanding about twenty times more than does invar.



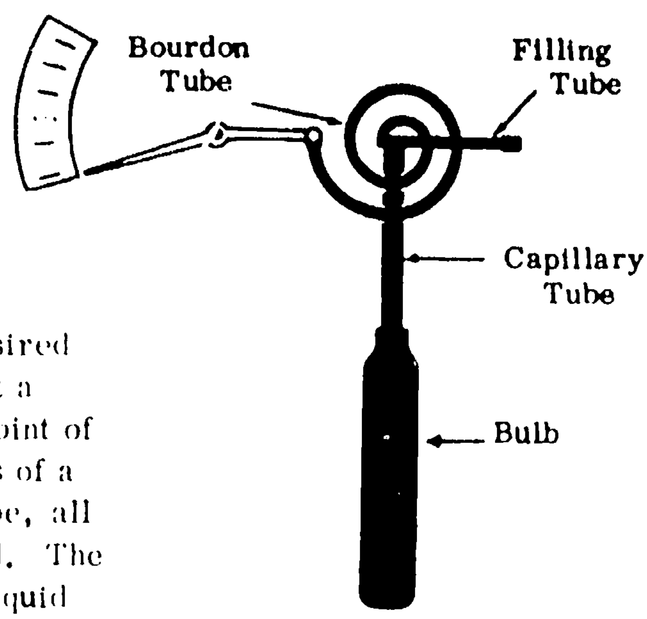
In order to obtain greater rotation of the pointer, the bimetallic strip is usually wound in the form of a helix as shown in Fig. 8.

Helical Bimetallic Strip Thermometer

Fig. 8

Remote-indicating Bulb Thermometers

This type is used where it is desired to indicate or record the temperature at a location some distance away from the point of measurement. The instrument consists of a bulb, a capillary tube and a Bourdon tube, all of which are filled with a gas or a liquid. The expansion or contraction of the gas or liquid due to temperature changes causes movement of the Bourdon tube which is linked to the indicating pointer or recording pen.

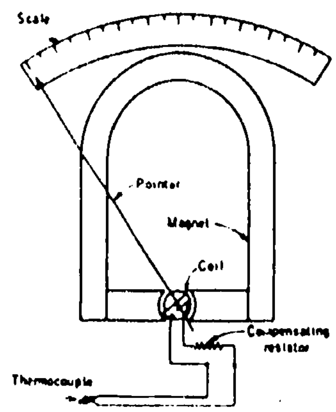


Remote Bulb Thermometer

Fig. 9

Fig. 9 illustrates the principle involved. The bulb, the Bourdon tube and the capillary tube are filled with liquid through the filling tube which is then sealed. Movement of the Bourdon tube due to expansion or contraction of the liquid will cause the pointer to move. Although the capillary tube shown in the illustration is quite short, it may in actual practice be 15 or even 30 m in length. (PE1-2-11-6)

Thermoelectric Pyrometers



Thermoelectric Pyrometer

Fig. 10

The thermoelectric pyrometer, shown in Fig. 10, makes use of a thermocouple which produces an electrical voltage which varies with temperature changes.

A thermocouple consists of two wires, each made up of a different metal. The two wires are joined together at one end and, if this junction is heated, a voltage is developed at the free ends of the wires. The high temperature joint is called the hot junction and the free ends are called the cold junction.

The voltage produced varies with the temperature difference between the junctions and this voltage is measured by connecting the free ends or cold junction of the thermocouple to a millivoltmeter which is calibrated to read in degrees of temperature. A bimetal strip is used to provide compensation for changes in cold junction temperature.

Various combinations of metals are used to make up the dissimilar wires, depending upon the temperatures being measured. For instance, for temperatures up to 400°C, one thermocouple wire would be copper and the other constantan, which is an alloy of copper and nickel. For temperatures up to 850°C, the wires are iron and constantan, for temperatures to 1100°C the wires are chrome and alumel, and for temperatures to 1400°C the wires are platinum and platinum-rhodium.

3. FLOW MEASUREMENT

In regard to the flow of a fluid in a pipe or other conductor, it can be shown that, if there is an increase in the fluid's velocity, then there will be a corresponding decrease in its pressure. This is in accordance to Bernoulli's theorem which states that the sum of the potential energy, the pressure energy, and the velocity energy is a constant for fluid flow in a conductor.

This principle can be used to measure flow in a pipe by placing a constriction in the pipe. The constriction causes a velocity increase and a corresponding pressure drop. This pressure drop will vary as the velocity varies and the velocity will vary if the flow varies. High flows give high pressure drops across the constriction and vice versa and the flow is proportional to the square root of the pressure drop produced by the flow.

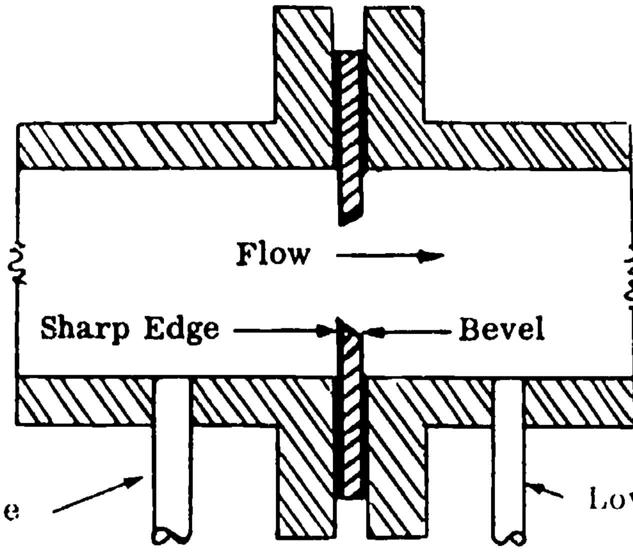
For steam flow measurement, it is customary to use a thin plate orifice or nozzle as the constrictive device. For liquid flow measurement, it is customary to use either a nozzle or a venturi tube, although orifice plates are sometimes used. For gas flow measurement in a pipe, orifice plates are probably used more than other devices. For measurement of air or flue gas through a boiler, drops across various sections such as the air heater or economizer can be used. In some cases this is not feasible and venturi sections may be built into the air ducts.

In order to measure the differential across the constriction or primary element it is necessary to use pressure taps. The location of these pressure taps in relation to the primary element is extremely important. The manufacturer of the flow meter equipment will give exact instructions as to the installation of the primary element and the exact measurement to be used from the primary element to the taps. The method of installing these taps is also important if good results are to be obtained.

The tap holes should be drilled radially to the pipe and at the exact location specified by the instrument manufacturer. For gas applications, taps should be located on the top of the pipe; for liquid or steam, at the side of the pipe. Under no conditions should they be located at the bottom of the pipe due to the possibility of dirt, mill scale, or other deposits. After drilling remove all burrs and round all edges inside the pipe. When installing the tap, do not allow it to project into the pipe as this will interfere with the flow pattern and cause errors in regard to the pressure differential being determined.

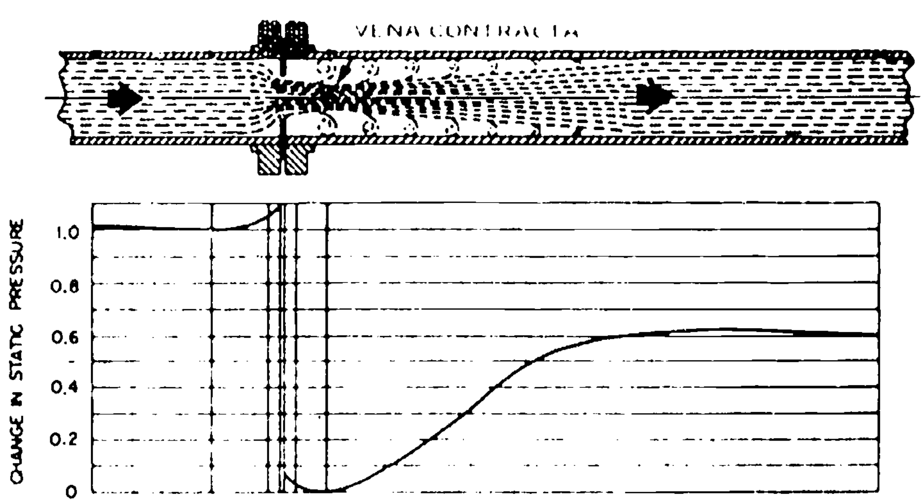
Fig. 11 shows the arrangement of an orifice plate with pressure taps while Fig. 12 illustrates the pressure variations produced by flow through an orifice plate.

Note that, in reference to Fig. 12, the lowest pressure occurs at the point where the fluid has the smallest cross-sectional area and this point is called the <u>vena contracta</u>. It is located a short distance downstream from the orifice plate and from this point the pressure begins to increase again.



Orifice Plate with Pressure Taps

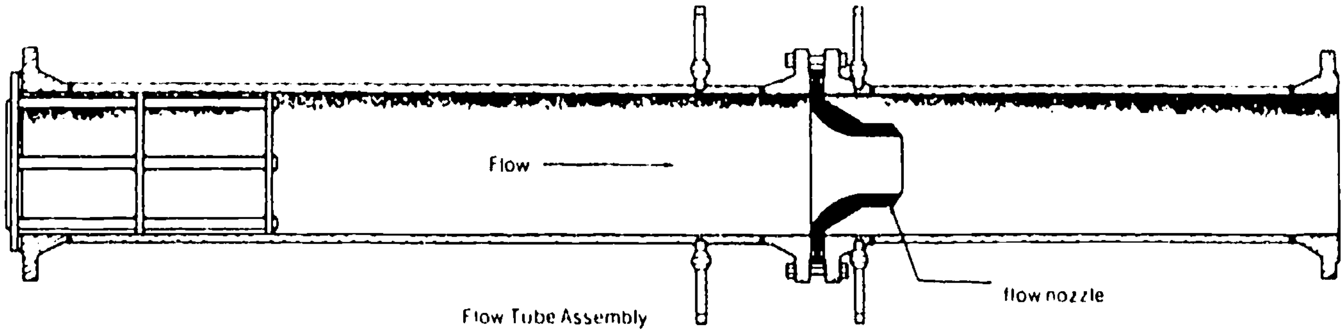
Fig. 11



Pressure Variations through Orifice Plate

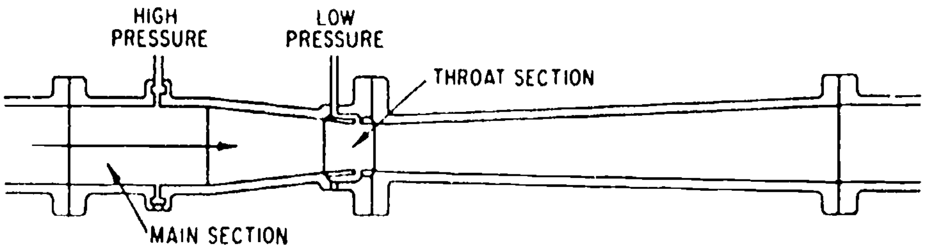
Fig. 12

Two other types of flow measuring constrictions, the flow nozzle and the venturi tube are shown in Figs. 13 and 14 respectively.



Flow Nozzle

Fig. 13



Venturi Tube

Fig. 14

The flow nozzle is much more expensive than the orifice plate and is more difficult to install. However, it requires less of a straight pipe run before and after it than does the orifice plate and in addition produces less permanent pressure drop.

The venturi tube also produces less permanent pressure drop than does the orifice plate and it has a smoother flow as well. Furthermore, it will handle 60% more flow with the same pipe size and the same pressure difference than will the orifice plate. However, the venturi is heavy and bulky and very expensive.

(PE1-2-11-10)

4. LEVEL MEASUREMENT

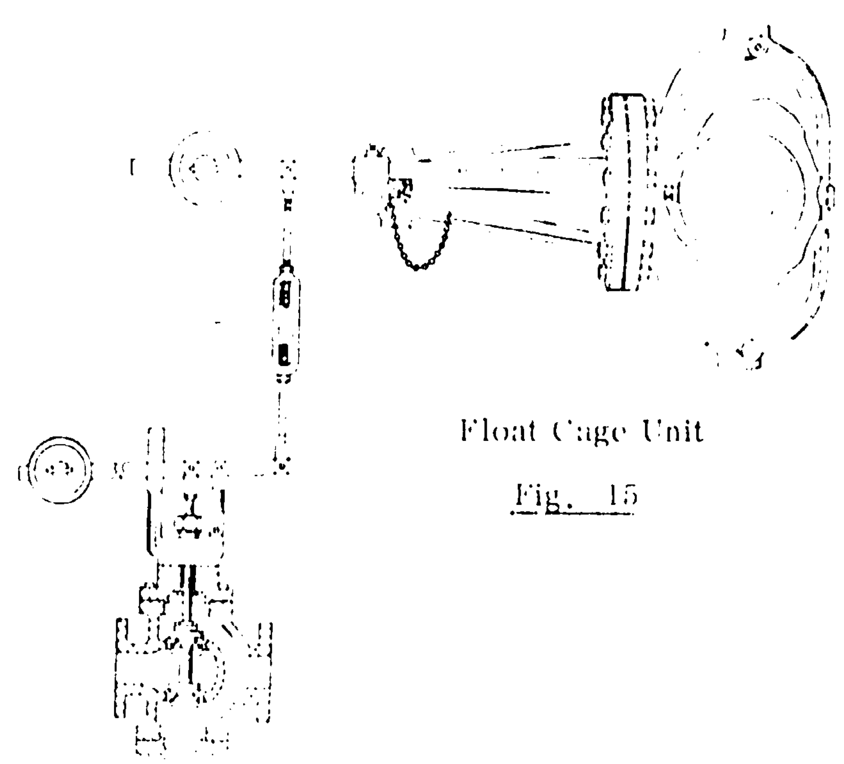
Level measurements required in power plant operation include boiler water level, condenser hot well level, fuel tank level, storage water tank level, etc.

A commonly used device which indicates visually the level in a tank or vessel is the gage glass. Another visual indicator is the float-weight device which uses a float attached to a weight by means of cables and pulleys. The float is positioned within the tank while the weight hangs outside adjacent to a scale which is marked with units of level. Still another method of indicating level is to blow air at a given point below the surface of the liquid and then measure the pressure of the air balanced by the head of liquid.

To provide indication of level that can be used to generate a signal for control systems, other methods are used such as the float cage or, more usually, some form of differential pressure gage such as a float manometer.

Float Cage Units

In this type, the float cage or float chamber is mounted on the outside of the pressure vessel and is connected at the bottom to the liquid space of the vessel and at the top to the vapor space of the vessel. As a result, the float within the cage will rise and fall with the liquid level in the vessel and this movement can be used to operate a valve or to vary a control signal.



Float Cage Unit

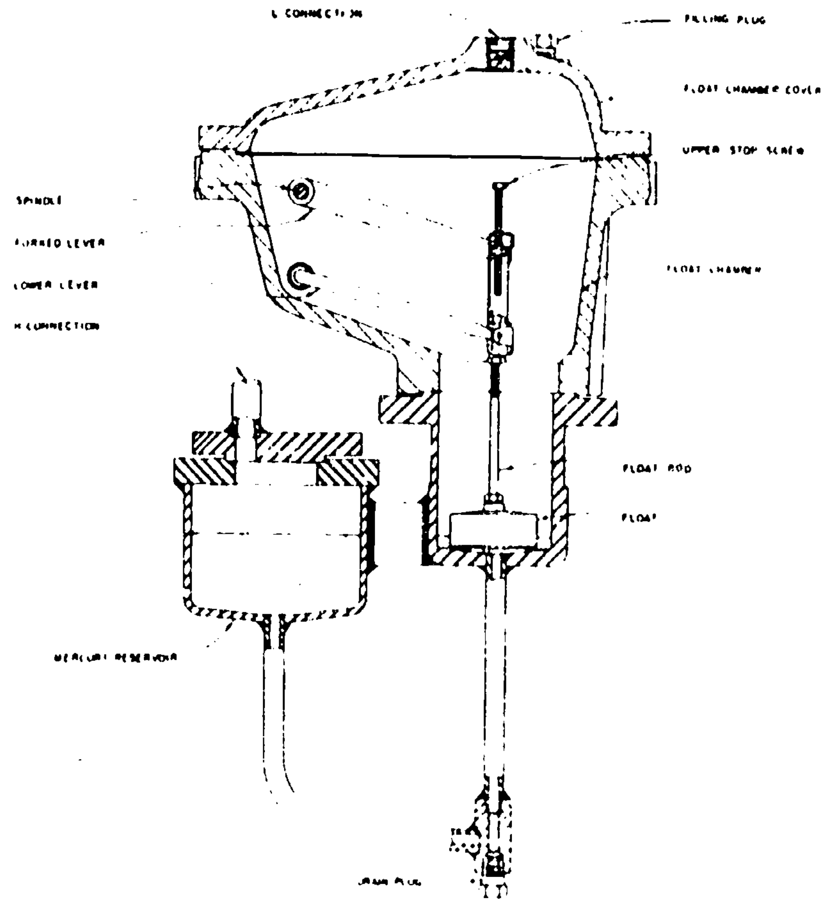
Fig. 15

Fig. 15 shows the arrangement of a float cage unit which operates a level valve.

