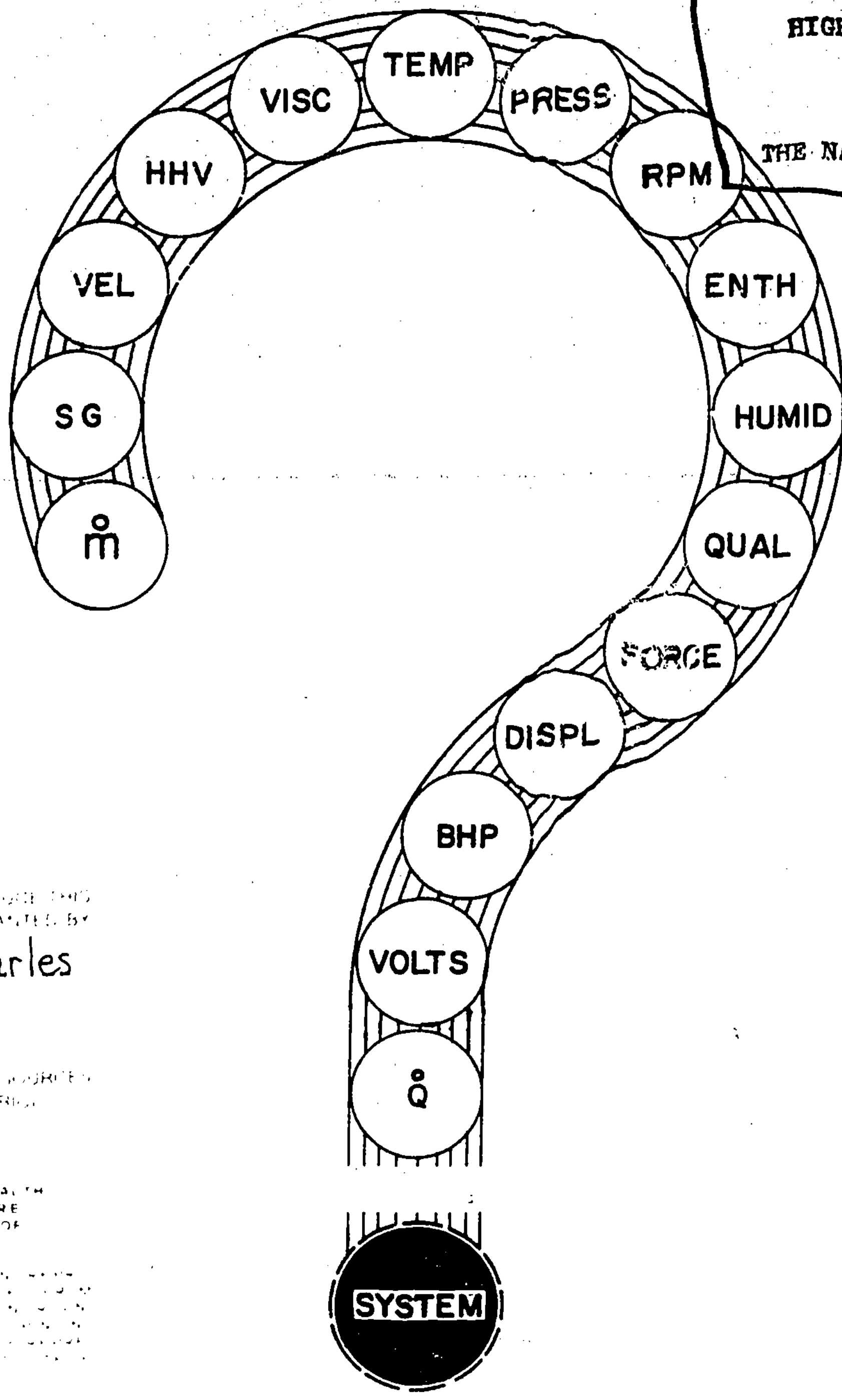
ED 174 462 SE 028 533

AUTHOR	Avakian, Harry; And Others
TITLE	Wentworth Institute Mechanical Engineering Laboratory Manual. Laboratory Study Guide.
INSTITUTION	Wentworth Inst., Boston, Mass.
SPONS AGENCY	National Science Foundation, Washington, D.C.
PUB DATE	Jun 75
GRANT	NSF-GY-9226
NOTE	120p.; For related documents, see SE 028 532 and SE 028 543; Page 18b, Chart A-4, "Pressure-Enthalpy Diagram," removed due to copyright restrictions
EDRS PRICE	MF01/PC05 Plus Postage.
DESCRIPTORS	College Science; *Engineering Education; Graphs; Heat; Higher Education; Illustrations; *Laboratory Manuals; Mechanics (Physics); *Physics; Science Education; *Science Experiments; Science Instruction; Temperature; *Thermodynamics

ABSTRACT

This publication is a laboratory study guide designed for mechanical engineering students. All of the experiments (with the exception of experiment No. 1) contained in the Mechanical Engineering Laboratory Manual have been included in this guide. Brief theoretical backgrounds, examples and their solutions, charts, graphs, illustrations, and sketches are also included for many experiments. The publication presents many questions to be answered, and many problems to be solved. Among other things, the questions and problems deal with pressure measurement, thermodynamics, fan laws, engine testing, and vapor compression systems. (GA)

MECHANICAL ENGINEERING LABORATORY MANUAL



AVAKIAN
JOBSE
LIPMAN
TAVARES
WHITTEMORE

LABORATORY STUDY GUIDE

WENTWORTH INSTITUTE
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Mechanical Engineering Laboratory Manual

Laboratory Study Guide

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Under Grant No. GY 9226 from National Science Foundation

June 1975

Name:

Section:

Experiment No. 2

Pressure Measurement

1. Convert 10 in Hg to the following:

   a. p.s.i. -

   b. feet of water -

   c. atmospheres -

   d. microns of Hg -

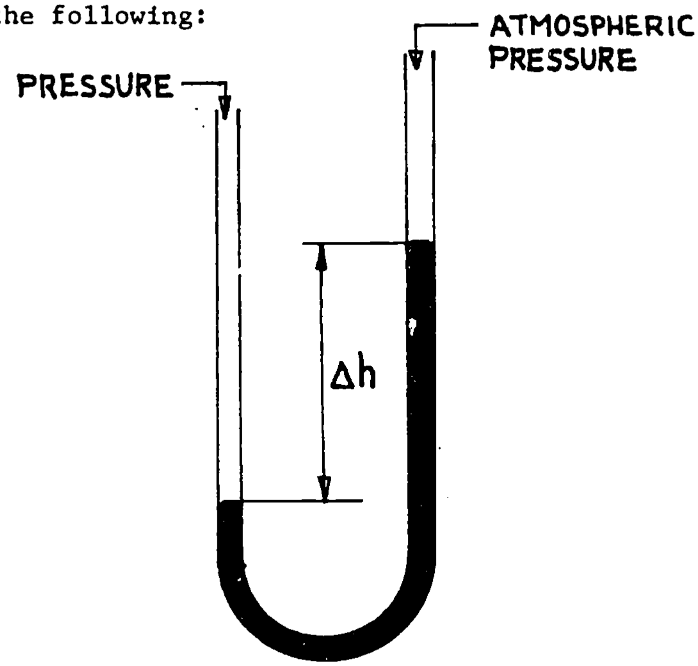
2. A mercury manometer reads 29.0 in vacuum at a location where the barometric pressure is 29.90 in Hg. Determine the absolute pressure in p.s.i.

3. A Bourdon tube gage reads 20 p.s.i. at a location where the barometric pressure is 29.92 in Hg. Determine the absolute pressure in p.s.i.

4. A Bourdon tube gage reads 10 in Hg vacuum at a location where the barometric pressure is 29.92 in Hg. Determine the absolute pressure in p.s.i.

5. In an inclined manometer, the inclined tube is at 10 degrees from the horizontal plane. By what factor is the sensitivity of this manometer increased as compared to that of a U-tube manometer.

6. For the U-tube manometer shown Δh = 20 in. liquid.
   Determine the following:



a. Gage pressure in p.s.i.g. if Δh = 20 in. H.g.

b. Absolute pressure in p.s.i. if the barometer reads 29.92 in Hg.

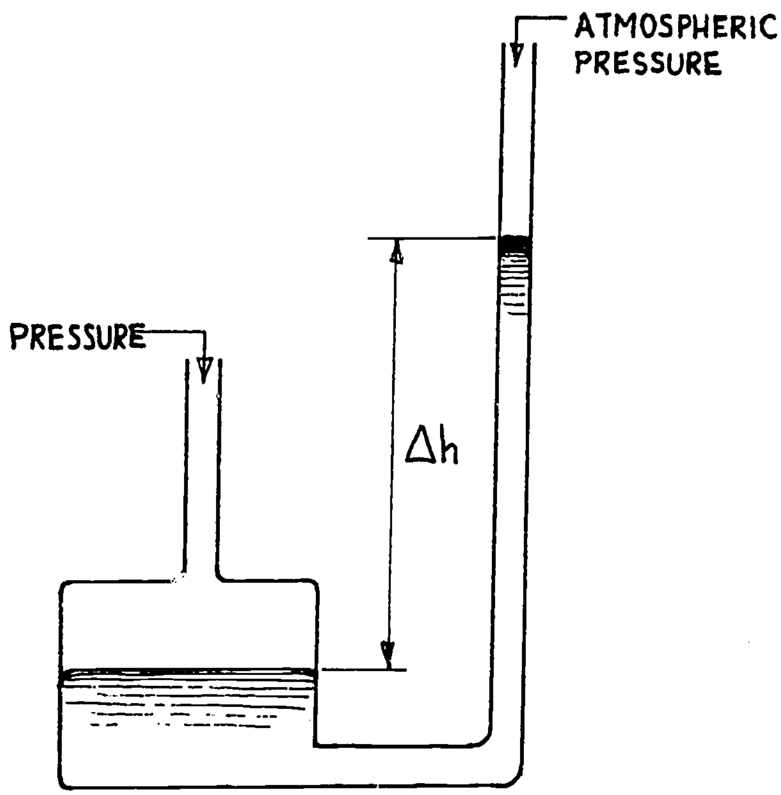
c. Gage pressure in p.s.i. if Δh = 20 in. liquid with a specific gravity of 0.8.

7. The following data is available for the mercury filled manometer.

Area of well = 10 in^2

Diameter of tube = 1/4 in

What would be the height of glass tubing required if the maximum pressure to be measured is 5 p.s.i?



Name: Section:

Experiment No. 3 Area Measurement

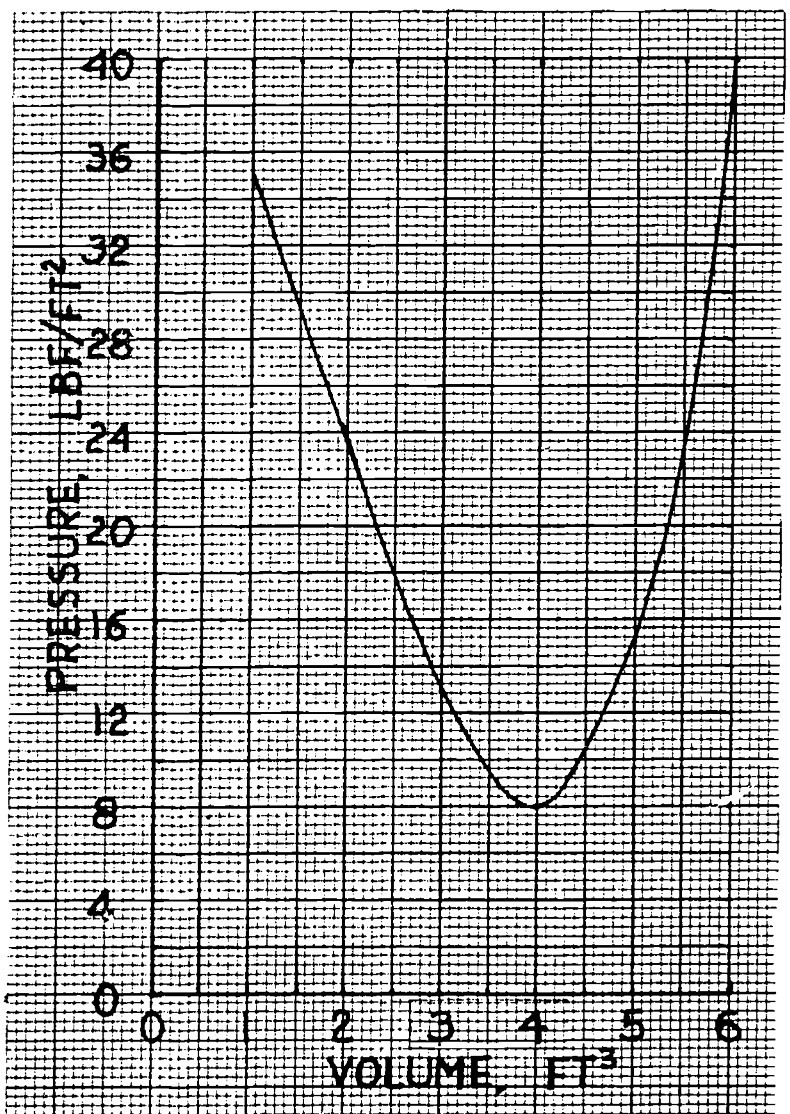
The relationship between the pressure and volume of a system during an expansion process is:

$$P = V^3 - 6V^2 + 40$$

$$P = lb_f/ft^2$$

$$V = ft^3$$

The following curve is a plot of this relationship.



3

1. Determine the area in ft-lbf under this curve by the following methods:

   a. Average height method

   b. Simpson's Rule

3

c. Integration

2. Calculate the percent error of each method by comparing it with the integrated result.

3. What is the significance of the area under the curve?

3

4. Convert the area obtained from the average height method into in^2.

5. Using the value obtained by integration, determine the mean ordinate (average pressure) in lb_f/ft^2.

4

Name: Section:

Experiment No. 4 Temperature Measurement:

1. The expansion of a liquid in a tube can be used to indicate a temperature change. Name other property changes that are used to indicate temperature changes.

2. Total immersion type thermometers often require a correction when used in partial immersion situations. Why is this correction necessary?

3. A total immersion mercury in glass thermometer is being used in a partial immersion situation. The thermometer reads 400^{o}F. and is immersed to a scale reading of 100^{o}F. A second thermometer attached to it (see Fig. 1 - experiment No. 4) indicates 120^{o}F. as the temperature of the exposed stem. Assuming no errors in the thermometer readings, determine the true temperature.

4

4. Convert the following centigrade readings to degrees Fahrenheit and degrees Rankine.

   a. $0^{\circ}C$

   b. $100^{\circ}C$

   c. $200^{\circ}C$

   d. $400^{\circ}C$

5. Most potentiometers can be compensated for room temperature or can be used uncompensated with a constant temperature reference junction such as an ice-water mixture. Which method should provide more accurate results? Why?

6. There are various methods that are used by manufacturers to express the accuracy of measuring devices. The following are typical:

$\pm$ % - Full Scale

$\pm$ % - Reading

$\pm$ % - Span

Assume you have three thermometers with ranges of 200°F. to 500°F. The accuracy of these thermometers are:

a. $\pm$ 1% - Full Scale

b. $\pm$ 1% - Reading

c. $\pm$ 1% - Span

The three thermometers are immersed in a bath maintained at 400°F. Which thermometers will be most accurate on an absolute basis?

Additional Information:

In many industrial applications, the primary system used for measuring temperature is the filled thermal system. These consist of a bulb, capillary tube, and Bourdon tube measuring element.

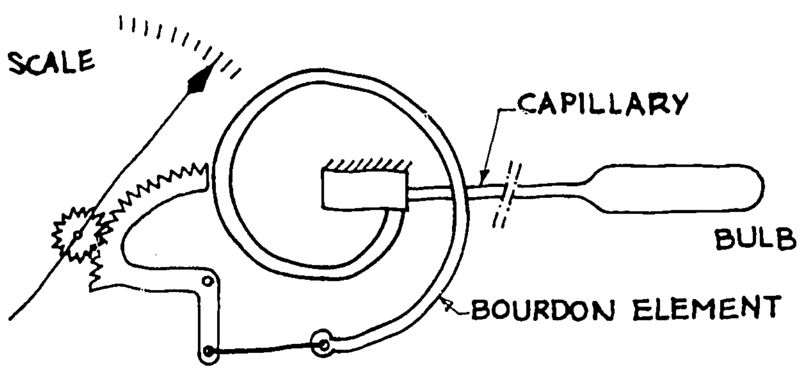
The Scientific Apparatus Manufacturers Association (SAMA) divides filled thermal systems into the following classification:

Class I — Completely filled with liquid (other than mercury), operates on the principle of liquid expansion.

Class II — Partially filled with a volatile liquid such as methyl chloride or ethyl alchohol, operates on the principle of vapor pressure.

Class III — Filled with an inert gas such as nitrogen or helium, operates on the principle that the pressure of a gas in a closed container is proportional to its absolute temperature.

Class V — Same as Class I - Mercury filled.



TYPICAL FILLED SYSTEM

Name:

Section:

Experiment No. 5

Specific Gravity Measurement

1. The weight of a cubic foot of lead is 707.6 lb at $60^{o}F$. while that of water is 62.4 lb. Compute the specific gravity of lead.

2. Gasoline has a specific gravity of 0.75. What is its density in:

   a. lbm/ft^3

   b. $Slugs/ft^3$

3. The A.P.I. reading of an oil is 35.4 degrees at a temperature of $82^{o}F$. Using appropriate tables what is the corrected A.P.I. reading at $60^{o}F$?

4. The A.P.I. reading of an oil is 35. degrees at a temperature of $60^{o}F$. What is its specific gravity?

5. The specific gravity of an oil is 0.8. What would be its A.P.I. reading at 60^{o}F.

6. A straight tube hydrometer sinks to a depth of 10 inches when immersed in water. To what depth will it sink if immersed in a liquid whose specific gravity is 0.75.

7. The following relationship can be used to correct a hydrostatic balance reading.

S.G. @ 60^{o}F. = Balance Reading + 0.000295 (sample temperature - 60^{o}F)

Determine the specific gravity at 60^{o}F., if the balance reads 0.8758 at a sample temperature of 78^{o}F.