Note that with this type, the float cage is under the same pressure that exists in the vessel, therefore, some type of a seal must be used at the point where the float arm extends from the float cage.

Differential Pressure Gage

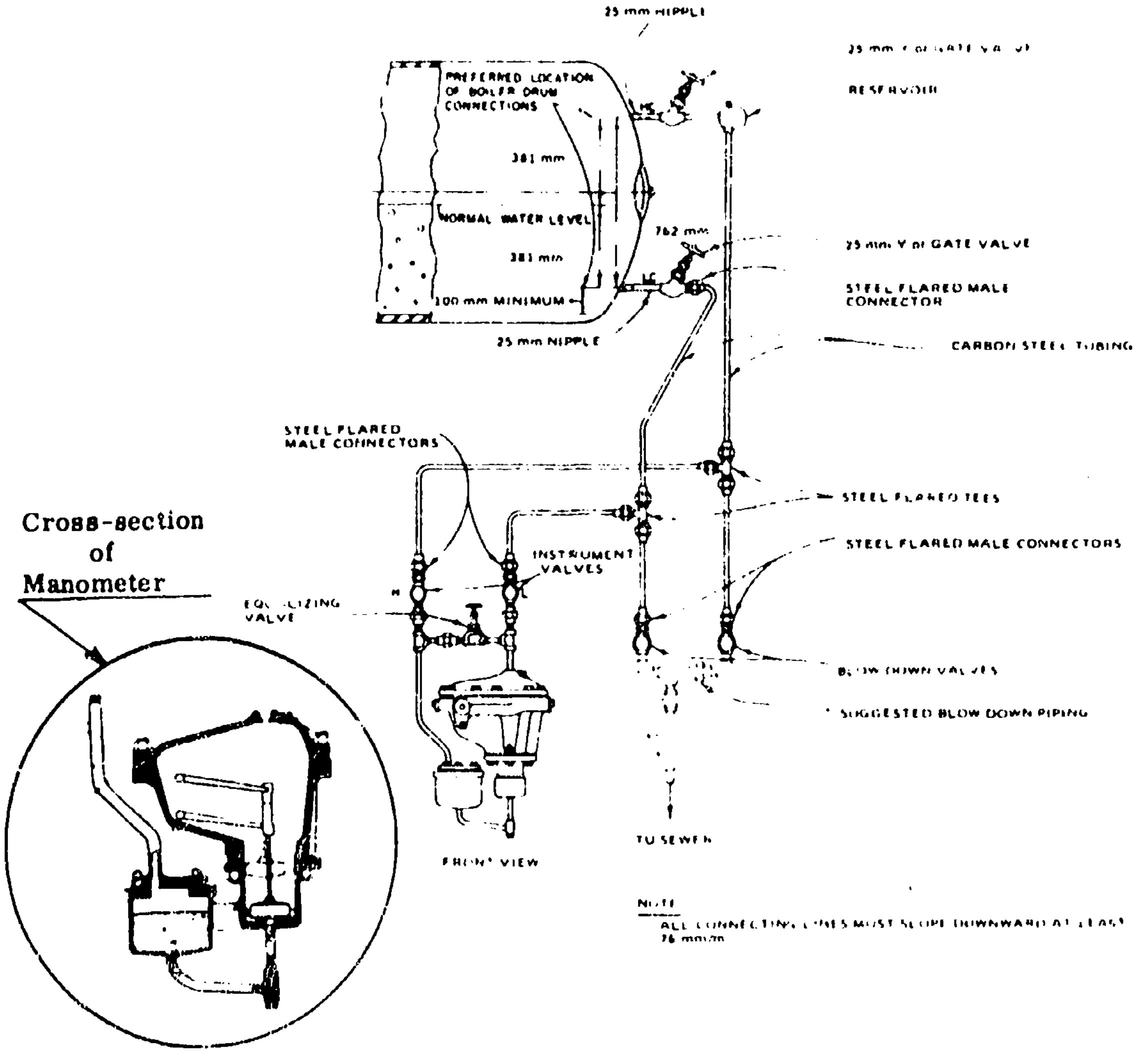
In this type, a mercury manometer, such as that shown in Fig. 16, is connected to the pressure vessel. The top connection from the vessel has a reservoir which maintains a constant head in the high pressure line of the manometer. The lower connection from the vessel has a varying head due to the rise and fall of the level in the vessel and this varying head is applied to the low pressure side of the manometer. This varying head will cause a rise and fall in the mercury level in the manometer and thus cause movement of the float. This movement is then used to vary a control signal.



Float Type Manometer

Fig. 16

Fig. 17 shows the arrangement applied to a steam boiler.



Float Manometer Arrangement

Fig. 17

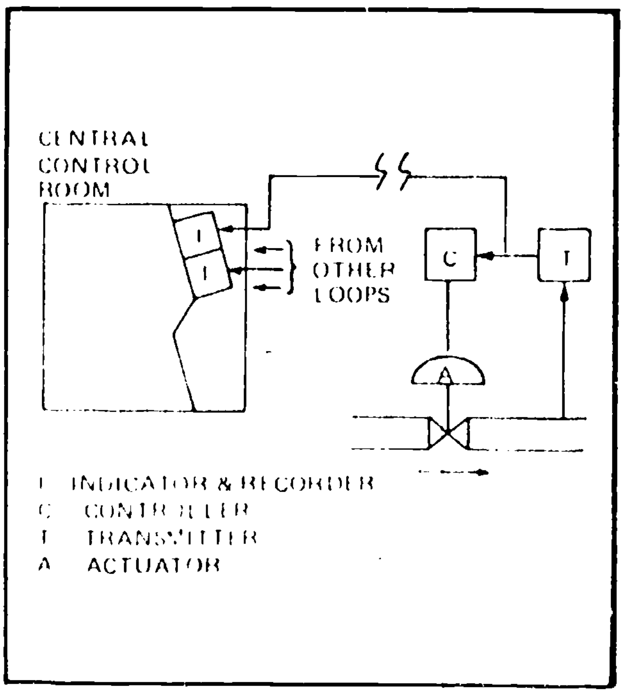
In addition to the above methods, steam boilers frequently use thermo-hydraulic and thermo-expansion devices to provide level control signals and these latter devices will be discussed under the heading of feedwater control.

CONTROLLERS, TRANSMITTERS, ACTUATORS

The basic components of a control system can generally be considered as the controller, the transmitter and the actuator.

The controller is equipped with a sensing device which recognizes changes in the controlled variable such as steam pressure, steam flow, temperature, etc. The controller responds to these changes by sending out varying pneumatic or electric-electronic output signals. These varying output signals are then responded to by actuators or positioners which cause movement of valves, dampers, etc.

In many cases, a transmitter is used to sense the changes in steam pressure, etc., rather than the controller. This transmitter then converts these changes into varying signals, either pneumatic or electric-electronic and transmits these signals to the controller which is usually located some distance away. In this case the controller would not be equipped with a sensing device as the sensing is being done by the transmitter. The transmitter signal is also used to operate indicating and recording instruments, normally located in a central control room, which then show changes in the value of the steam pressure or other controlled variable.

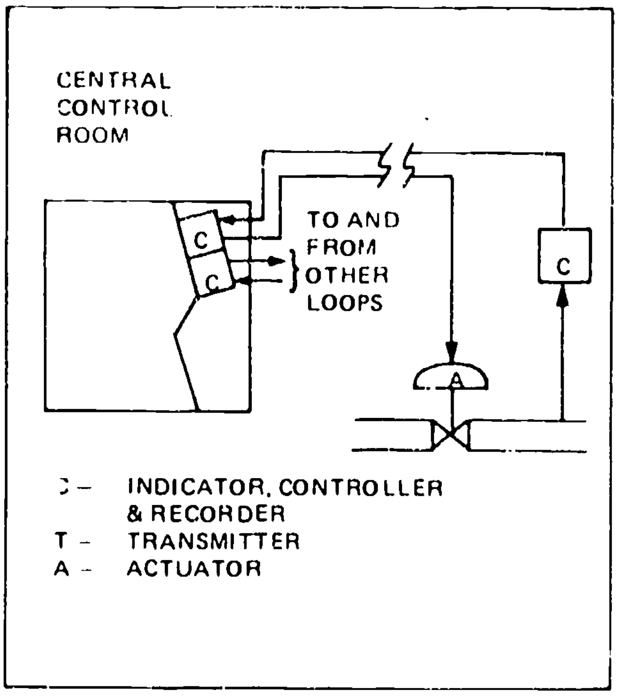


Simple Control Arrangement

Fig. 18

Fig. 18 shows a simple pressure control system where changes in the pressure within the pipe is sensed by a transmitter. The transmitter signal is sent to a controller and also to an indicator and recorder located in the control room. The controller, which is located adjacent to the control valve, causes the actuator to operate the valve in accordance to the pressure changes within the pipe.

A system which is used more often than that in Fig. 18 is shown in Fig. 19.



Central Control Arrangement

Fig. 19

In the system in Fig. 19 the controller, indicator and recorder are all located in a central control room where they receive the transmitter signals. The controller in turn sends a signal to the actuator to operate the valve in accordance to pressure changes in the pipe.

With this method, the operator is able to make adjustments to the controller without leaving the control room. Another advantage is that the controller is located in a clean environment where ambient temperatures and vibration are not extreme.

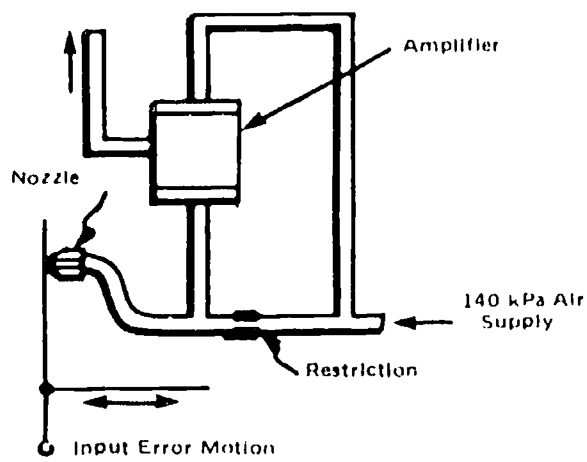
As mentioned previously, the control signals or impulses may be pneumatic or they may be electrical or electronic. The advantage of one system over the other depends upon the application requirement. The pneumatic signal is much slower than the electrical-electronic signal and for long distances the transmission speed may be very important.

The first cost of a pneumatic system, however, is much less than an electronic system. The power output from a pneumatic controller is sufficient to directly drive an actuator while the output from an electronic controller is a control signal only and therefore the actuator must have a separate power source which may be pneumatic, electrical or electric hydraulic.

1. CONTROLLERS

On-Off Controller

A simple sketch of the most basic of controllers appears in Fig. 20.



On-Off Controller

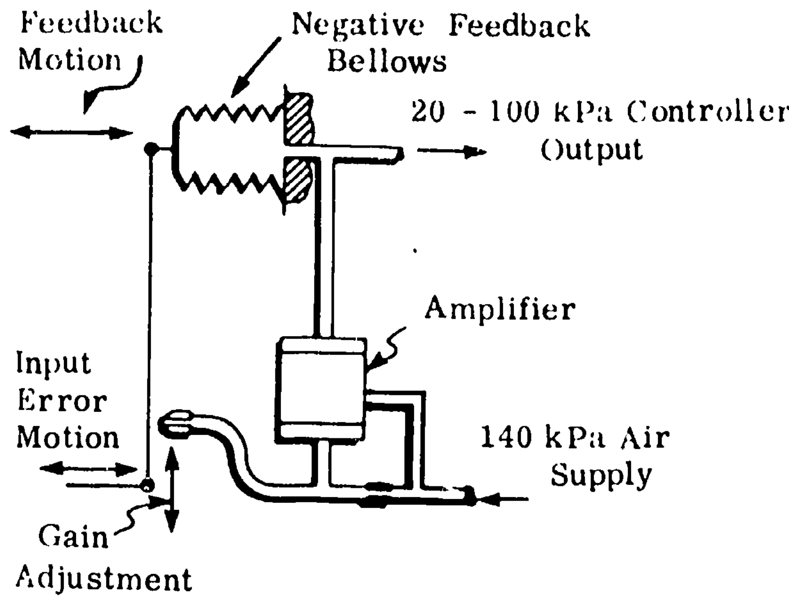
Fig. 20

The unit shown in Fig. 20 is a pneumatic type and is known as an on-off controller. The sensing device which is not shown in the sketch, provides the input error motion which, depending upon whether the value of the measured variable is above or below the set point, will cause the flapper to be either held against the nozzle or away fr·m it. If the flapper is held against the nozzle then the output from the controller will be at a maximum. Conversely, if the flapper is held away from the nozzle, then the output from the controller will be at a minimum.

Proportional Controller

The on-off controller sketched in Fig. 20 only recognized whether the measured variable was above or below the set point and therefore it controlled by means of an on-off cycle. To eliminate this cycling a proportional controller, such as that sketched in Fig. 21, can be used.

The proportional controller not only recognizes whether the measured variable is above or below the set point, but it also takes into account the amount that the measured variable is above or below the set point.



Proportional Controller

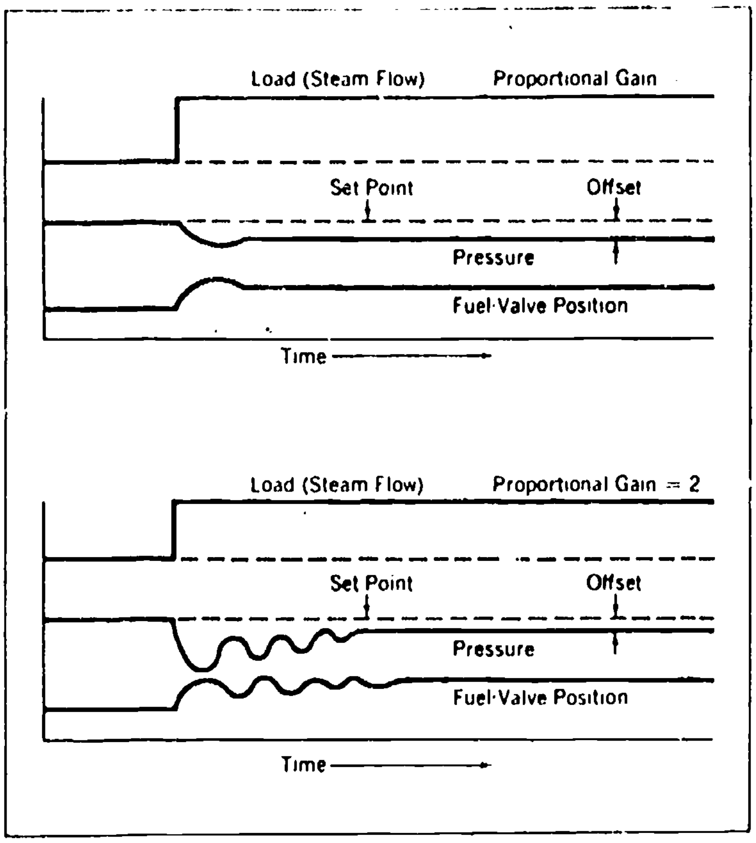
Fig. 21

Referring to Fig. 21, the controller sensing device, not shown in the sketch, produces the input error motion in either direction according to whether the measured variable is above or below the set point. For example, if the measured variable is pressure then the sensing device could be a Bourdon tube and on an increase in pressure the Bou- on tube will move the flapper toward the nozzle. This will cause an increase in controller output pressure. At the same time this increased output will act within the negative feedback bellows which will expand and re-position the flapper in a direction opposite to the original motion. The resulting effect of this is that for every value of the measured variable there is one and only one clearance between flapper and nozzle and only one controller output pressure.