6

Name: Section:

Experiment No. 6 Speed Measurement

A problem that arises in the use of instruments for measurement of physical properties is related to the accuracy of the device being used. The inability of any instrument to indicate the exact value of the measured quantity is a function of:

a. Condition of instrument
b. Accuracy of instrument
c. Human error

If accuracy is to be maintained, periodic calibration of instruments must be made against some acceptable standard. Three sets of curves may be generated indicating the accuracy of the device to be used. These are:

a. Calibration curve
b. Error curve
c. Correction curve

A calibration curve is a plot of instrument reading as ordinate and the "true" value as the abscissa.

The error curve is algebraically opposite to the correction curve. The error is the observed value minus the true value. The error curve is plotted with instrument reading as abscissa.

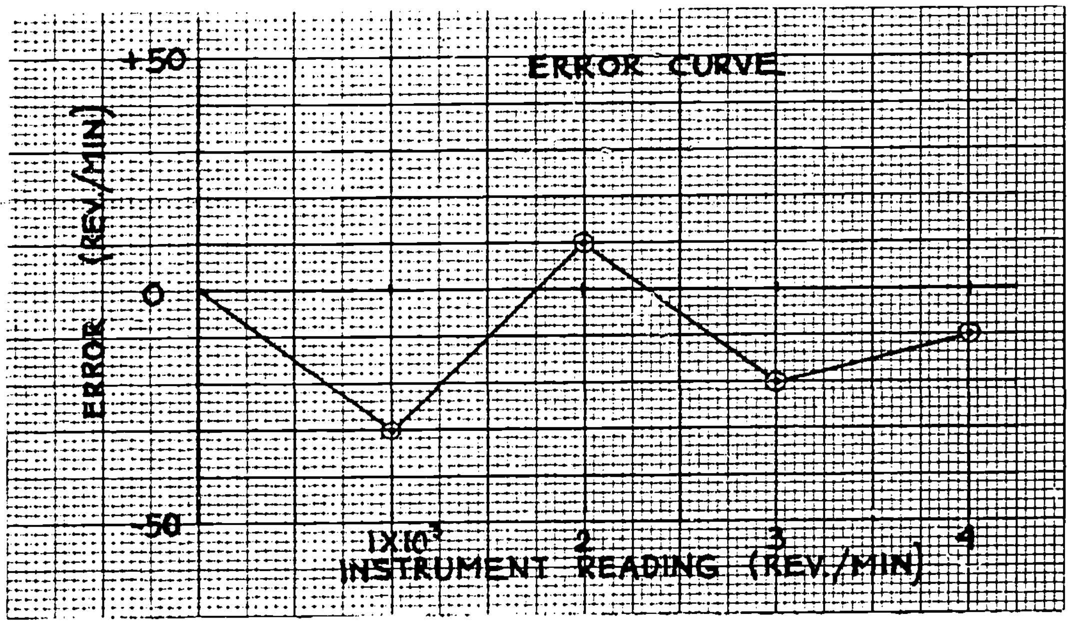
True value = instrument reading - error

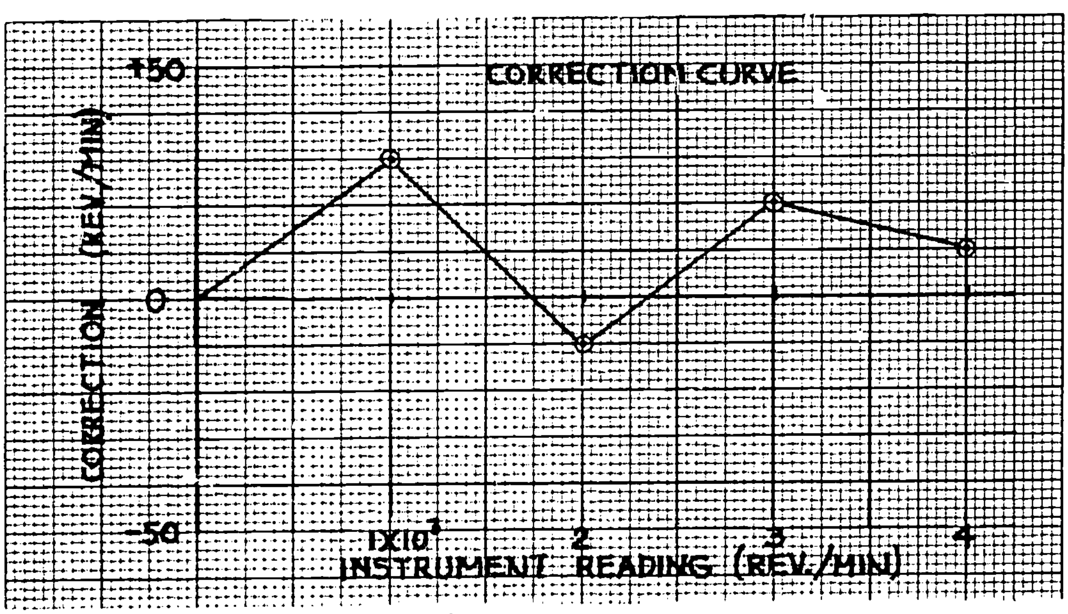
The correction curve has as its abscissa the instrument reading and as its ordinate the value which must be added algebraically to obtain the true value. The correction curve has negative as well as positive numbers

6

True value = instrument reading + correction

The following two sets of curves have been generated for a measuring device:





1. Using the curves generated on previous page, fill in the following table.

INSTRUMENT READING	TRUE VALUE	
	ERROR CURVE	CORR. CURVE
1000		
2000		
3000		
4000		

The following table shows data obtained for purposes of calibrating a hand tachometer. The strobatac is used as the standard of calibration.

STROBOTAC READING RPM	INSTRUMENT READING RPM	ERROR RPM	CORRECTION RPM
2000	2060		
1800	1780		
1500	1630		
1400	1400		
1200	1210		
1000	970		

2. a) Fill in error and correction values.
   b) Draw a correction curve.
   c) Draw a calibration curve.

7

1. Using appropriate refrigerant tables, identify the refrigerant represented by each plot.

curve no. 1 refrigerant ________

curve no. 2 refrigerant ________

curve no. 3 refrigerant ________

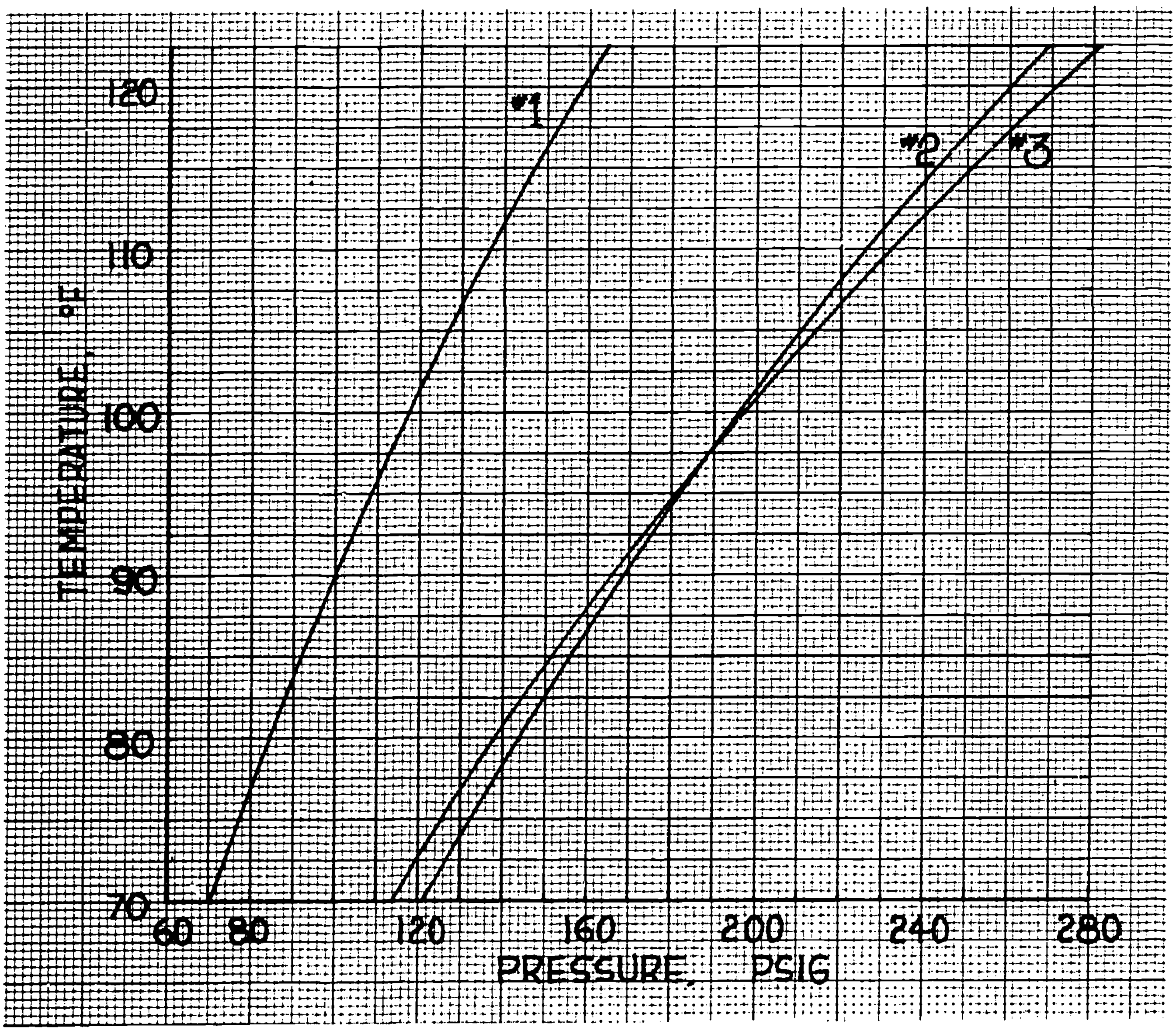
2. Referring to curves, complete the following table.

REFRIGERANT	TEMPERATURE °F	PRESSURE PSIG
	70	70
R-22		145
R-717	70	
	100	198
R-717		166
R-12		146.7
R-22	115	
	120	262
R-12		136
	90	170

Name: Section:

Experiment No. 7 Pressure-Temperature Relationship

The following curves of pressure versus temperature for three commonly used refrigerants have been generated from tabular data:



3. Answer the following questions:

   a. A refrigeration system is not in operation. The room temperature is 80°F., and a pressure gage attached to the receiver containing liquid and vapor at room temperatures reads 84.1 p.s.i.g. What refrigerant is being used in system?

   b. A drum contains an unknown refrigerant at 80°F., the pressure gage reads 145 p.s.i.g. What refrigerant is contained in drum?

   c. It is necessary to determine the temperature in a given space. No thermometers are available, however a drum of R-22 and pressure gages are available. How may the space temperature be determined?

d. A container of pure water at $70^{\circ}F$. is subjected to a vacuum.

1. What is the minimum absolute pressure that would precipitate the boiling process?

2. If the pressure was lowered, what would happen to the temperature of the water in the container?

Name:

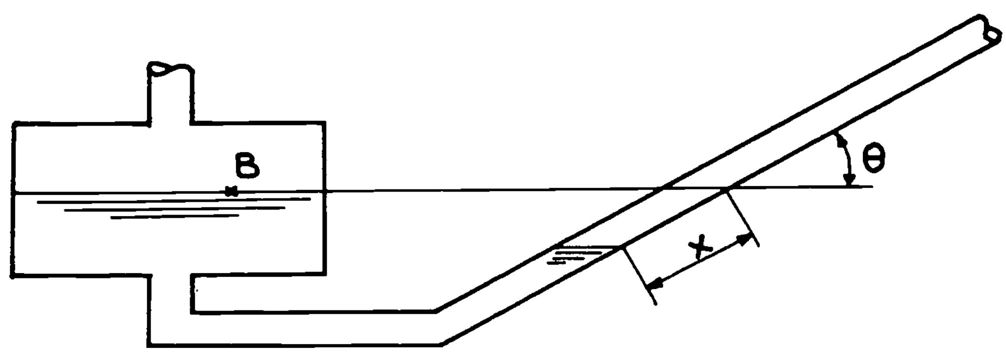
Section:

Experiment No. 8

Calibration of Inclined Manometer

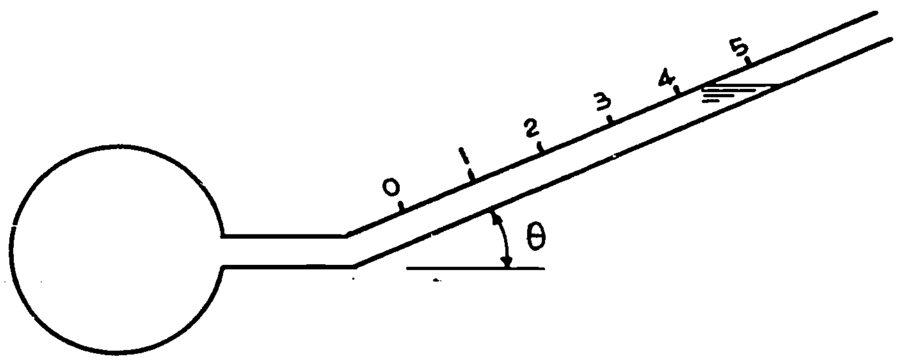
1. Give some reasons why an inclined manometer should be calibrated using a hook gage and not be relied upon for complete accuracy.

2. For the inclined manometer shown, determine the gage pressure in psi at B, if the inclined end is open to atmosphere. The oil used has a specific gravity of 0.870., $x = 5.00$ in, and $\Theta = 20^{\circ}$.



8

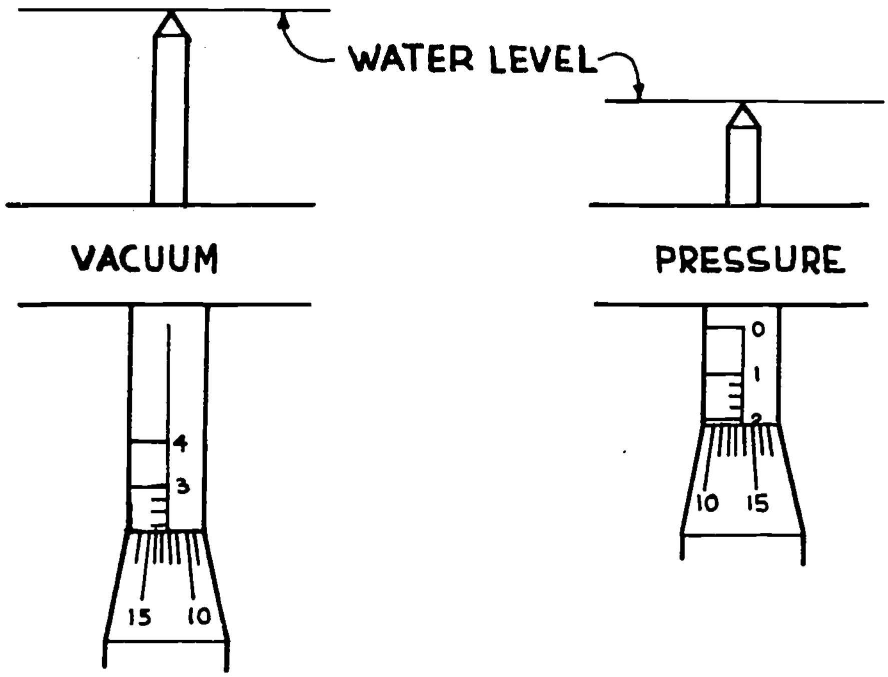
3. A draft gage is connected to a large container as shown. The fluid in the container and gage is mercury. At what angle should the small tube be inclined, if a differential reading of 8 in. is required for each change of pressure of 1 psi?



4. The diagram shown on the following page indicates readings in inches taken on hook gage micrometers. The same pressure is also read on an inclined manometer using water. The reading obtained on the manometer was 5 1/4 inches measured from zero.

Determine:
- a. the correction for the manometer
- b. the angle at which the manometer is inclined
- c. the angle for the same reading with a fluid having a specific gravity of 0.825 in the manometer
- d. repeat part c using a specific gravity of 1.72

8

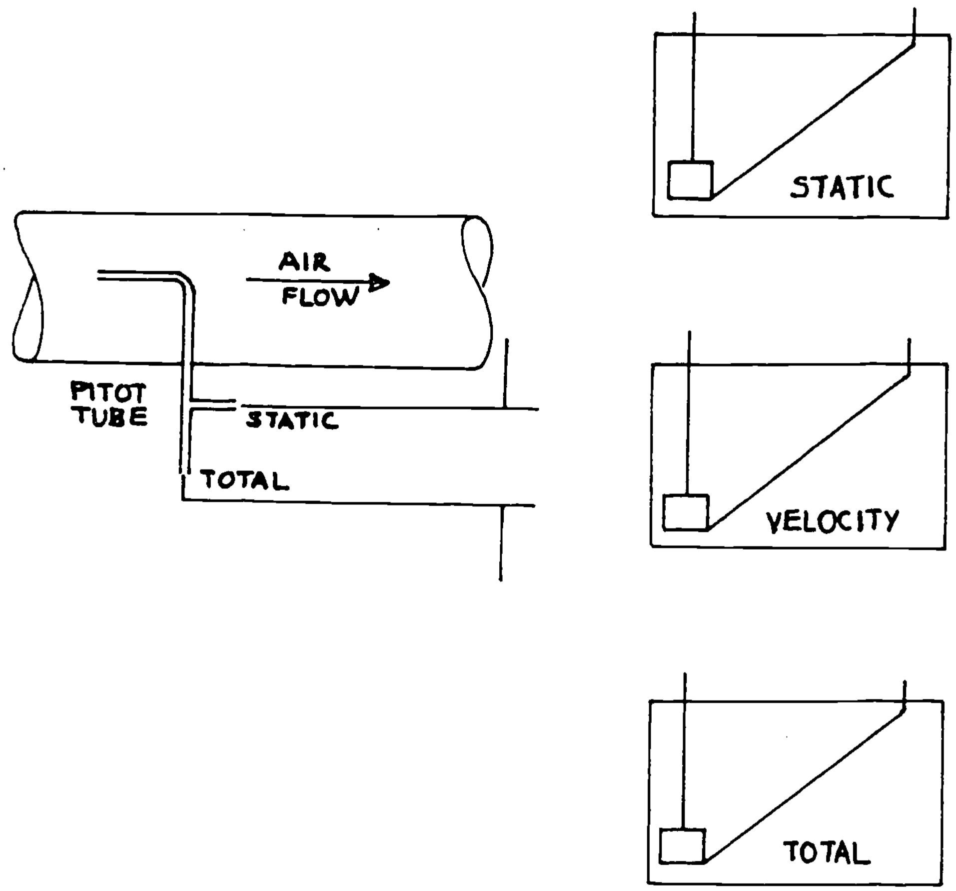


9

Name: Section:

Experiment No. 9 Velocity Measurement

The Pitot tube is an instrument for measuring static pressure, velocity pressure and total pressure. If static, velocity and total pressures are measured simultaneously three draft gages may be used.