The term "proportional gain" or "gain" is used to denote the ratio of the change in controller output to the change in the measured variable. To illustrate, if the measured or controlled variable changes in the amount of 100% of its range and this causes a 100% change in the controller output, then the gain is $\frac{100}{100}$ or 1. If a 50% change in the controlled variable causes a 100% change in controller output then the gain is $\frac{100}{50}$ = 2.

A limitation of a proportional controller is that it cannot entirely eliminate error and return the variable to the set point. There will always be a difference between the new corrected value of the variable and the set point and this difference is known as "offset".

This offset and the effect of gain upon the offset is shown in Fig. 22.



Controller Offset

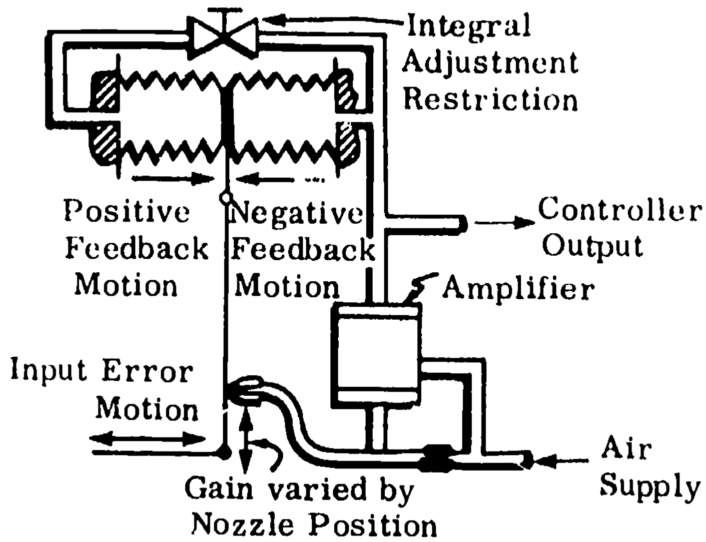
Fig. 22

It can be seen by comparing the two graphs in Fig. 22 that increasing the gain of the controller will reduce the offset but will not eliminate it. If the gain is increased too much in an effort to further reduce the offset then oscillation or hunting of the system will occur.

Proportional Plus Integral (Reset) Controller

The offset of the system can be eliminated by the addition of the integral or reset device to the proportional controller. This integral device causes the proportional action of the controller to repeat itself until the controlled variable returns to its set point. In other words the integral or reset device keeps increasing the controller output until the variable is at the set point once again.

A proportional plus reset controller is shown schematically in Fig. 23.



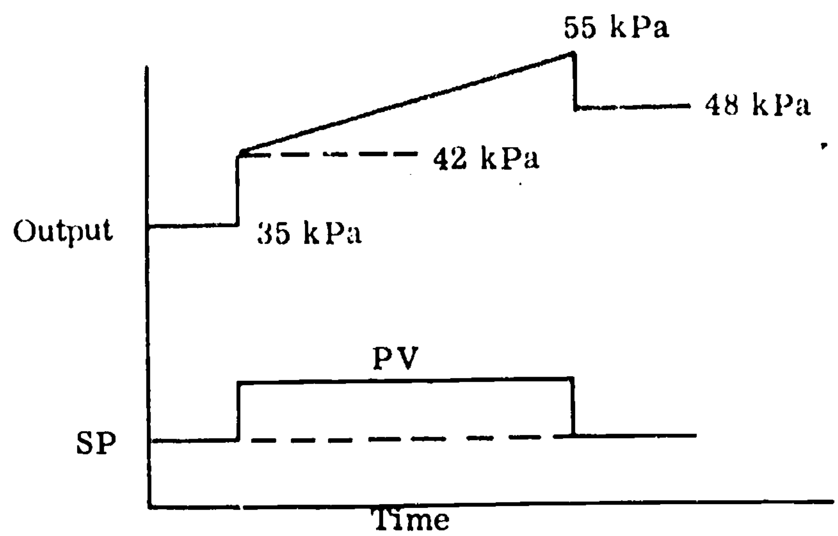
Proportional Plus Integral (Reset)

Fig. 23

The controller in Fig. 23 is in effect a proportional controller to which has been added an adjustable restriction and a positive feedback bellows. The positive feedback bellows provides the reset action while the negative feedback bellows provides the proportional action.

The operation of the controller is as follows: When the variable is at the set point the pressure in both bellows is the same, say 35 kPa. If the variable increases above the set point the controller sensor, not shown, will move the flapper toward the nozzle. The controller output will increase to say 42 kPa and this pressure will also exist in the negative bellows and will for a short time exceed that in the positive bellows. However, due to the air passing through the restriction, the pressure in the positive or reset bellows will also increase and the flapper will be moved toward the nozzle again causing a further increase in controller output to say 55 kPa. This further increase will return the variable to the set point and the flapper will move away from the nozzle once again which will reduce the controller output to say 48 kPa and the variable will be maintained at the set point.

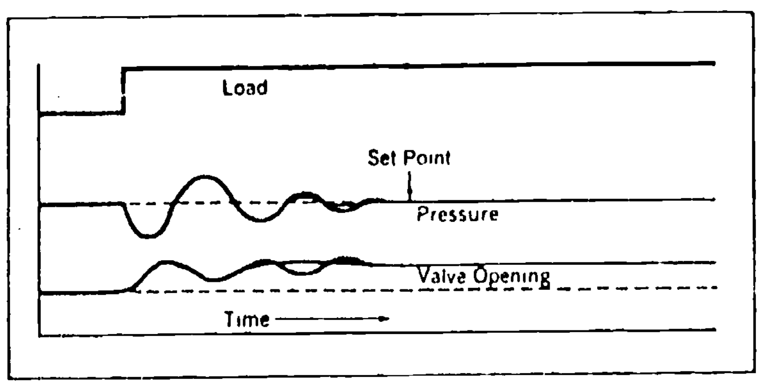
The above operation is shown graphically in Fig. 24 where SP is the set point and PV is the process variable, say steam pressure.



Proportional Plus Reset Action

Fig. 24

The same situation is shown in Fig. 25 in reference to boiler load, boiler pressure and fuel valve opening.



Proportional Plus Reset Boiler Control

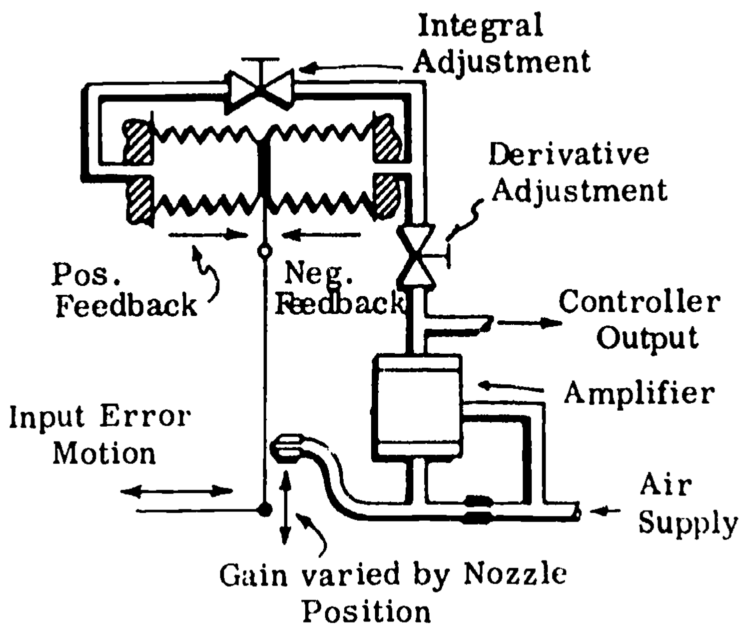
Fig. 25

Proportional Plus Reset Plus Derivative Controller

In many cases the variable will increase or decrease from the set point very rapidly and at an increasing rate. For instance if all load is suddenly lost from a boiler then the variable steam pressure will increase above the set point rapidly and at an increasing rate. When this happens the fuel valve controller output must be increased even further than that achieved by the proportional and reset action. This further increase is provided for by derivative (rate) action.

Derivative or rate action is a mode of control that provides an output from the controller that is proportional to the rate of change of the deviation from the set point.

To add derivative action to a proportional plus reset controller it is necessary only to add a restriction in the air line to the feedback bellows as shown in Fig. 26.

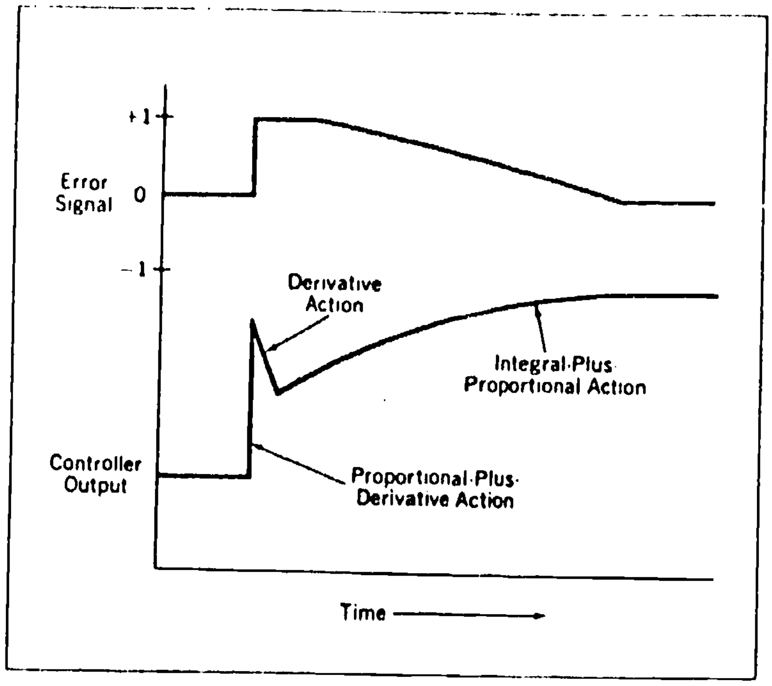


Proportional Plus Reset Plus Derivative Controller

Fig. 26

Referring to Fig. 26 when the variable deviates from the set point the flapper is moved by the controller sensor, not shown, toward the nozzle. The derivative or rate restriction causes a time delay in the action of the negative feedback bellows which allows for an immediate and large increase in controller output. Then as the output pressure seeps through the rate restriction, the negative feedback bellows repositions the flapper giving proportional action. Reset action by the positive feedback bellows is further delayed by the reset or integral restriction.

The final result of a proportional plus reset plus rate controller is a quicker return to the set point because the controller output causes the final control element, such as a fuel valve, to move further in the required direction than if only proportional plus reset action was used and this is illustrated by the graph in Fig. 27.



Proportional Plus Reset Plus Rate Action

Fig. 27

2. TRANSMITTERS

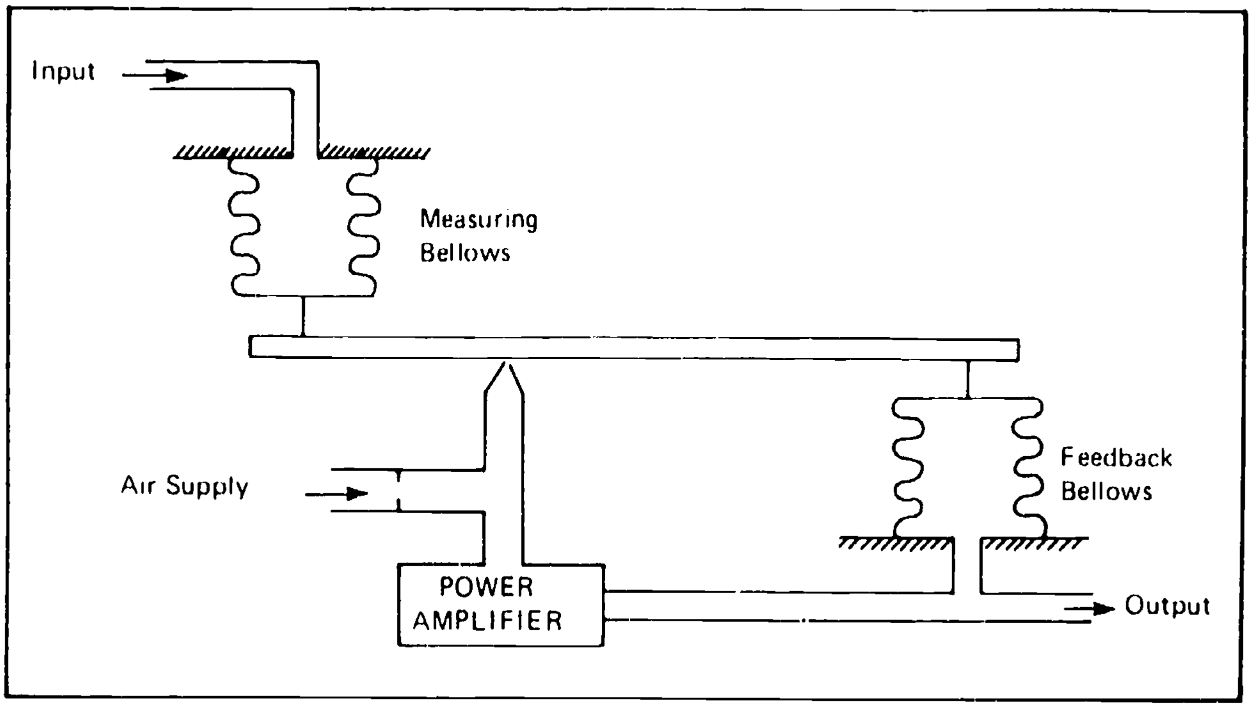
The transmitter is a device which measures the controlled variable and converts this measurement into a standard transmission signal such as 20 to 100 kPa pneumatic or 4 to 20 milliamps electrical. This signal is then sent to a controller as well as to recording and indicating instruments.

Pressure Transmitters

The sensor, or measuring element, of most pressure transmitters is some type of bellows, Bourdon tube or diaphragm and the basic mechanism of a pneumatic pressure transmitter is the flapper - nozzle assembly.