1. Complete schematic so that draft gages would indicate respectively the static, velocity and total pressures.

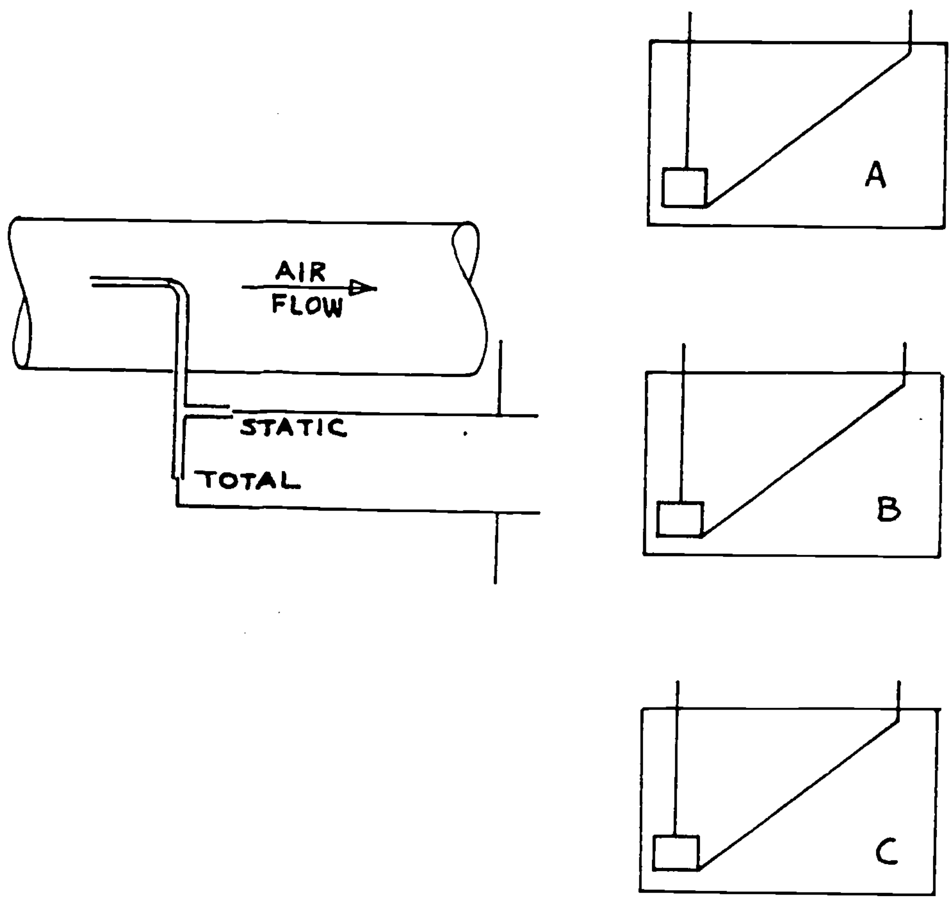


FIG. 2

In Fig. 2, the total pressure in the duct is negative since air is being exhausted.

2. Connect up the Pitot tube to gages A, B and C so that they will read static, velocity and total pressure respectively.

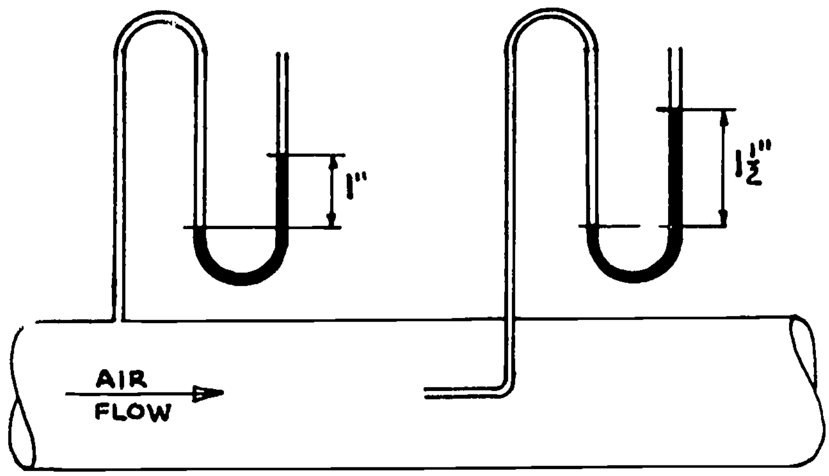


FIG. 3

3. Using the information as indicated in Fig. 3, calculate the velocity of air flowing in duct. The manometers read in inches of water. Consider standard densities for air and water.

4. What is meant by a Pitot tube traverse and why is such a traverse needed when measuring flow in a duct?

10

Name: Section:

Experiment No. 10 Reynolds Number

1. Which force predominates in laminar flow through a pipe?

   a. inertial

   b. pressure

   c. gravity

   d. viscous

2. Which force predominates in turbulent flow through a pipe?

   a. inertial

   b. pressure

   c. gravity

   d. viscous

3. Given V in ft/sec, D in ft and μ in slugs/ft-sec. What units of ρ are necessary to make the Reynold's number dimensionless?

4. For water of standard conditions ($\rho = 62.4$ lb/ft^3, $\mu = 2.391 \times 10^{-5}$ slugs/ft sec) flowing at 20 ft/sec through a 2 - in diameter pipe, determine the Reynold's number?

Additional Information:

In many situations it is often more convenient and economical to investigate flow phenomena about a model of the actual structure or device. In order for this study to be done, the model and prototype (actual) not only have to be geometrically similar but the ratio of forces acting in the flow processes must be the same. This is known as dynamic similarity and is an important and useful concept of dimensionless parameters.

Example:

Air at 14 psia and 250°F. is to flow in a 4 ft diameter pipe at 10 ft/sec. A 2 inch diameter pipe is constructed in the laboratory using water at standard conditions. What velocity of water is necessary for dynamic similarity to exist?

For air at 250°F.

$$\mu = 0.0475 \times 10^{-5} \text{ slugs/ft sec.}$$

For water at standard conditions

$$\nu = 1.233 \times 10^{-5} \text{ ft}^2\text{/sec}$$

$$(Re)_p = (Re)_m$$

$$\frac{\rho_p V_p D_p}{\mu_p} = \frac{V_m D_m}{\nu_m}$$

$$\frac{144 P_p}{R_p T_p} \frac{V_p D_p}{\mu_p} = \frac{V_m D_m}{\nu_m}$$

$$\frac{144(14)\ (10)\ (4)}{53.3(710)\ (0.0475 \times 10^{-5})(32.2)} = \frac{V_m \frac{2}{12}}{1.233\text{x}10^{-5}}$$

$$V_m = 10.31 \text{ ft/sec}$$

5. An airplane wing of 3 ft chord is to move at 90 mph in air. A model of 3 in chord is to be tested in a wind tunnel with air velocity of 108 mph. For air temperature of 68^{o}F. in each case, what should be pressure in the wind tunnel?

6. It is desired to obtain dynamic similarity between 5 gallons/sec of water at 50^{o}F. flowing in a 6-in. pipe and linseed oil flowing at a velocity of 30 ft/sec and 100^{o}F. What size of pipe is necessary for linseed oil? (Linseed oil SG = 0.942, μ = 5.2 x 10^{-4} slug/ft-sec; water SG = 1.0, μ = 2.74 x 10^{-5} slug/ft-sec).

11a

Name:

Section:

Experiment No. 11(a)

Velocity Profile

In many practical situations, it is necessary to determine the average velocity of a fluid moving through a duct or conduit for design calculations. The object of experiment 11 is to determine the average velocity. The method used involves plotting the profile and using a planimeter.

The standard test code method of determining the average velocity is to perform a Pitot tube traverse according to Figure 1, if circular pipe, or Figure 2, if rectangular duct. The method is based upon zones of equal area.

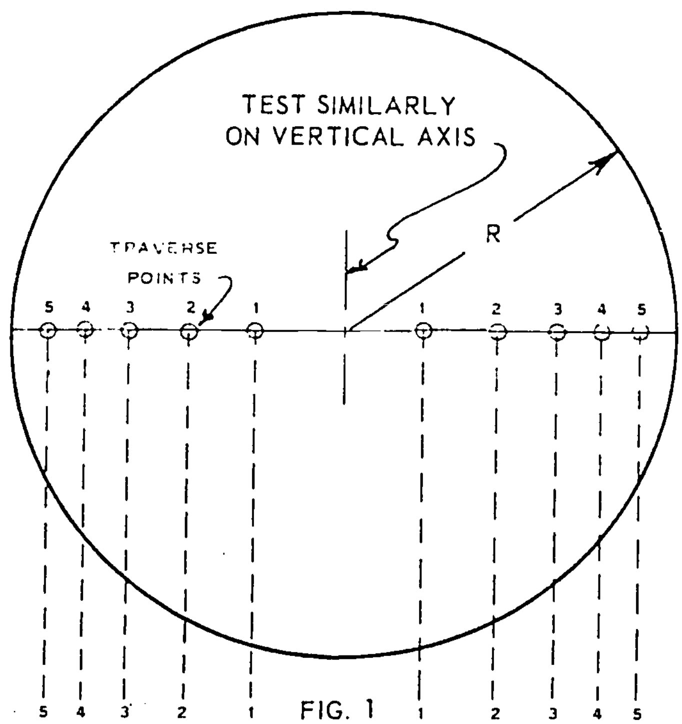


FIG. 1

Fig. 1 shows the locations for Pitot tube tip making a 10-point traverse across one circular pipe diameter. In making a traverse across two pipe diameters, readings are taken at right angles to each other. The traverse points shown represent 5 annular zones of equal area.

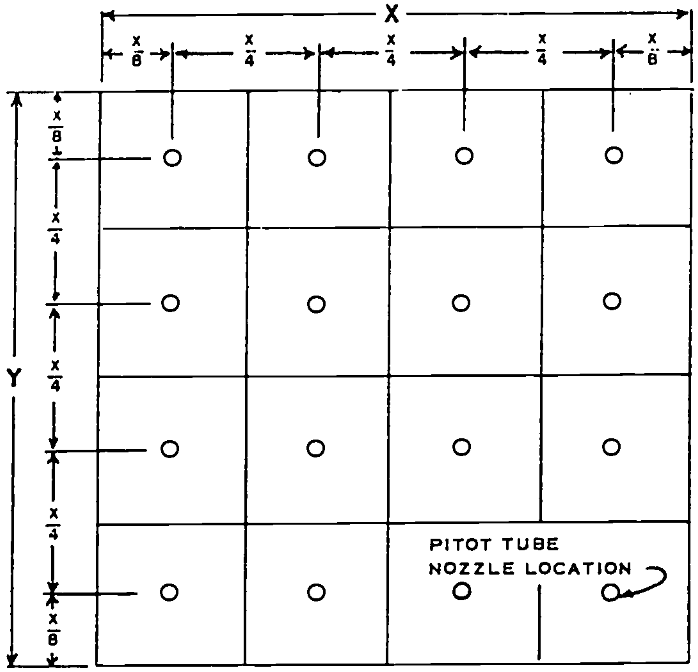


Fig. 2

The average velocity is obtained by taking the average of the velocities (not the velocity pressures) at each described position.

Table 1 describes traverse positions relative to pipe diameters.

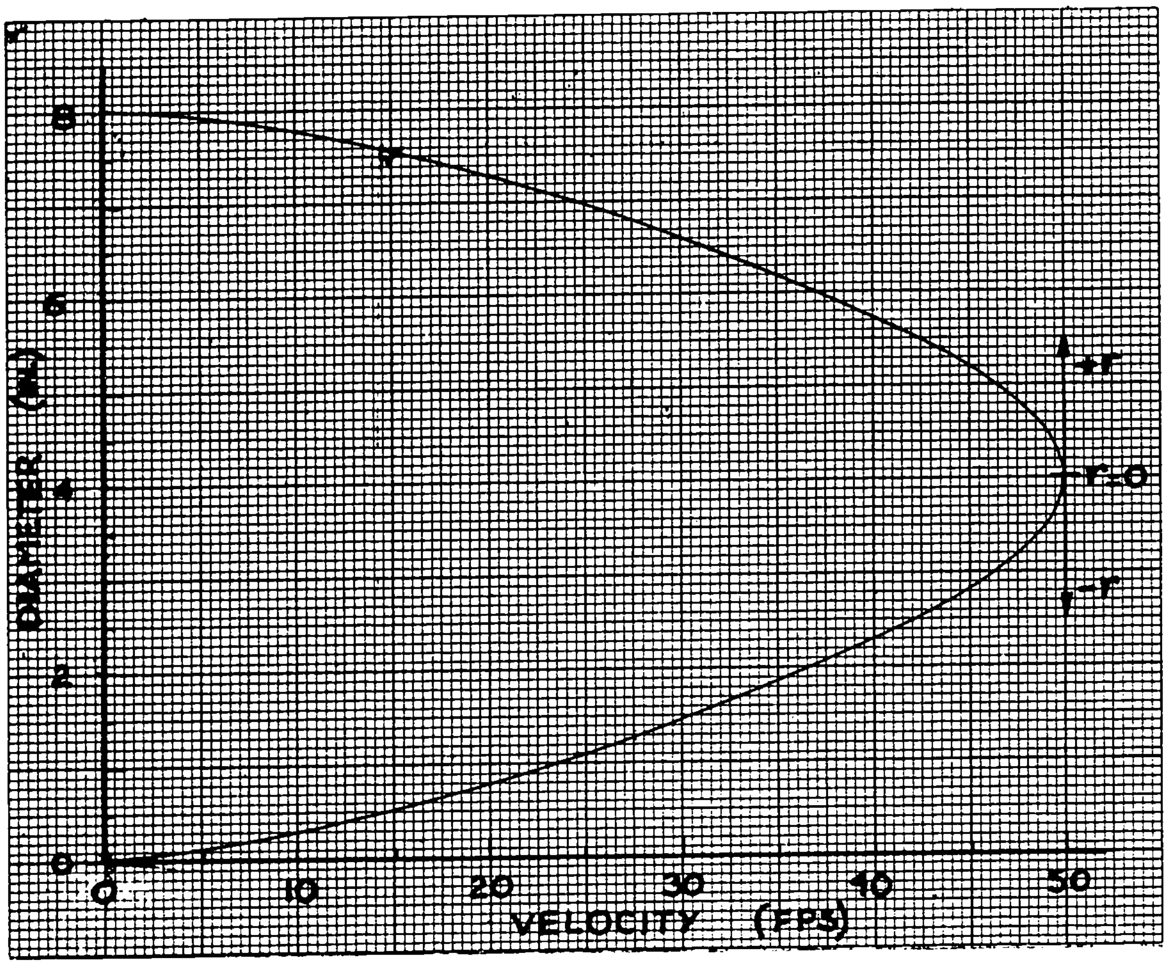
TABLE 1

Pipe diam.	Readings in one diam.	Distances of Pitot Tube Tip From Pipe Center Point 1	Point 2	Point 3	Point 4	Point 5
3 in.	6	.612"	1.061"	1.369"		
4 in.	6	.812"	1.414"	1.826"		
5 in.	6	1.021"	1.768"	2.282"		
6 in.	6	1.225"	2.121"	2.738"		
7 in.	6	1.429"	2.475"	3.195"		
8 in.	6	1.633"	2.828"	3.651"		
9 in.	6	1.837"	3.182"	4.108"		
10 in.	8	1.768"	3.062"	3.950"	4.677"	
12 in.	8	2.122"	3.674"	4.740"	5.612"	
14 in.	10	2.214"	3.834"	4.950"	5.857"	6.641"
16 in.	10	2.530"	4.382"	5.657"	6.693"	7.589"
18 in.	10	2.846"	4.929"	6.364"	7.530"	8.538"
20 in.	10	3.162"	5.477"	7.077"	8.367"	9.487"
22 in.	10	3.479"	6.025"	7.778"	9.203"	10.435"
24 in.	10	3.795"	6.573"	8.485"	10.040"	11.384"
26 in.	10	4.111"	7.120"	9.192"	10.877"	12.333"
28 in.	10	4.427"	7.668"	9.900"	11.713"	13.282"
30 in.	10	4.743"	8.216"	10.607"	12.550"	14.230"
32 in.	10	5.060"	8.764"	11.314"	13.387"	15.179"
34 in.	10	5.376	9.311"	12.021"	14.233"	16.128"
36 in.	10	5.6[illegible]2"	9.859"	12.728"	15.060"	17.176"

11a

Problem 1

The profile below was obtained for air flowing through an 8 inch diameter duct. Complete the test report included if the profile in the horizontal plane is assumed equal to that in the vertical plane as shown.