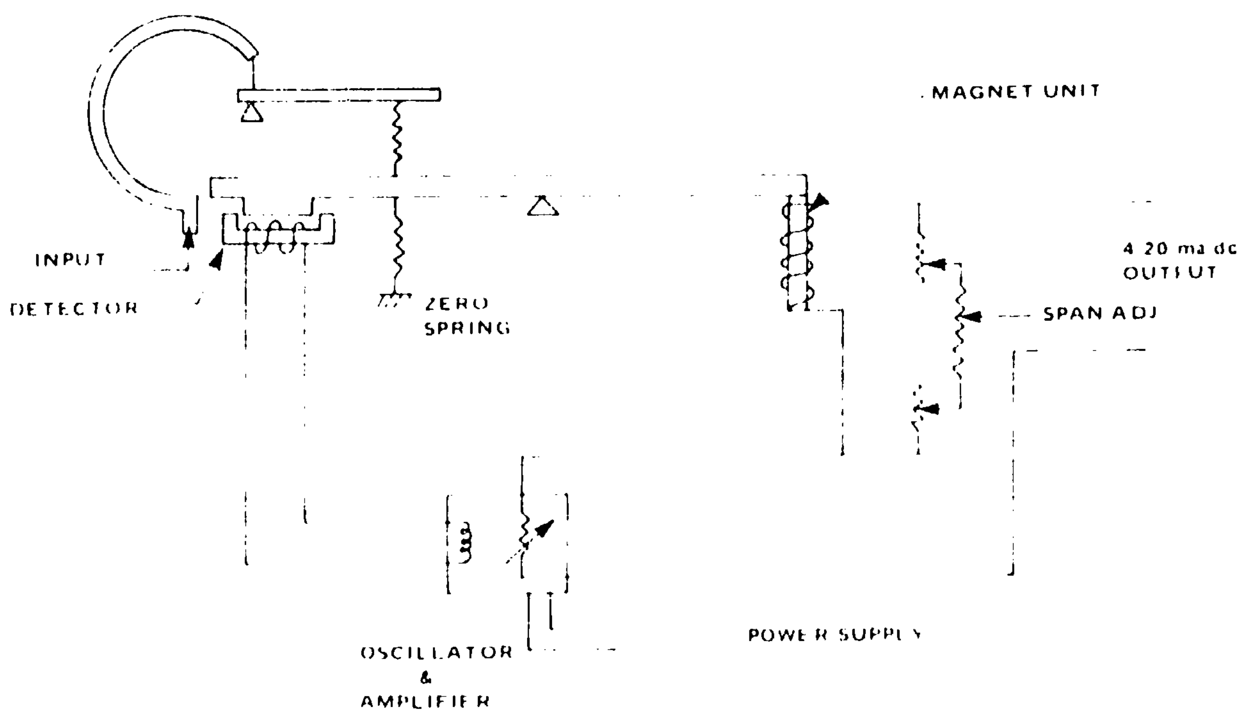
A pneumatic pressure transmitter is shown schematically in Fig. 28.

In the transmitter in Fig. 28 when changes in the measured pressure occur the measuring bellows will move the flapper in relation to the nozzle. This will change the output pressure or signal from the transmitter. The feedback bellows, which is acted upon by the output pressure, repositions the flapper and in this way the output is kept in proportion to the measured variable.



Pneumatic Pressure Transmitter

Fig. 28



Electronic Pressure Transmitter

Fig. 29

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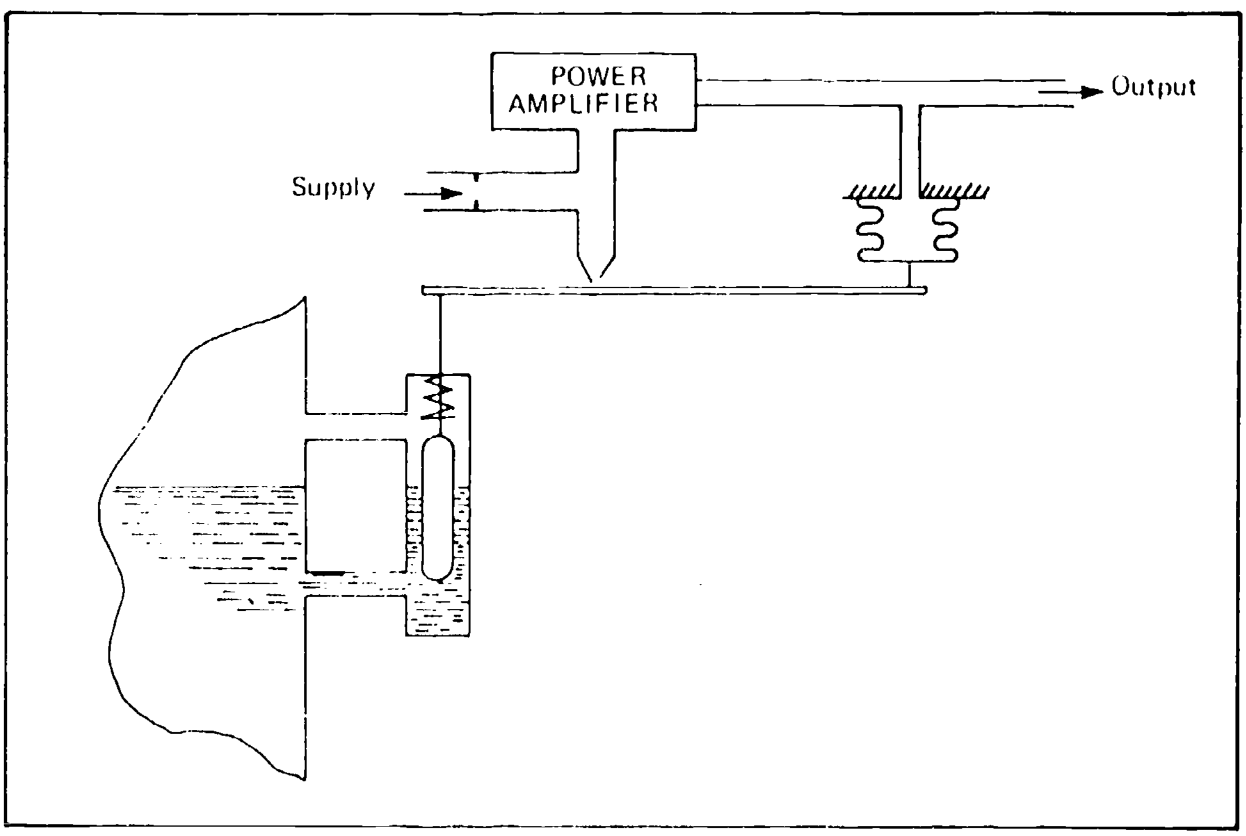
The electronic pressure transmitter in Fig. 29 consists of a movable beam, detector, oscillator, magnet unit and Bourdon tube sensor. If the pressure being measured is at a minimum then the gap between the beam and the detector coil will also be at a minimum. As a result the inductive reactance in the detector coil will be at a maximum and therefore the output from the oscillator will be at a minimum value (4 ma). When the measured pressure increases, the Bourdon tube will move the beam away from the detector coil thus reducing the inductive reactance and increasing the transmitter output. This output current passes through the magnet unit which exerts an upward force upon the beam that opposes the force of the Bourdon tube. This magnet unit can be compared to the feedback bellows in the pneumatic transmitter in Fig. 28.

The zero spring and span adjustment are used for calibrating purposes. When the value of the controlled variable is at minimum the zero spring adjustment is used to adjust the detector gap so that the transmitter output is also at minimum. As the controlled variable varies over a desired range, the transmitter output varies from minimum to maximum due to the span adjustment.

Level Transmitter



Pneumatic Level Transmitter

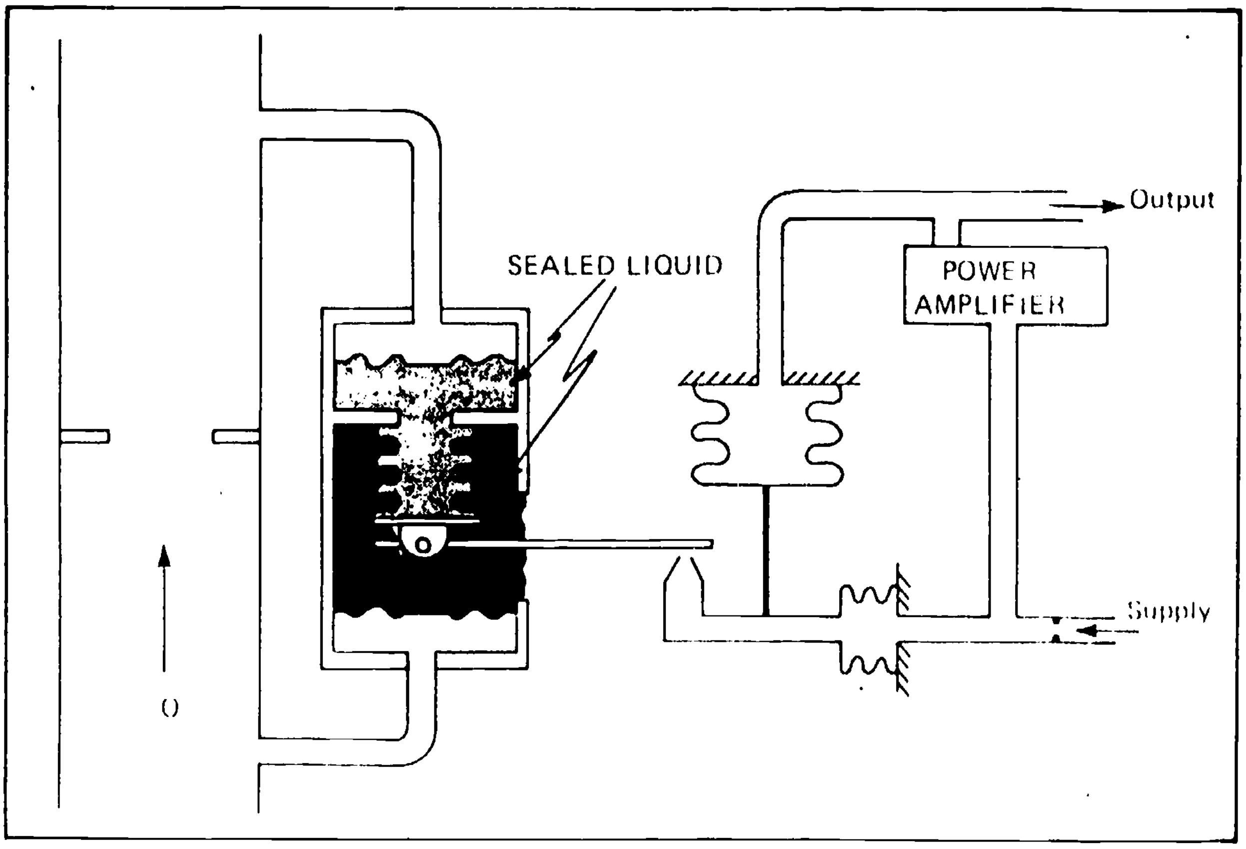
Fig. 30

(PEI-2-11-24)

Fig. 30 shows a schematic sketch of a pneumatic level transmitter which uses a float to move the flapper as the level varies. This changes the transmitter output and the feedback bellows repositions the flapper to keep the output proportional.

Flow Transmitter

The pneumatic flow transmitter shown in Fig. 31 uses an orifice plate to produce a pressure drop which varies with flow and a bellows type sensor to measure the pressure drop.

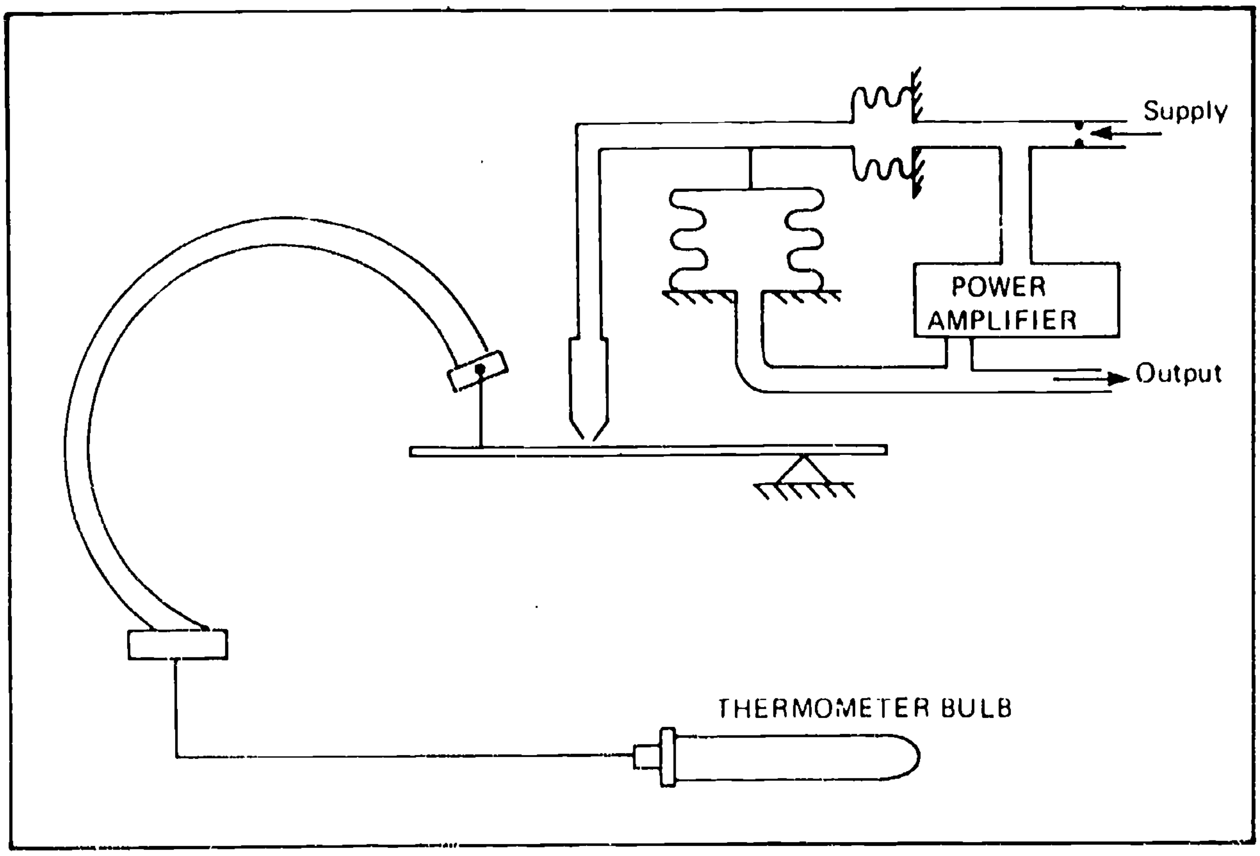


Pneumatic Flow Transmitter

Fig. 31

The bellows moves the flapper in relation to the nozzle thus varying the transmitter output. The feedback bellows maintains the proportional action.

Temperature Transmitter



Pneumatic Temperature Transmitter

Fig. 32

Fig. 32 is a schematic diagram of a pneumatic temperature transmitter. The thermometer bulb causes a varying pressure within the Bourdon tube as the temperature changes. The Bourdon tube moves the flapper in relation to the nozzle and the output is maintained in proportion by the feedback bellows.

3. ACTUATORS

Actuators are the devices which receive the output signals from the controllers and convert these control signals to mechanical motion in order to operate valves, dampers, etc.

Actuators may be classified according to the type of signal they receive-pneumatic or electric. They may also be classified according to the method used to convert to mechanical motion and this method of conversion may be either pneumatic or some form of electric system. A further classification of actuators has to do with the type of mechanical motion which they produce, rotary or linear.