PITOT TUBE TEST REPORT

11a

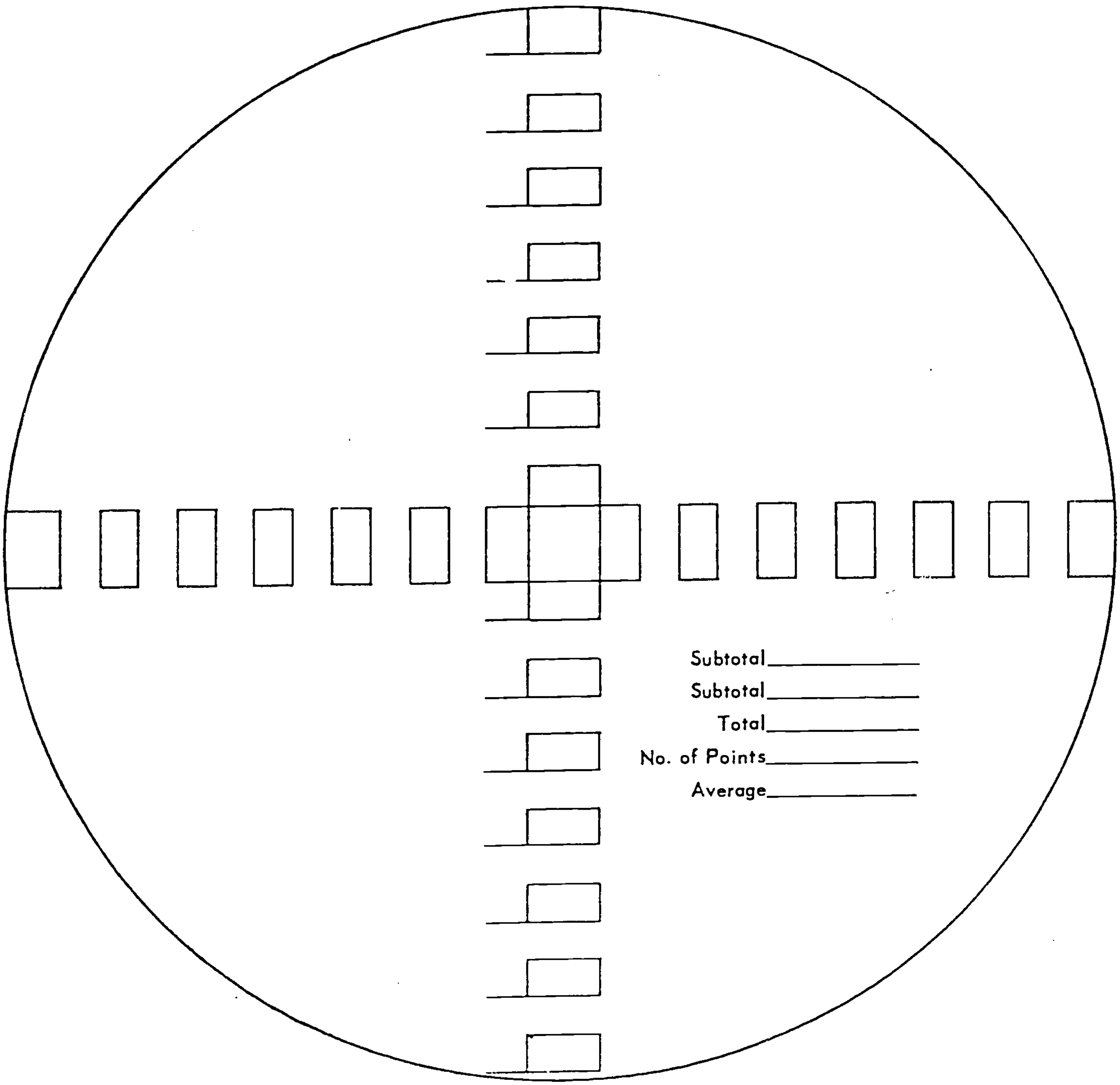
PROJECT: Test

SYSTEM/UNIT: Centrifugal Fan Unit

ADDRESS: Wentworth

LOCATION/ZONE: ____

DUCT		REQUIRED		ACTUAL	
SIZE ____	SQ. FT. ____	FPM ____	CFM ____	FPM ____	CFM ____



Subtotal ____

Subtotal ____

Total ____

No. of Points ____

Average ____

T DATE ____ READINGS BY ____ CERTIFIED BY ____

11a

Problem 2

A Pitot tube traverse was conducted on a 19" x 16" rectangular duct according to the test code shown in Figure 2. The results in ft/min are listed on the test report on the following page. Determine the average velocity and complete the test report.

PITOT TUBE TEST REPORT

11a

PROJECT Test SYSTEM/UNIT V-1 Unit

ADDRESS Wentworth LOCATION/ZONE

DUCT	REQUIRED	ACTUAL
SIZE 19" x 16" SQ. FT.	FPM CFM	FPM CFM

POSITION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	600	1200	1550	1500	1600	0								
2	0	0	600	1500	1500	1600	1675								
3	0	400	1100	1600	1750	1700	1900								
4	0	250	1200	1450	1700	1850	1700								
5															
6															
7															
8															
9															
10															
11															
12															
13															
VELOCITY SUB-TOTALS															

REMARKS:

TEST DATE READINGS BY CERTIFIED BY

11b

Student: Section:

Experiment No. 11 (b) Velocity Profile

Since all flow situations are two or three dimensional, it may be necessary to determine the velocity profile for accuracy of data. The method described in the experiment is primarily mechanical and the results produced are more than sufficient.

A second method is the mathematical approach. This involves some knowledge of calculus and a few assumptions. Its accuracy is debateable depending upon how close the assumed curve fits the actual profile.

Laminar Flow

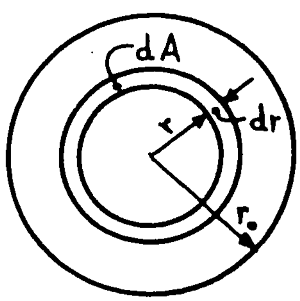
The general equation for laminar flow assuming a parabolic profile is given by

$$V = V_m \frac{(r_o^2 - r^2)}{r_o^2} \quad \text{(Eq. 1)}$$

In order to determine the average velocity, the flow surface must be known.

Consider the flow in a pipe.

By definition



$$V_{ave} = \frac{\int VdA}{A}$$

$$A = \pi r_o^2 \text{ , } dA = 2\pi r dr$$

$$V_{ave} = \frac{\int V_m (r_o^2 - r^2) / r_o^2 (2\pi r dr)}{\pi r_o^2}$$

$$V_{ave} = \frac{2\pi V_m}{\pi r_o^4} \int_o^{r_o} (r_o^2 - r^2) \, r dr$$

$$V_{ave} = \frac{2V_m}{r_o^4} \left\{ \int_o^{r_o} r_o^2 \, r dr - \int_o^{r_o} r^3 dr \right\}$$

$$V_{ave} = \frac{2V_m}{r_o^4}\left\{r_o^2 \frac{r^2}{2}\Bigg|_o^{r_o} - \frac{r^4}{4}\Bigg|_o^{r_o}\right\}$$

$$V_{ave} = \frac{2V_m}{r_o^4}\left(\frac{r_o^4}{2} - \frac{r_o^4}{4}\right) = \frac{2V_m}{r_o^4}\ \frac{r_o^4}{4}$$

$$\text{or } V_{ave} = \frac{V_m}{2} \text{ (eq. 2)}$$

This is the average velocity for laminar flow in a pipe.

Turbulent Flow

For turbulent flow, the profile can not be described as easily as for laminar flow. A general expression is given by

$$V = V_m \left(\frac{r}{r_o}\right)^{1/n} \quad \text{(eq. 3)}$$

where the numerical value of n varies somewhere between 5 and 9. Although the mathematical treatment produces reasonable results, it is much easier and less time consuming to obtain the average velocity with the use of the pitot-tube.

1. In the continuity equation ($\dot{m} = \rho\ AV$) and the kinetic energy equation $KE = 1/2\ m\ V^2$, what velocity value is used, average or maximum?

2. By using equation (1) and letting $r = y$ and $r_o = y_o$, determine an expression for V_{ave} in terms of V_m for laminar flow between two flat plates y_o distance apart.

3. Compare the results of question 2 to equation (2). Why the difference?

4. Using equation (1), determine an expression for the velocity gradient $\frac{dV}{dr}$.

5. From equation (3) with n = 7, determine an expression for V_{ave} in terms of V_m for flow in a pipe of radius r_o.

Name: Section:

Experiment No. 12 Flow Meters

1. A weighing tank and scale are used to measure the flow rate of water in a piping system. The temperatures of the water is at $60^{o}F$. and the data obtained shows that it takes 3 minutes to fill 500 lbm in the tank. What is the flow rate in gpm?

2. A rotameter is calibrated to read 5 gpm of water at 50% rated flow. Assume the fluid is changed to gasoline and the float remains at the 50% rating mark. Is the flow rate more or less than 5 gpm? Why?

3. a. If you had the choice of using either a venturi or orifice plate to measure the flow rate of a dirty fluid, which one would you use? Why?

b. Which element would have a lower net pressure drop? Why?

c. Which element would cost less? Why?

4. While observing a flow metering installation, it was noted that the pressure difference indicated across the orifice plate represented a flow rate of 10 gpm. Some time later the observer noticed that the pressure differential had doubled. Assuming all other parameters have remained constant, find the new flow rate.

5. Flow of water to a process varies from 60 to 160 gpm. Assume you have three meters available in this span. The accuracies are as follows:

1. $\pm$ 0.25% full scale,

2. $\pm$ 0.5% of rate,

3. $\pm$ 0.5% of span:

Which meter would be most accurate on an absolute basis?

a. When flow is at 150 gpm?

b. When flow is at 75 gpm?

6. a. An orifice develops 100 in H_2O differential pressure at 100% rated flow. How many inches of water pressure will it develop at 10% rated flow?

b. Due to a measurement error, the pressure is read as 99.5 in water instead of 100. What would be the error in the flow, expressed in per cent of rate?

c. At 10% rated flow this meter should develop 1 inch of water differential pressure (answer to part (a)). Due to a measurement error, the pressure is read as 1/2 inch of water. What would be the error in the flow, expressed in per cent of rate?

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Name: Section:

Experiment No. 13 Lost Head In Pipes and Fittings

There are three methods of determining the lost head or pressure drop due to friction across lengths of pipe or in fittings.

Method 1. By actual experimentation and measurement of the pressure drop and determination of friction factor f and/or K.