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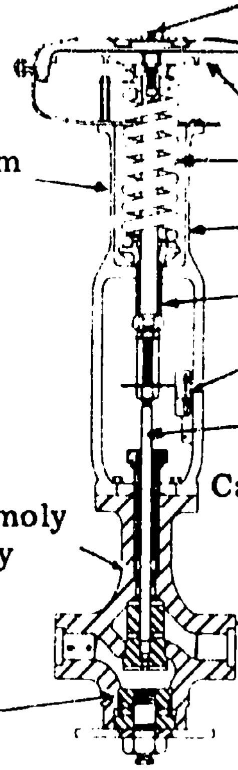


Diaphragm Actuator

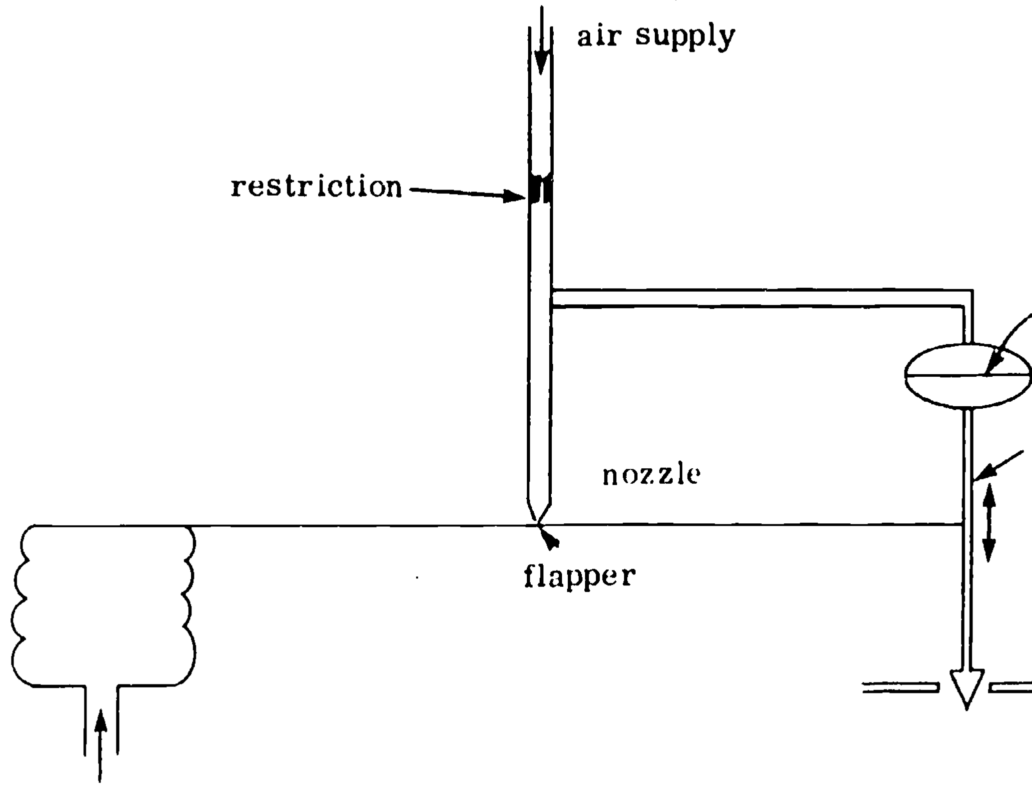
Fig. 33

Fig. 33 shows a pneumatically operated diaphragm actuator which produces a linear motion to operate a valve. In operation, this actuator receives an air pressure signal from a controller through the air pressure connection above the diaphragm. Usually the air signal ranges in value from 20 to 100 kPa depending upon this value, the actuator diaphragm will move the valve a certain amount. In moving downward, the diaphragm works against a spring which returns the diaphragm when the signal pressure reduces. The adjusting screw allows for setting of the spring compression and it is usually adjusted so that the valve stem just starts to move when the signal pressure is at the minimum of 20 kPa.

Normally the position of the valve depends upon the control signal. However, due to valve stem friction or process variations, the position of the valve may tend to deviate from that desired. If this is the case, a positioner is usually used in conjunction with the actuator.

Basically the positioner is an amplifier taking the control signal at low pressures and using a higher pressure air supply to move the actuator according to variations in the control signal.

A schematic arrangement of a positioner appears in Fig. 34.

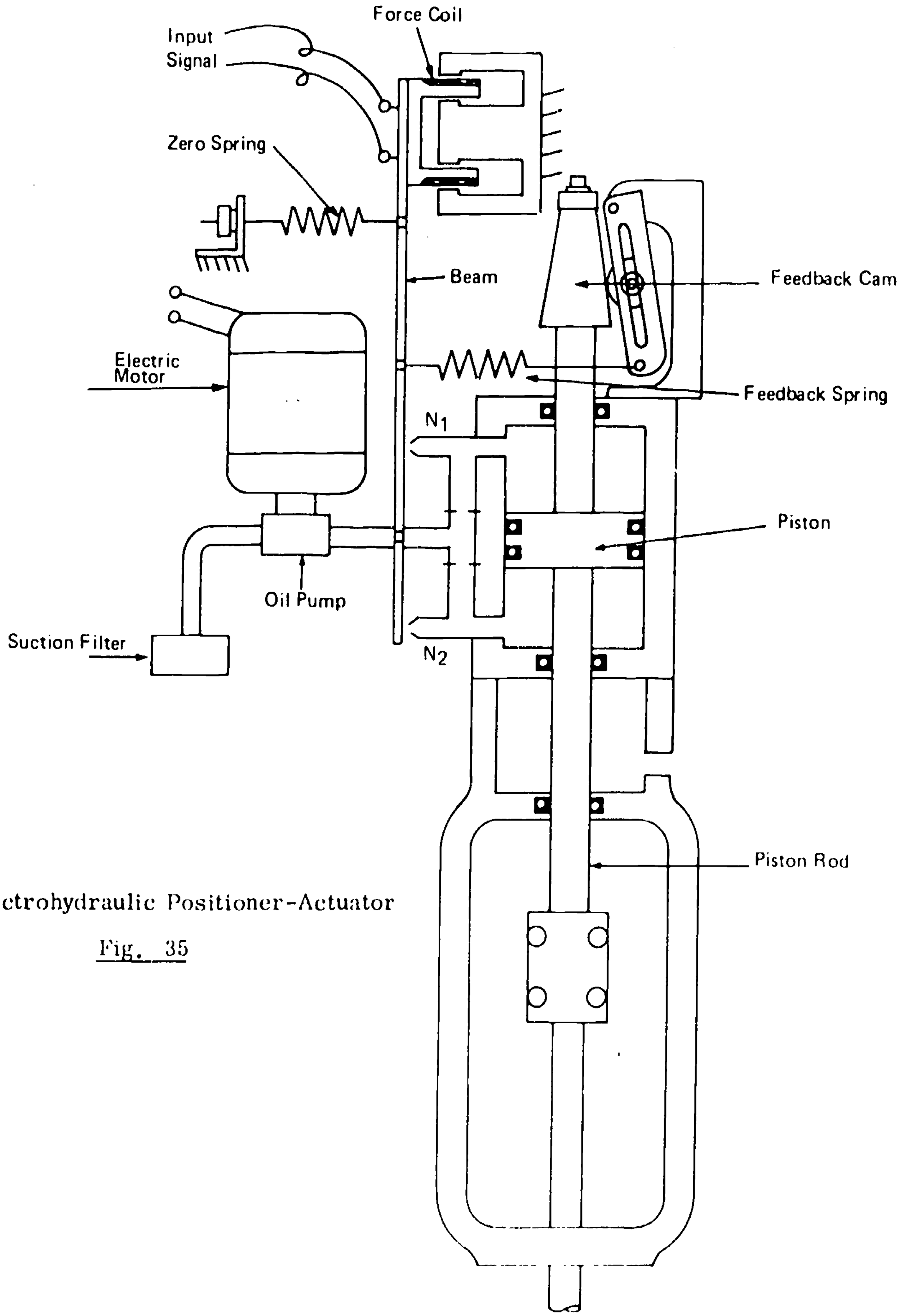


Positioner Arrangement

Fig. 34

With this arrangement the control signal is applied to a bellows which positions a flapper in relation to a nozzle. An increase in control signal pressure will move the flapper closer to the nozzle causing the nozzle pressure to increase and downward movement of the valve stem results. As the valve stem moves downward the flapper is moved away from the nozzle giving proportional action and stabilizing the valve movement. If valve stem movement is prevented due to friction or other cause, the nozzle pressure will continue to increase until the resisting force is overcome.

A schematic diagram of an electrohydraulic positioner-actuator appears in Fig. 35. In this type the control signal is electric and the mechanical movement is linear and is produced by hydraulic action on a piston.



Electrohydraulic Positioner-Actuator

Fig. 35

(PE1-2-11-29)

Referring to Fig. 35, the electric motor runs continuously driving the oil pump which produces a high pressure flow of oil through the nozzles N_1 and N_2. The control signal is applied to a force coil and on an increase of signal the coil will move within the core surrounding it. This moves the beam and restricts nozzle N_1 causing a build up of pressure above the piston. As the piston moves down, the feedback cam allows the beam to be repositioned. If the signal decreases, nozzle N_2 will be restricted and the piston will move upwardly. The movement of the piston rod can be used to position a valve, damper etc.

FEEDWATER CONTROL SYSTEMS

Most shop-assembled boilers in the lower capacity range and the lower operating pressure range are equipped with self-contained feedwater systems of the thermo-hydraulic or thermo-expansion types. For higher capacity boilers and those operating at higher pressures, a pneumatic or electrically operated feedwater control system is used. These may be single, two, or three element types.

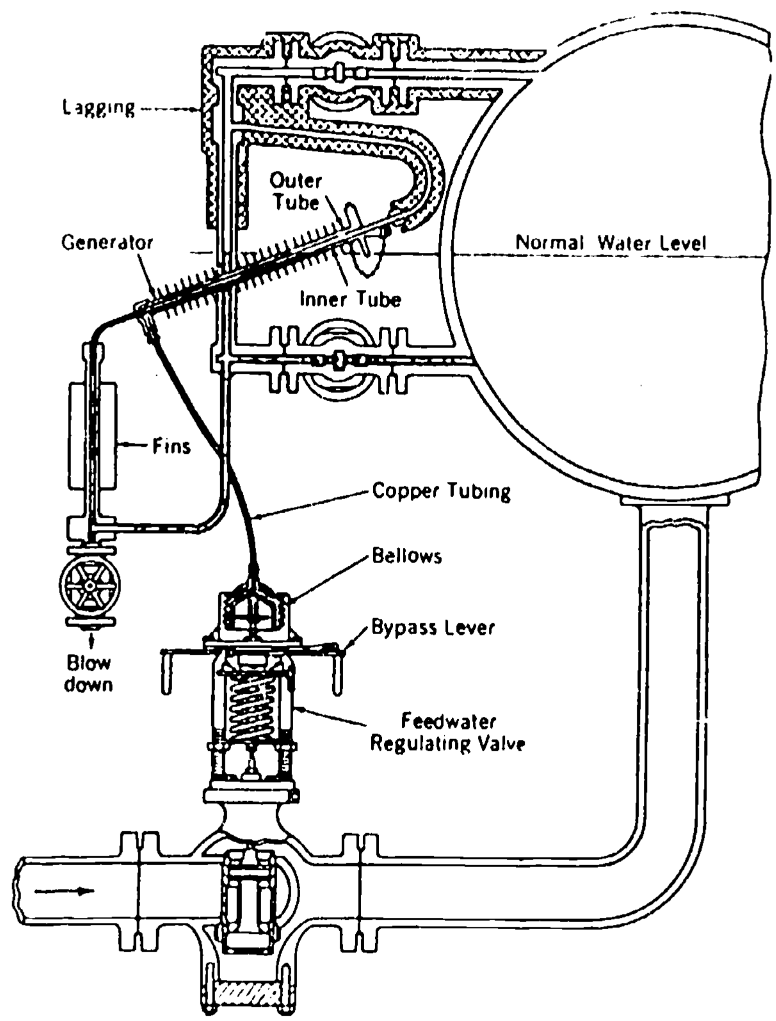
Thermo-hydraulic Regulator

This system consists essentially of a feedwater regulating valve which is actuated by a generator. The generator consists of two tubes, one within the other. The ends of the inner tube are connected to the steam and water spaces of the boiler thus the level of water in the inner tube will be the same as the boiler drum level. The outer tube is connected at the bottom to a bellows on the feedwater regulating valve.

To put the regulator into operation the outer tube and the bellows are filled with water and sealed off. In operation the heat from the steam in the upper portion of the inner tube causes the surrounding water in the outer tube to flash to steam, forcing water down into the bellows until the water levels in the inner and outer tubes are equal. This will cause the bellows to expand and open the feedwater valve in direct proportion to the water level in the generator.

If the water level in the boiler and therefore in the inner tube rises, some of the steam in the outer tube will condense which will decrease the pressure in the bellows. As a result the feedwater valve will close in proportion.

Fig. 36 shows the arrangement of the thermo-hydraulic regulator.



Thérmo-hydraulic Control

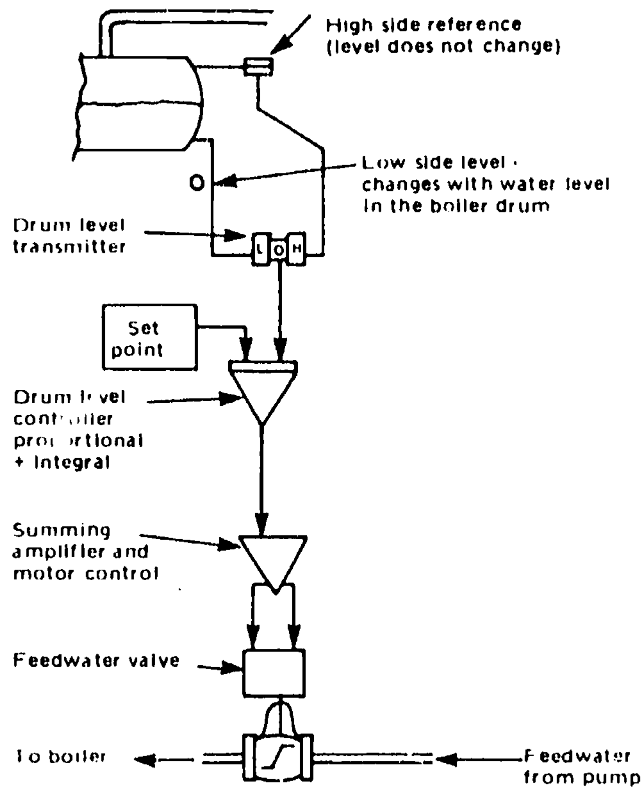
Fig. 36

Thermo-expansion Regulator

This regulator consists essentially of a tube mounted on a rigid beam. The tube is connected to the steam and water spaces of the boiler, the water level in the tube thus varying with the water level in the boiler.

Upon a drop of water level in the boiler, the water will also drop in the tube thus exposing more of its length to high temperature steam. This causes the tube to lengthen due to expansion and this movement is transmitted by a linkage to a feedwater regulating valve causing it to open. When the water level increases, the tube will contract due to the effect of the comparatively cool water. This movement will tend to close the regulating valve.

Single Element Feedwater Control



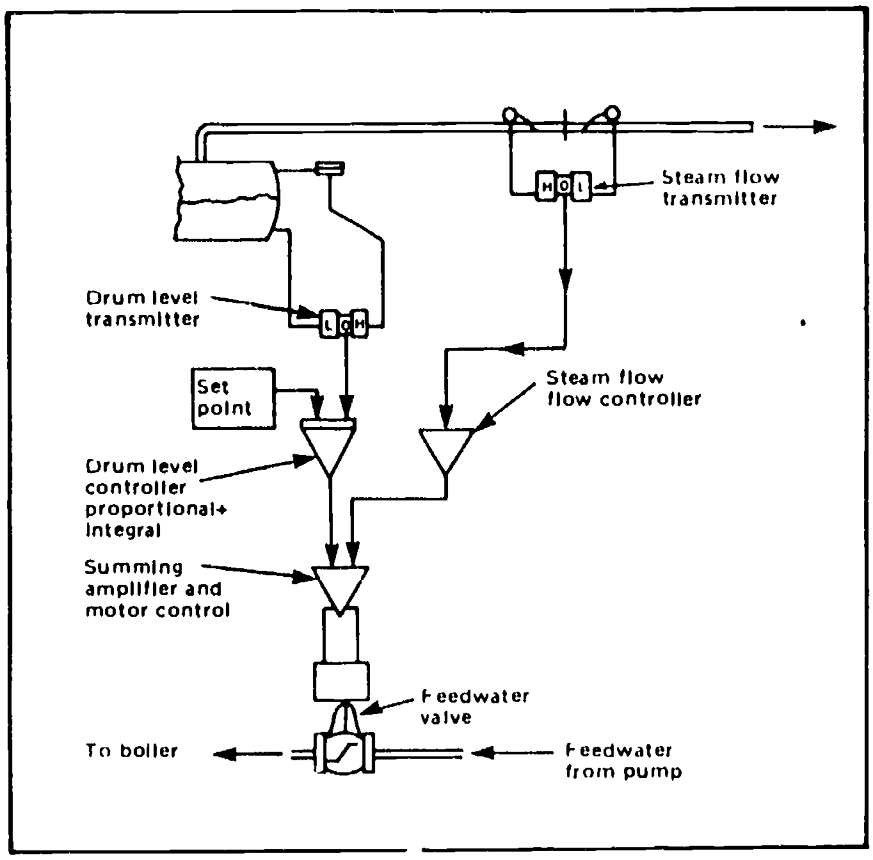
Single Element Control

Fig. 37

Referring to the single element control in Fig. 37, the drum level transmitter sends a signal to the controller which applies proportional-plus-integral action according to the difference between the drum level signal and the set point and thus the position of the feedwater valve is changed.

This type of control will maintain a constant drum level for slow load changes but during more rapid changes it will not compensate for swell or shrinkage. Load increases create swell which causes the single element control to see an increased drum water level. This results in the control reducing feedwater flow when, instead, an increased flow is required because of the increased steam flow from the boiler. Conversely, load decreases cause shrinkage so the control will see a low drum level and will admit large amounts of water into the boiler which are not required due to decreased steam flow.

Two Element Feedwater Control



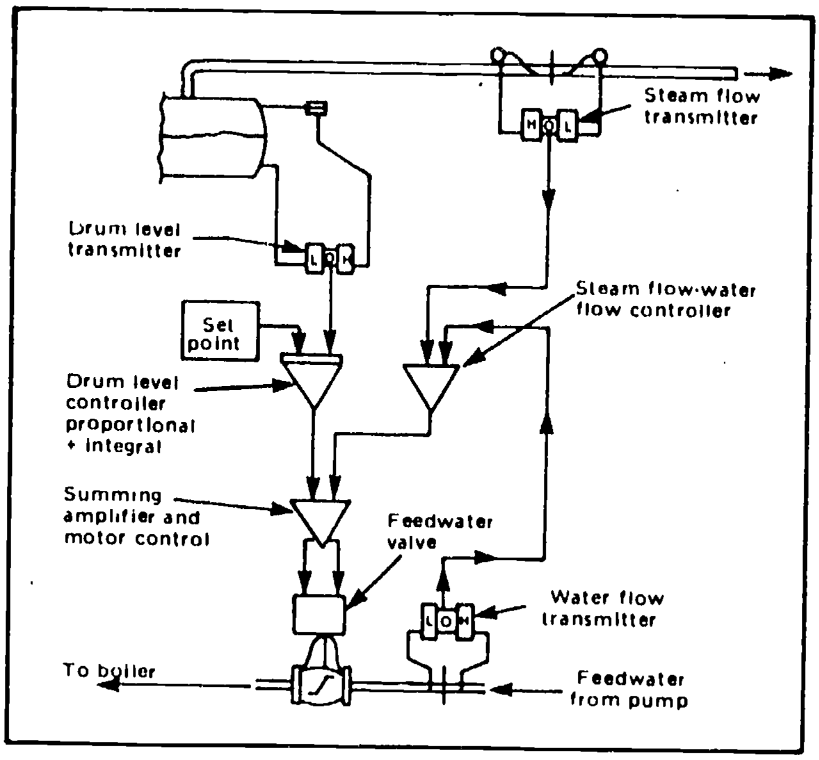
Two Element Control

Fig. 38

The two element control in Fig. 38 measures and responds to two variables, steam flow and drum level. The steam flow measurement maintains feedwater flow proportional to steam flow and the drum level measurement corrects for any imbalance between water input and steam output. In this way, the control can make the necessary adjustments to cope with the swell and shrinkage characteristics of the boiler.

Three Element Feedwater Control

The three element control in Fig. 39 incorporates steam flow measurement, feedwater flow measurement, and drum level measurement. The steam flow measurement provides a set point for the steam flow-water flow controller. Feedback is provided by the feedwater flow measurement and feedwater flow is matched to steam flow. Drum level measurement keeps the level in the drum from varying due to flow meter errors, blowdown, etc.



Three Element Control

Fig. 39

COMBUSTION CONTROL SYSTEMS

The combustion process in the boiler furnace must be regulated in accordance to the demand for steam from the boiler. If the steam demand increases, then so must the combustion increase in order to maintain the required steam pressure. Similarly, if the steam demand drops, then the combustion of fuel must be reduced accordingly.

Combustion is regulated by controlling fuel flow and air flow into the furnace and the flow of combustion products out of the furnace. In addition to making sure that sufficient fuel and air are admitted, the control must maintain the proper ratio of air to fuel in order to achieve safe and efficient combustion.

Combustion control systems can be categorized as on-off, positioning, and metering.

On-Off Control

On-off control systems, also called two-position systems, are found only on firetube and small watertube boilers. The main control element is a bellows operated switch which is activated by the boiler steam pressure. When the pressure drops to a preset " cut-in " value the pressure switch starts up the draft fans and the burner. When the boiler pressure reaches a preset " cut-out " value then the pressure switch shuts down the boiler again.

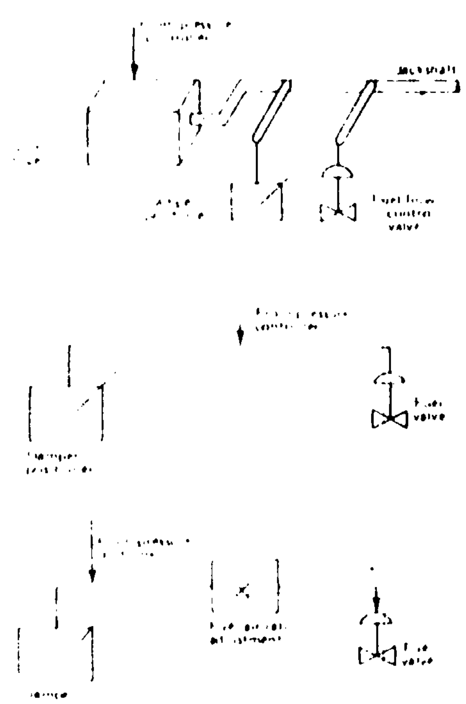
The main disadvantage of this system is that the boiler operation is inefficient plus the fact that boiler pressure varies appreciably between the " cut-in " and the " cut-out " point.

Positioning Control

In this system, as in the on-off control, steam pressure is the measured variable. The master controller responds to changes in steam pressure by positioning draft dampers and fuel valve by means of actuators in order to maintain the firing rate in accordance to boiler load.

The most simple arrangement of positioning control is to have the master controller operating a jackshaft. The jackshaft is linked to the damper and the fuel valve and operates these in parallel.

Another simple arrangement is to have the master controller send a signal in parallel to the damper actuator and to the fuel valve actuator. This arrangement can be improved by including a manual air/fuel ratio adjustment.



Parallel Positioning Arrangement

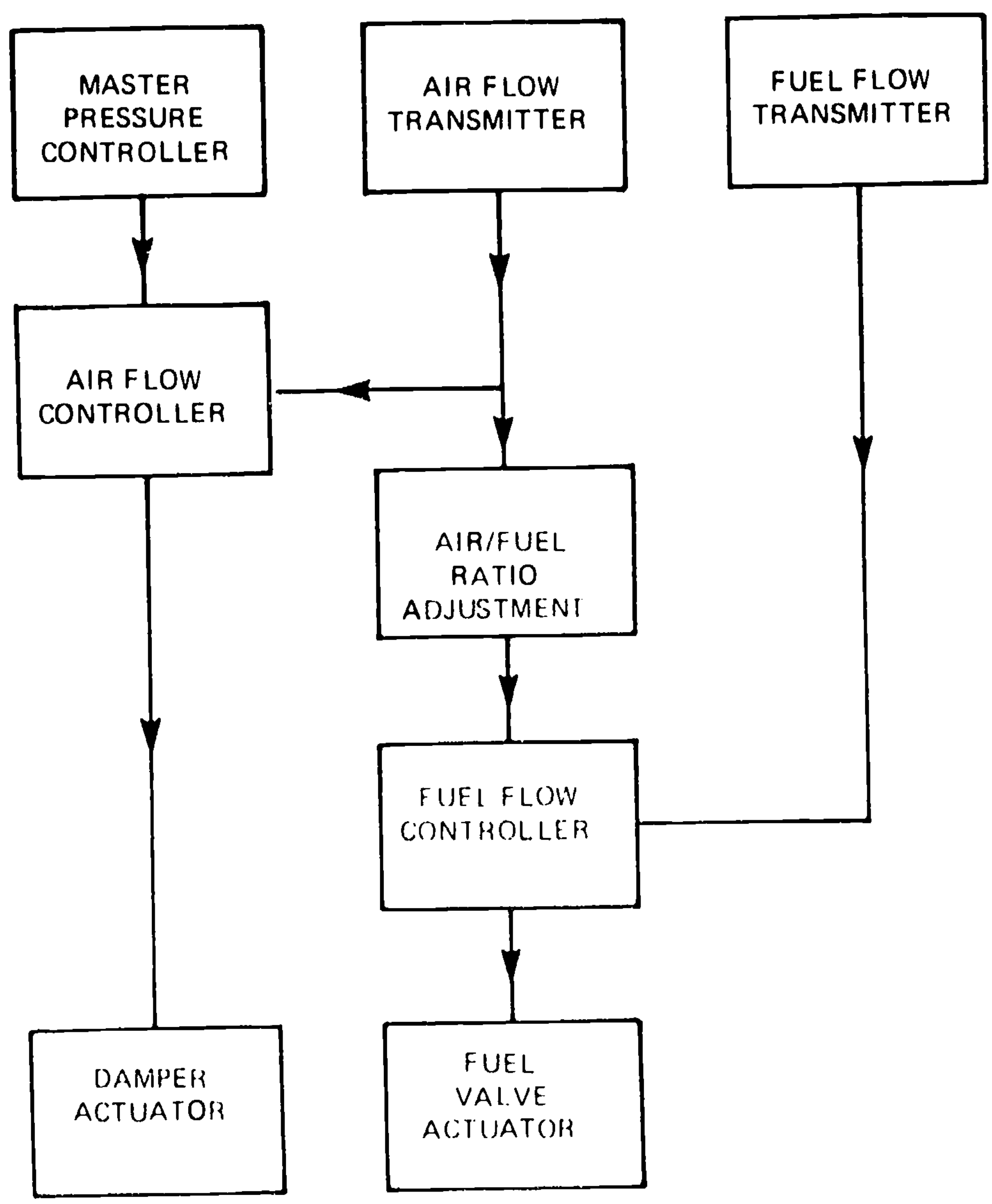
Fig. 40

Fig. 40 shows the three positioning control arrangements described above.

Metering Control

In the metering control system the master controller sends signals to the fuel valve and draft dampers as was done in the positioning system. However, with metering control these controller signals are modulated in accordance to actual fuel and air flows which are measured or metered. In this way an optimum fuel/air ratio can be maintained over the entire operating range.

The metering control system may be arranged in series or parallel. A block diagram of a series arrangement is shown in Fig. 41.



Metering Control Series Arrangement

Fig. 41

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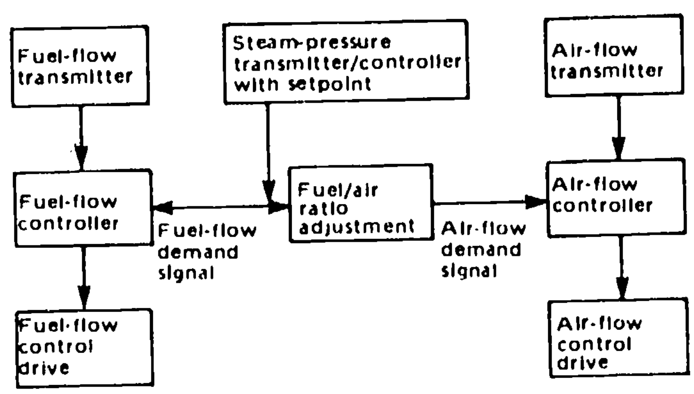
Referring to Fig. 41, on a change in boiler pressure the master controller signal will change causing the air flow controller to adjust damper position by means of the damper actuator. The air flow transmitter will sense the change in air flow and a feedback signal will be sent back to the air flow controller. The same signal will be sent through the air/fuel ratio adjustment to the fuel flow controller which will reposition the fuel valve by means of the fuel valve actuator. The fuel flow transmitter senses the change in fuel flow and a feedback signal is sent to the fuel flow controller. The amount that the fuel flow changes with a change in air flow depends upon the air/fuel ratio adjustment.

The parallel system of metering control is more commonly used than is the series system because it offers greater response to load changes since air and fuel flow corrections are made simultaneously.

A block diagram of a simple parallel system appears in Fig. 42.



Metering Control Parallel Arrangement

Fig. 42

Referring to Fig. 42, if the steam pressure decreases from the set point of the steam pressure transmitter/controller then this controller will transmit a demand signal to the air flow controller which compares the new air flow requirement with the metered feedback signal from the air flow transmitter. The resulting corrective output signal is sent to the air flow control drive which opens dampers or increases fan speed until the actual air flow matches the demand signal. At the same time the signal from the steam pressure transmitter/controller is also being received by the fuel flow controller which compares the new fuel flow requirement with the metered feedback signal from the fuel flow transmitter. The resulting corrective output signal is sent to the fuel flow control drive which adjusts the fuel valve until the actual fuel flow matches the demand signal.

Combustion Control Arrangements

It is necessary that the amount of combustion air be proportioned to the amount of fuel being burned and this proportioning can be done manually or automatically. The amount of air supplied must be over and above that required for theoretical perfect combustion in order to assure that sufficient oxygen contacts all the fuel. This air is referred to as excess air and it must be kept to a minimum otherwise boiler efficiency will decrease. Conversely if insufficient excess air is supplied then incomplete combustion will result giving lower boiler efficiency as well as the formation of combustible products that can present an explosion hazard in the boiler furnace and passes.

In order to determine the amount of air required for varying boiler loads, three basic guides are used for control systems. These are steam flow-air flow, fuel flow-air flow, and gas analysis.

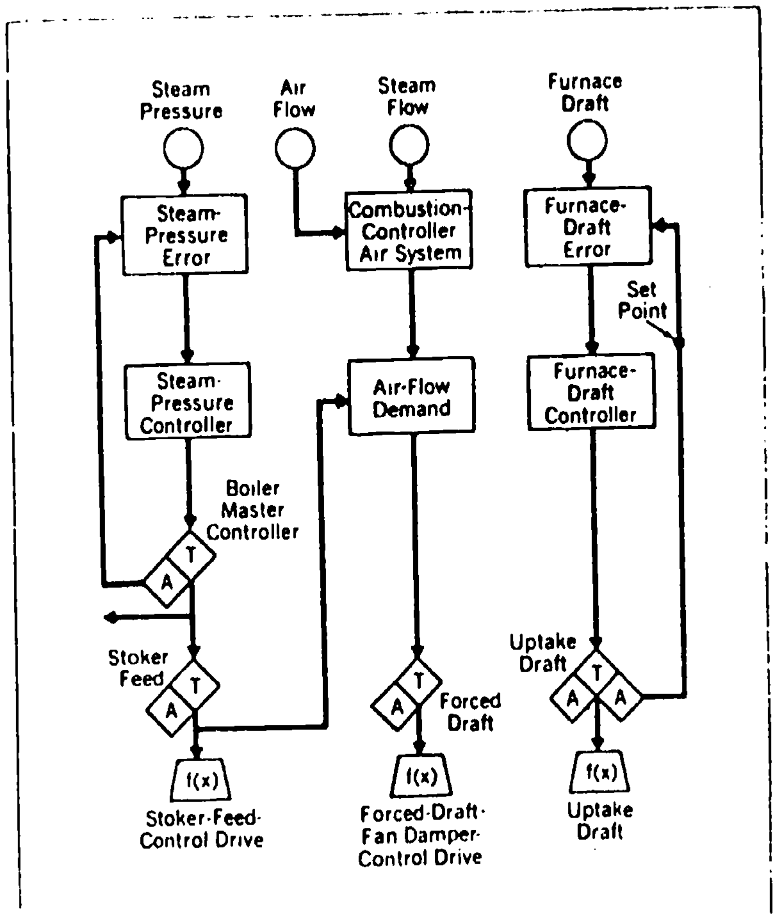
1. Steam Flow - Air Flow

As mentioned in the previous section, the proportion of air to fuel (air/fuel ratio) is extremely important as far as boiler efficiency and safety are concerned. The most direct way to determine whether the air and the fuel are in the correct amounts would be to measure the fuel flow and the air flow and to adjust them when necessary in order to maintain the correct ratio. However, with certain types of fuel, such as coal, it is difficult to measure fuel flow. In these cases, the steam flow is measured and is used as an indication of fuel consumption or heat absorption. The air flow is also measured and is maintained in a certain ratio with the steam flow. In this way a ratio is indirectly maintained between the air flow and the fuel flow.

A block diagram of a steam flow - air flow combustion control system is shown in Fig. 43.

Control symbols used in Fig. 43 are defined in Table 1.

Referring to Fig. 43, upon a change in boiler pressure, the steam pressure transmitter will simultaneously signal a change in both fuel flow and air flow through the steam pressure controller and boiler master controller. The correct air/fuel ratio is maintained by the combustion controller which receives signals from the steam flow transmitter and the air flow transmitter.



Steam Flow - Air Flow Control
(Babcock and Wilcox)

Fig. 4.

O -- Transmitter
— Hand-automatic selector station (analog control)
— Hand-automatic selector station (analog control)with bias
f (X) -- Power device (valves, drives, etc.)

Control Symbols

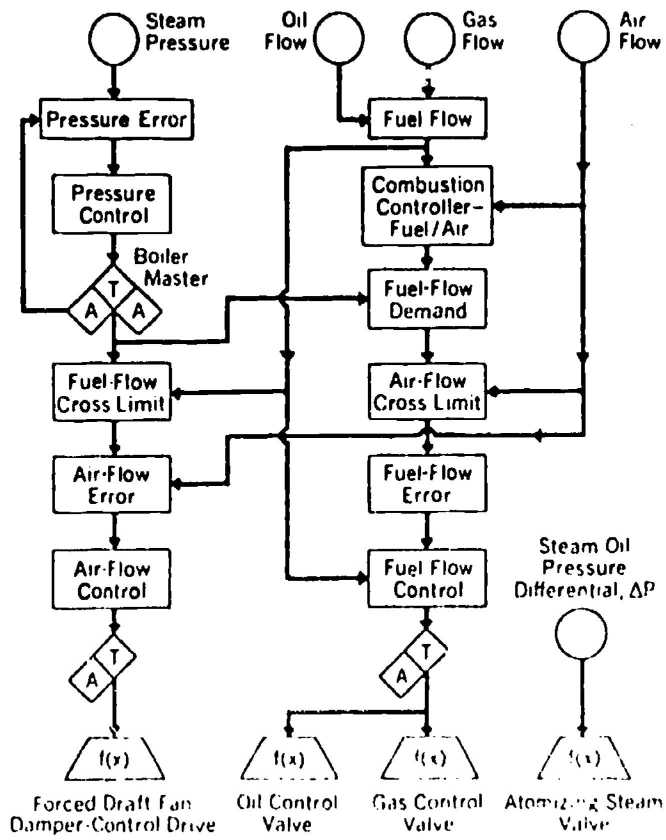
Table 1

A change in the air flow to the furnace will cause a change in furnace draft and the furnace draft controller will change the uptake draft to maintain the correct furnace draft.

2. Fuel Flow - Air Flow

The fuel flow - air flow system can be used where it is practicable to measure the fuel flow to the furnace as well as the air flow. These measurements can then be used to maintain the correct air/fuel ratio.

Fig. 44 is a block diagram of a fuel flow-air flow control system for a dual fuel boiler which can burn oil or gas separately or together.



Fuel Flow - Air Flow Control
(Babcock and Wilcox)

Fig. 44

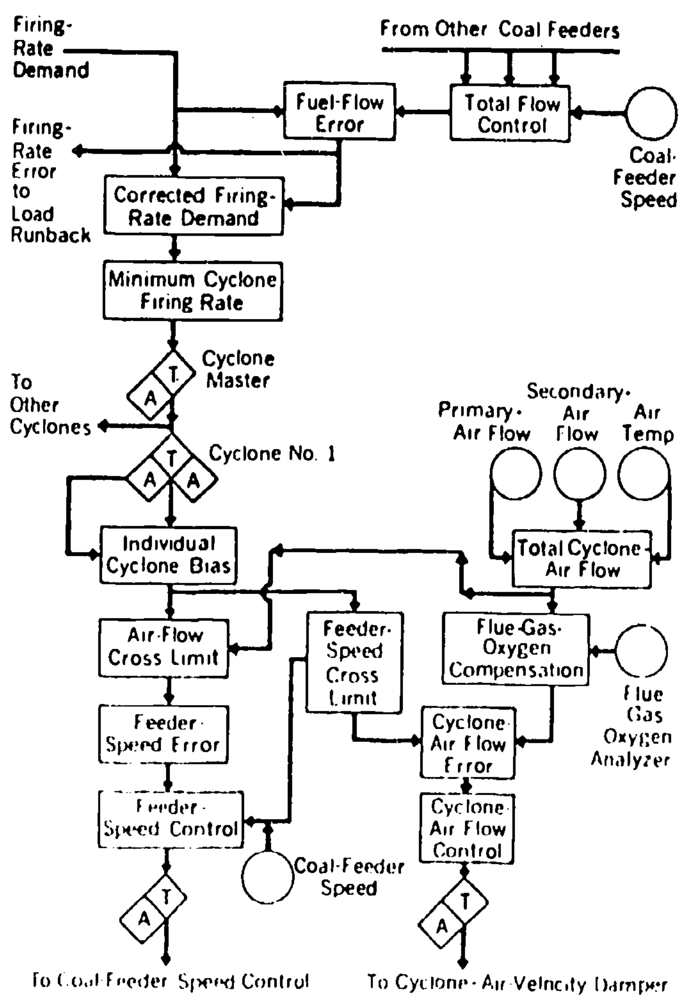
In the system in Fig. 44, the fuel and air flows are controlled according to changes in boiler steam pressure. The steam pressure transmitter signals through the boiler master to both the forced draft fan control and to the fuel control valves. The fuel flow is then readjusted to maintain correct air/fuel ratio by the fuel/air controller.

(PE 1-2-11-40)

3. Gas Analysis

Gas analyzers can be used to maintain correct air-fuel ratios. Flue gas samples are continuously analyzed and indications are made of the amounts of oxygen and combustibles present in the flue gas. The percentage of oxygen in the flue gas relates to the air/fuel ratio and a signal from the analyzer can be used for control purposes in adjusting the air flow to the furnace.

A block diagram illustrating a system of combustion control using a gas analyzer appears in Fig. 45.



Combustion Control with Gas Analyzer
(Babcock and Wilcox)

Fig. 45

(PE1-2-11-41)

The system in Fig. 45 is for a cyclone furnace fired boiler. On a change in firing rate demand due to a change in boiler pressure, a signal change is sent to the coal feeder speed control and to the cyclone air damper. The air flow is readjusted to maintain the correct air/fuel ratio by a signal from the flue gas oxygen analyzer.

A new concept for a combustion control guide is megawatt generation-air flow. The megawatts generated represent a direct index of heat input to the unit and this system is more accurate than the steam flow-air flow system as the relationship of steam flow to heat input can be affected by changes to feedwater or steam temperature. This is because a variation of either temperature necessitates more or less transfer of heat to each pound of steam. The megawatt generation-air flow method is now being applied in new boiler instrumentation and control systems for steam electric generating plants.

STEAM TEMPERATURE CONTROL

In the case of steam generators which produce superheated steam, it is necessary to maintain the temperature of the superheated steam at a constant value. The following reasons make this particularly important when superheated steam is used to drive a turbine.

1. Turbines are designed to operate most efficiently under set conditions of temperature.
2. Steam temperature changes will cause differential expansion or contraction between the turbine rotor and the turbine casing.
3. Excessive rise in steam temperature will cause weakening of metals used in both the superheater and the turbine.
4. Excessive drop in steam temperature will result in condensation taking place in the turbine low pressure stages with subsequent blade erosion and loss of efficiency.

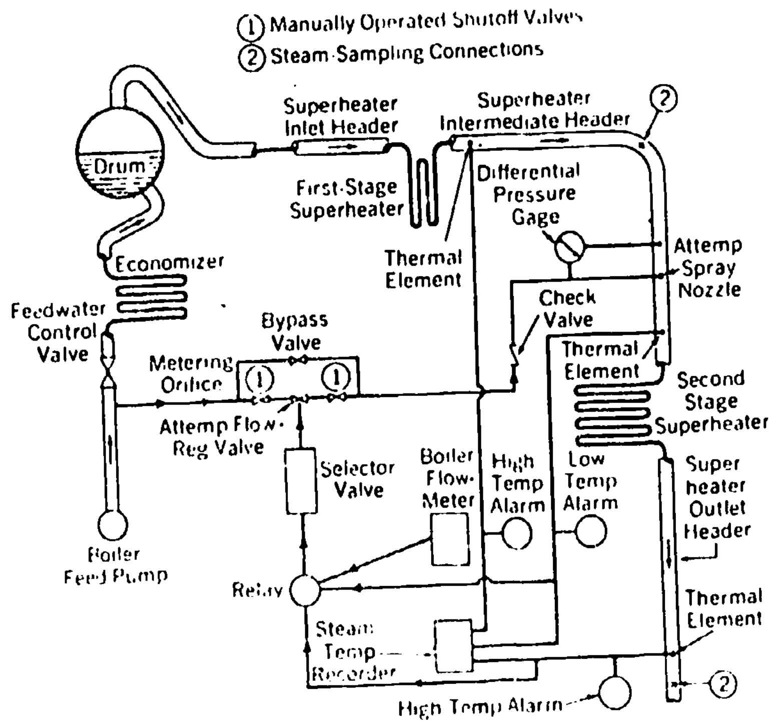
The main problem in steam temperature control is to maintain the same final steam temperature at both high and low loads. One or more of the following methods may be used to achieve this control.

1. Desuperheating
2. Attemperation
3. Gas recirculation
4. Gas bypass
5. Twin furnace
6. Tilting burners

These methods were all described in Lecture 3, Section 2.

Because of the thermal inertia in large superheaters, the response of steam temperature to the controlling mechanism is quite slow. Therefore in order to anticipate any steam temperature changes, the combustion air flow or the steam flow is measured and a signal transmitted which governs the initial adjustment of the control. The final adjustment is by final steam temperature. This arrangement is known as a two element control, the two elements being air or steam flow and final steam temperature.

An improvement on the foregoing system is the three element control which can be used with spray attemperators. Fig. 46 illustrates the arrangement.



Three Element Temperature Control
(Babcock and Wilcox)

Fig. 46

In the system in Fig. 46, three signals are received by the attemperator regulating valve relay. One signal from the flow meter (steam or air), one signal from the thermal element located after the attemperator spray nozzle and before the second stage superheater, and one signal from the thermal element located after the second stage superheater (final steam temperature). The initial response to temperature changes is provided by the signal from the flow meter and the signal from the thermal element located just after the attemperator spray nozzle. Final adjustment is according to final steam temperature as signalled by the thermal element located after the second stage superheater.

(PE1-2-11-43)

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 11

1. (a) Sketch, describe, and compare the three principle primary flow elements used to create differential pressure in a line.

   (b) Explain the relationship between flow and differential pressure.

2. Sketch and describe briefly the arrangement of a float manometer used for boiler water level indication.

3. Describe the functions of the following control co. ,onents:

   (a) the controller

   (b) the transmitter

   (c) the actuator

4. With the aid of simple sketches, define and explain:

   (a) On - off action

   (b) proportional action

   (c) integral action

   (d) derivative action

5. With the aid of sketches, describe the operation of the following:

   (a) pneumatic transmitter

   (b) electronic transmitter

6. Explain the purpose of a positioner used in conjunction with an actuator.

7. Describe briefly the basic arrangement of each of the following feedwater control systems:

   (a) single element

   (b) two element

   (c) three element

(Continued)

8. Describe generally the following combustion control systems:

   (a) On - Off

   (b) positioning

   (c) metering

9. Explain the principle of operation of each of the following combustion control arrangements:

   (a) steam flow-air flow

   (b) fuel flow-air flow

10. Discuss steam temperature control with reference to methods, problems, and necessity.

INSTRUCTIONAL LEARNING SYSTEMS

7.9

BOILERS -- PIPING AND STEAM TRAPS

Goal:

The apprentice will be able to describe the parts of a boiler piping system.

Performance Indicators:

1. Describe piping materials and connections.
2. Describe types of valves.
3. Describe steam traps.
4. Describe bypass and drain lines.
5. Describe water hammer.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Alloy steel pipe
* Brass pipe
* Bypass and drain line
* Carbon steel pipe
* Check valve
* Control chamber
* Couplings
* Drag Valve
* Elbows
* Flanges
* Gate valve
* Globe valve
* Impulse trap
* Inverted bucket trap
* Laterals
* Outlet orifice
* Plastic pipe
* Plug valve
* Reducers
* Stainless steel pipe
* Steam trap
* Tees
* Water hammer

Introduction

The piping for transporting water, steam and condensate through the power plant is a complex system. These materials are handled at a wide range of temperatures and pressures. Each set of conditions require piping with characteristics for handling the material without becoming corroded or eroded.

The piping system must have valves for controlling the movement of the fluids through the plant. Steam traps are necessary for removing condensate from the steam as it travels through the piping.

Information

Piping

There is a wide variation of pressures, temperatures and chemical composition of fluids handled through a power plant. Different fluids require different pipes for their transport through the plant. Some of the common piping materials and their applications are listed below.

Alloy steel -- high pressure, high temperature.

Carbon steel -- high pressure, moderate temperature.

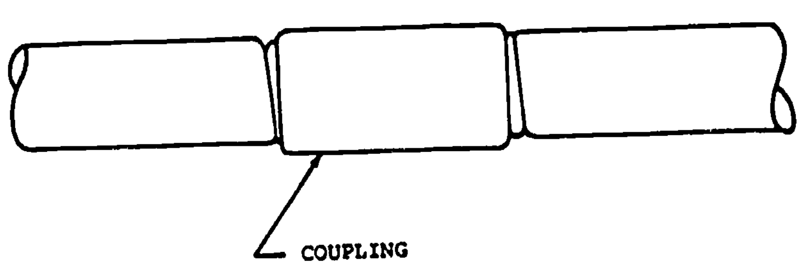
Stainless steel -- extreme high pressure and temperature and maximum corrosion and erosion resistance.

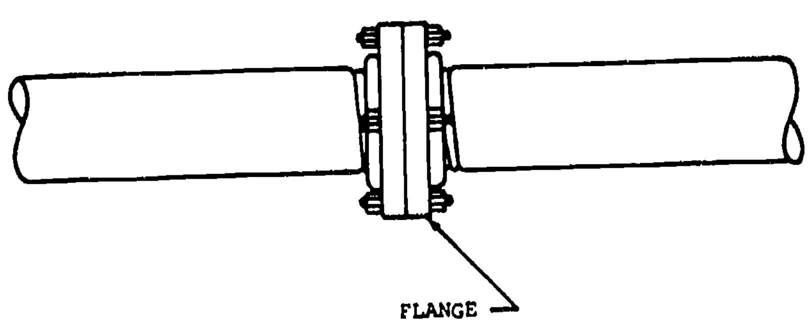
Copper -- Low pressure, low temperature where cleanliness is essential.

Brass -- low pressure, low temperature where corrosion resistance is important.

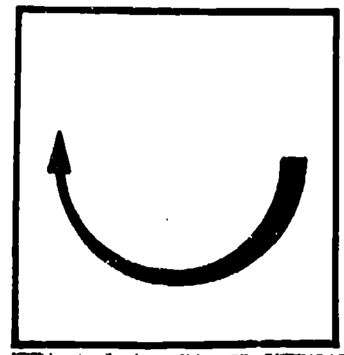
Plastic -- low pressure and temperature where corrosion resistance is important.

Pipes are joined together with couplings, flanges and welded connections.

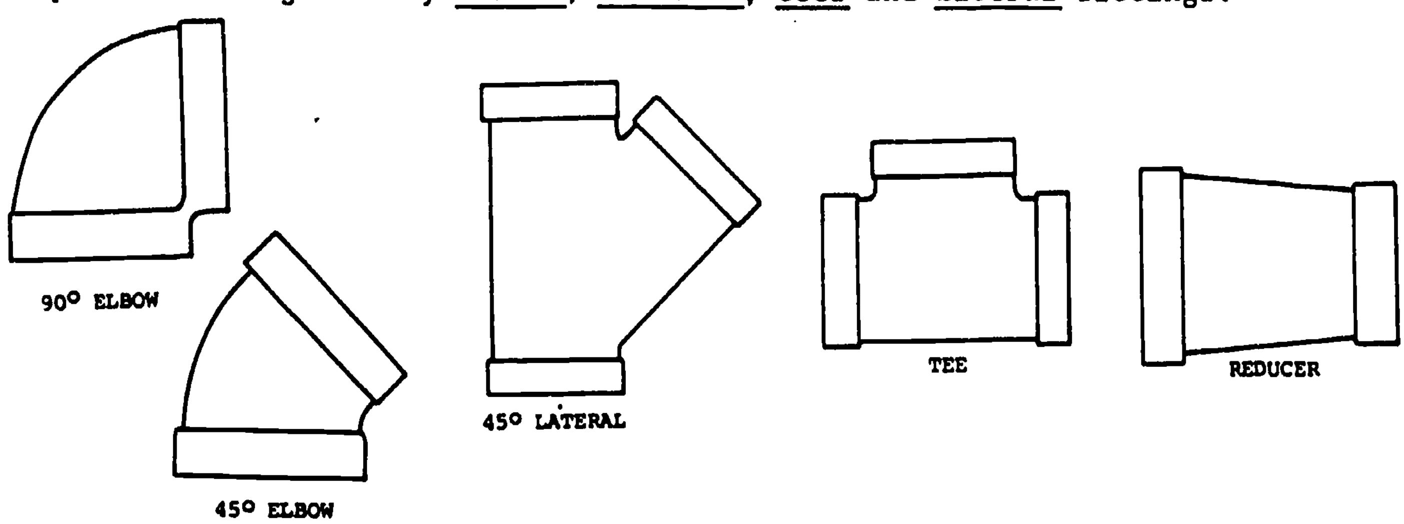




Information



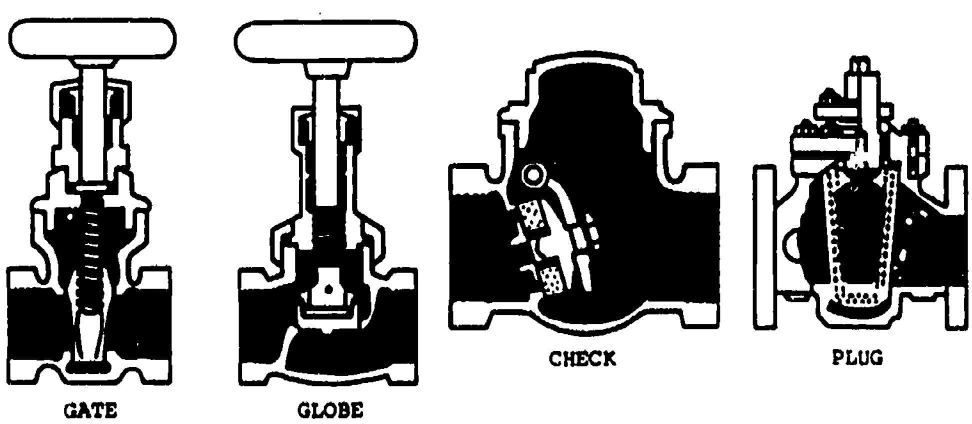
Pipes are also joined by elbows, reducers, tees and lateral fittings.

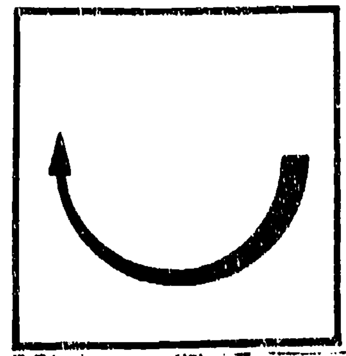


As pipe is subjected to extremes in temperature, it tends to expand and contract. This can cause problems unless allowances have been made for handling expansion and contraction. Expansion can be controlled by use of expansion joints and levels and loops.

Valves

The pipeline contains several valves which control the flow of liquid. One classification of valves is by their function, i.e. stop valve, throttle valve, control valve. Another method of classification is according to the construction of the valve. The gate valve, globe valve, check valve and plug valve are shown below.

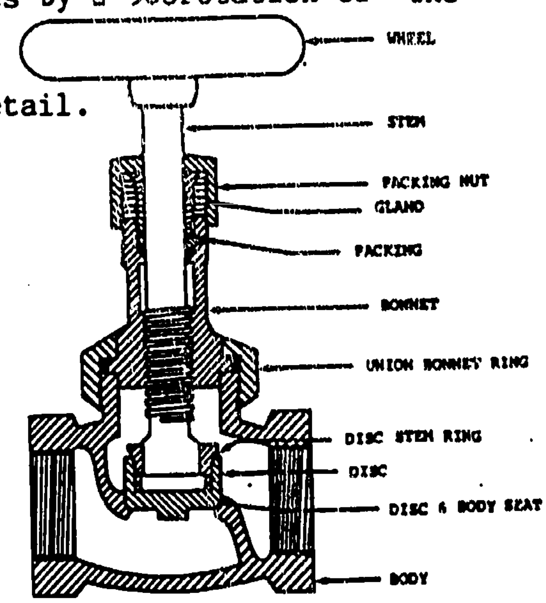




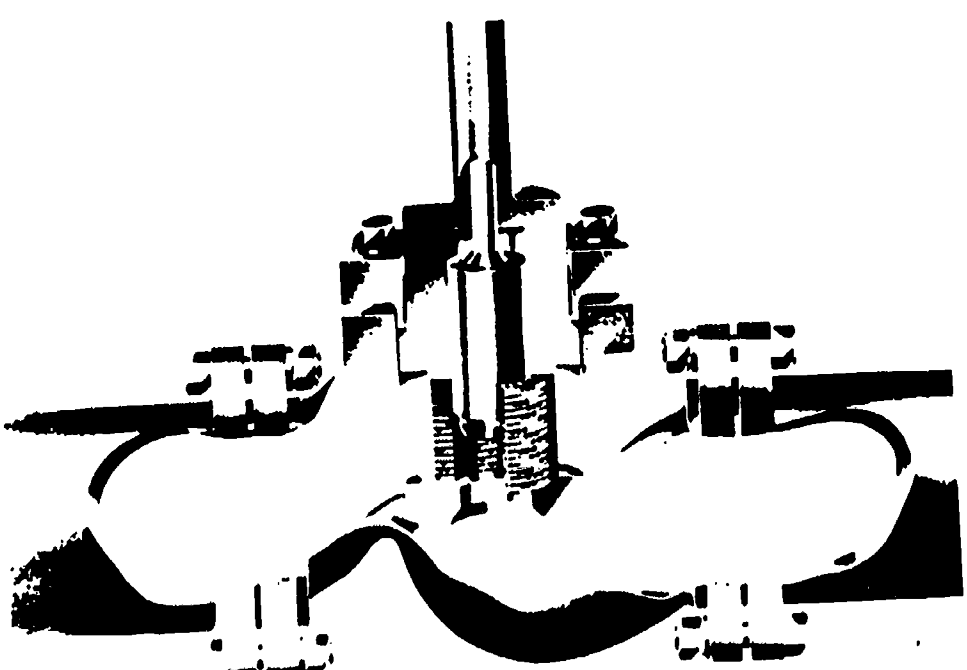
Information

Note that the gate valve is closed by a wedge that moves up and down from a central stem that is perpendicular to the line of flow. The globe valve has a seat ring that lies parallel to the line of flow. Check valves only allow a flow in one direction. A plug valve opens and closes by a 90o rotation of the cylinder.

The individual parts of a globe valve are shown in detail.



There are a number of special valves used in power plants. One of these is the drag valve. The drag valve is a pressure control valve which consists of a series of stacked discs with flow passages etched into their faces.



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Information

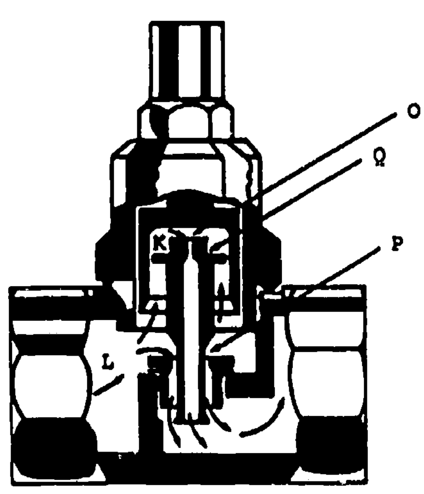
Valves are usually provided with handwheels or other means of leverage that make them easy to open. Care must be excercised to prevent leakage through closed valves. Once a valve starts to leak through, it will continue to erode. No matter how much pressure is applied, it will continue to leak.

Steam Traps

A steam line must be drained of condensate. All steam lines need drains to remove the condensate. The removal of condensate from a steam line is done with steam traps. A steam trap holds the steam while condensate continues to flow. Two types of steam traps are commonly used:

* Impulse traps
* Inverted bucket traps

In the impulse trap, the pressure of the condensate acts on the underside of the control disc (Q). This opens the outlet orifice (P) which allows condensate to flow through. As the condensate drains it is replaced by more and hotter condensate. The arriving condensate flashes into steam around the edge of the control disc into control chamber (K). This pressure forces the control disc down and shuts off the trap. When the condensate cools, the trap will open again.



IMPULSE TRAP

L. INLET CHAMBER

K. CONTROL CHAMBER

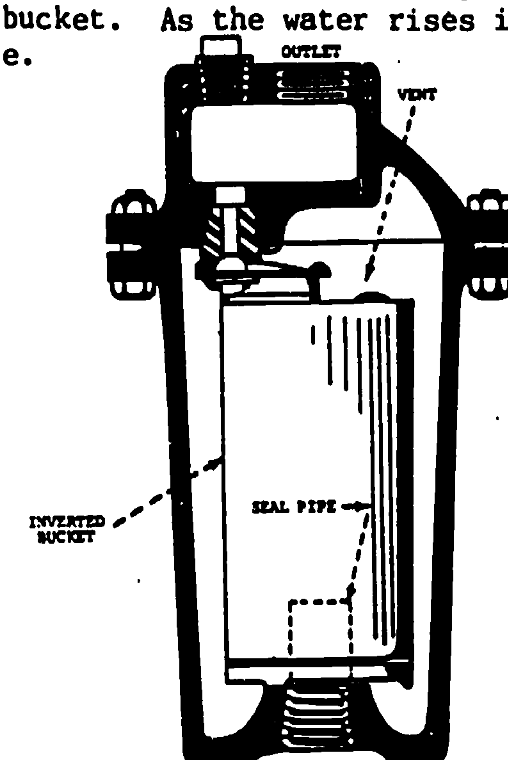
O. CONTROL ORIFICE

Q. CONTROL DISC

P. OUTLET ORIFICE

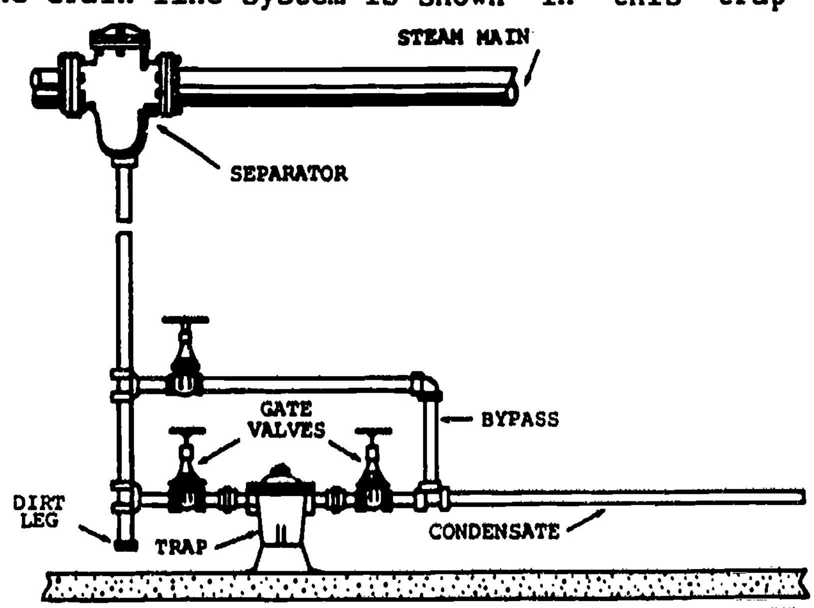
Information

The inverted bucket trap operates somewhat differently than the impulse trap. When the trap is full of water, the bucket rests on the bottom of the reservoir with its open end over the trap inlet. The trap discharge valve is open. When steam acts upon the water, it causes water to be pushed out of the trap. Steam replaces the discharged water, causing it to rise and close the discharge valve. The closed end of the bucket has a vent hole for air and steam to escape. As steam and air escape, more water rises in the bucket. As the water rises in the bucket, it sinks and closes the discharge valve.



Bypass and Drain Lines

Bypass lines are secondary pipelines through which fluids are routed while the main lines are out of service. Drain lines are used to remove condensate from steam lines. A typical bypass and drain line system is shown in this trap installation.



Information

Water Hammer

When water is confined under high pressure, it can be very dangerous. If the flow of water is suddenly stopped, it can lead to a condition known as water hammer. It is a shock force that can cause explosion of the line. Vertical waterlines are more likely to have water hammer than horizontal lines. Valves should be opened slowly to avoid waterhammer in either water or steam lines. Hammers in steam lines can occur when hot water is admitted into a cold line. Within steam lines, this condition is more likely to happen in long, horizontal lines. This differs from waterlines which more often occur in vertical lines.

Assignment

* Complete job sheet.
* Complete self-assessment.
* Complete post-assessment.

Job Sheet

INSPECT THE PIPING OF A STEAM PLANT

* Carefully inspect each pipe that enters the boiler.
  - Where does the pipe come from?
  - What does it carry?
  - How are pipes connected? flanges, couplings?
  - What type of material? alloy steel, copper?
  - What kinds of valves do you see? gate, globe, plug, etc.?
  - Can you locate the steam traps?
  - What type of steam trap?
  - Is there bypass and drain lines?
  - Do you find piping, valves and traps that are different from the descriptions in the learning package?
* Ask the operator to explain those items that were not described in package.

Self Assessment

Match the following terms with the most appropriate description.

_______	1. Gate valve	A.	Materials used for high temperature and high pressure pipe.
_______	2. Inverted bucket	B.	Material used for extreme high pressure and temperature pipe with maximum corrosion resistance.
_______	3. Water hammer in waterlines	C.	Method of joining sections of pipe together.
		D.	Valve seat ring lies parallel to the line of flow.
_______	4. Alloy steel	E.	Valve wedge lies perpendicular to the line of flow.
_______	5. Copper	F.	A type of steam trap.
		G.	More likely to occur in vertical lines.
_______	6. Stainless steel	H.	More likely to occur in long, horizontal lines.
_______	7. Couplings	I.	Material used in low pressure, low temperature piping that requires cleanliness.
_______	8. Waterhammer in steam lines		
_______	9. Globe valve	J.	Material used in low temperature, low pressure piping where corrosion resistance is important.
_______	10. Plastic		

Self Assessment Answers

___E___ 1.

___F___ 2.

___G___ 3.

___A___ 4.

___I___ 5.

___B___ 6.

___C___ 7.

___H___ 8.

___D___ 9.

___J___ 10.

Post Assessment

1. What causes a water hammer in a waterline?

2. What causes a water hammer in a steam line?

3. What piping material would you select for extreme high temperature and pressures and corrosion resistance?

4. What piping material would you select for high pressure and moderate temperatures?

5. Which piping material would you select for low temperatures, low pressures and cleanliness?

6. List two connecting methods for joining pipe.

7. List two fittings used to join pipe together.

8. List two types of steam traps.

9. What kind of valve is a drag valve?

10. Which type of valve allows water to flow in only one direction?

Instructor Post Assessment Answers

1. Sudden stopping of flow of water under pressure.

2. Admitting hot water into a cold steam line.

3. Stainless steel

4. Carbon steel

5. Copper

6. Couplings, flanges, welding

7. Elbows, tees, reducers, laterals

8. Impulse, inverted bucket

9. Pressure control valve

10. Check

Supplementary References

* Instruction Manual. Operator Training Program. Volume I. Pacific Gas and Electric Company. 1974.