Method 2. By use of the Moody diagram and the equation

$$h = f \frac{L}{D} \frac{V^2}{2g}$$

Method 3. By use of different nomographs for various flow situations.

Methods 1 and 2 has or will be covered in classroom or laboratory work.

Method 3 can be outlined as follows:

Using the equation $h = f \frac{L}{D} \frac{V^2}{2g}$ and the volume flow rate as $Q = AV$, we can arrive at

$$h = f \frac{L}{D} \frac{Q^2}{A^2 2g}$$

with proper substitution and manipulation of units and constants, the equation will become

$$\frac{P_1 - P_2}{100 \text{ ft}} = 0.0864 \, f \, \rho \, \frac{Q^2}{D^5}$$

where

$P_1 - P_2$ is the pressure drop in psi

f is the friction factor

ρ is the fluid density in lb/ft^3

Q is the volume flow rate in gallons per minute

D is the inside pipe diameter in inches

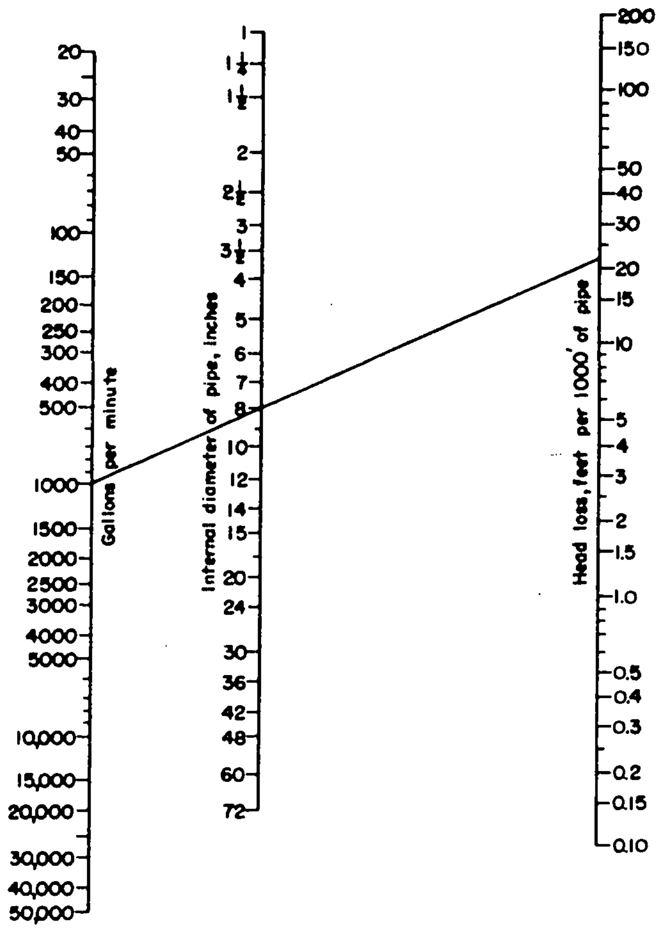
The nomographs are constructed by assuming an average value for the friction factor "f" and are used for estimating. Many piping manufacturers publish more comprehensive charts allowing for varying friction factor values.

The nomographs included are derived in the same manner as above; some of the units and constants are different depending upon the fluid used.

Example 1

What is the head loss per 1,000 ft. of pipe when 1,000 gpm flows through 8 in ID pipe?

WATER-FLOW CHART



Solution:

Drawing a line from 1,000 gpm on flow scale through 8 in. on pipe scale gives 22 feet head loss per 1,000 ft.

or

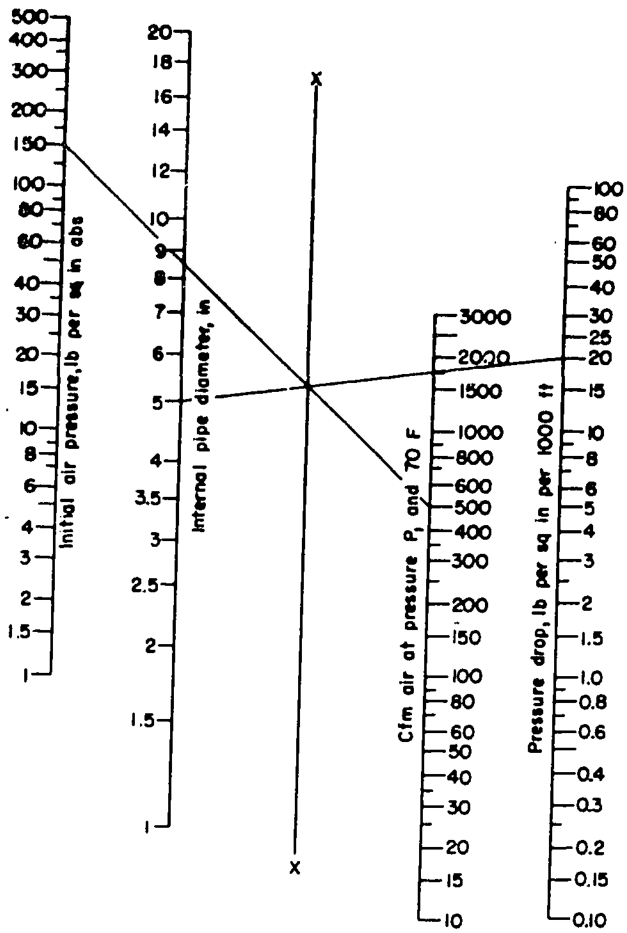
$$\frac{P_1-P_2}{1000\text{ ft.}} = \frac{h}{1000\text{ ft.}} = \frac{22\text{ ft.}}{1000\text{ ft.}} = \frac{22\frac{14.7}{33.9}}{1000\text{ ft.}} = \frac{9.6\text{ psi}}{1000\text{ ft.}}$$

13

Example 2

A 600 foot straight air line made of 5 in. ID pipe delivers 500 cfm from a receiver at 135 psig. What is the discharge pressure?

AIR-FLOW CHART



Solution:

The absolute pressure is 135 + 14.7 = 149.7 = 150 psia. Connect 150 psi to 500 cfm. Draw a second line from 5 inches ID through the intersection of the first line with the dummy to read the pressure loss of 20 psi per 1,000 ft. The total pressure drop is

$$\frac{20\text{ psi}}{1000\text{ ft}}(600\text{ ft}) = 12\text{ psi}$$

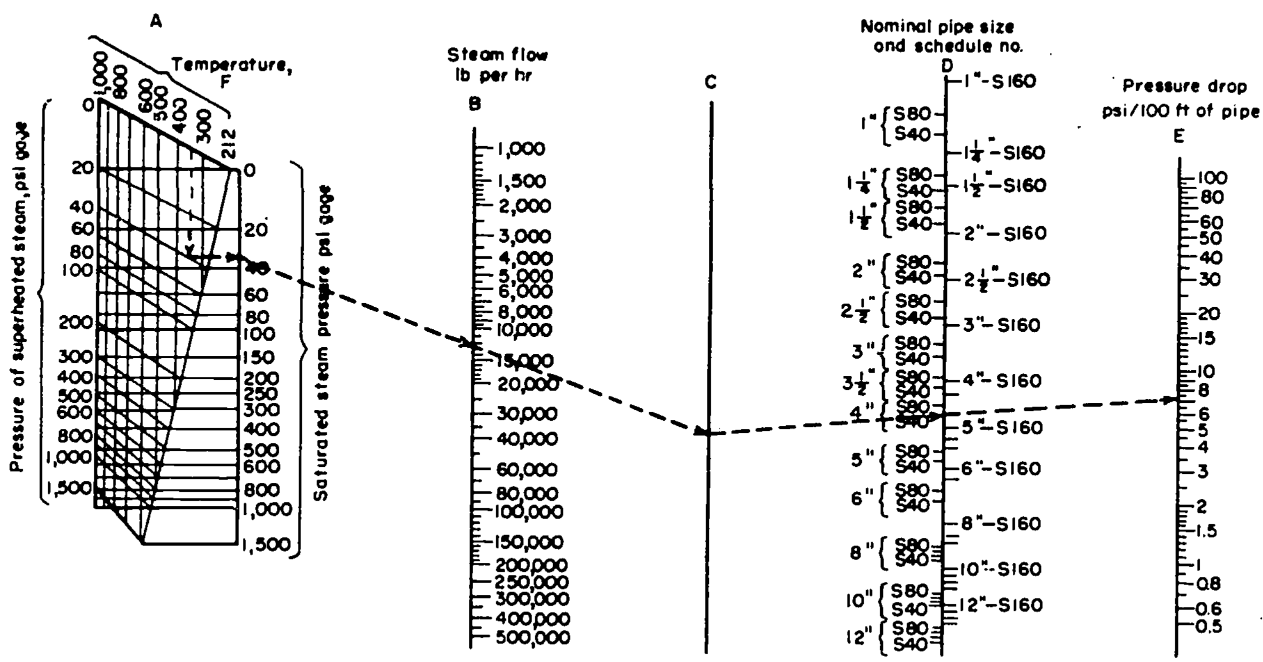
The outlet pressure is

$$135 - 12 = 123\text{ psig.}$$

Example 3

If 12,500 lb. per hr. of steam starting at 40 psi gage and 350°F. flow through 50 ft. of 4 in. schedule - 40 pipe, what is the total pressure drop?

STEAM-FLOW CHART



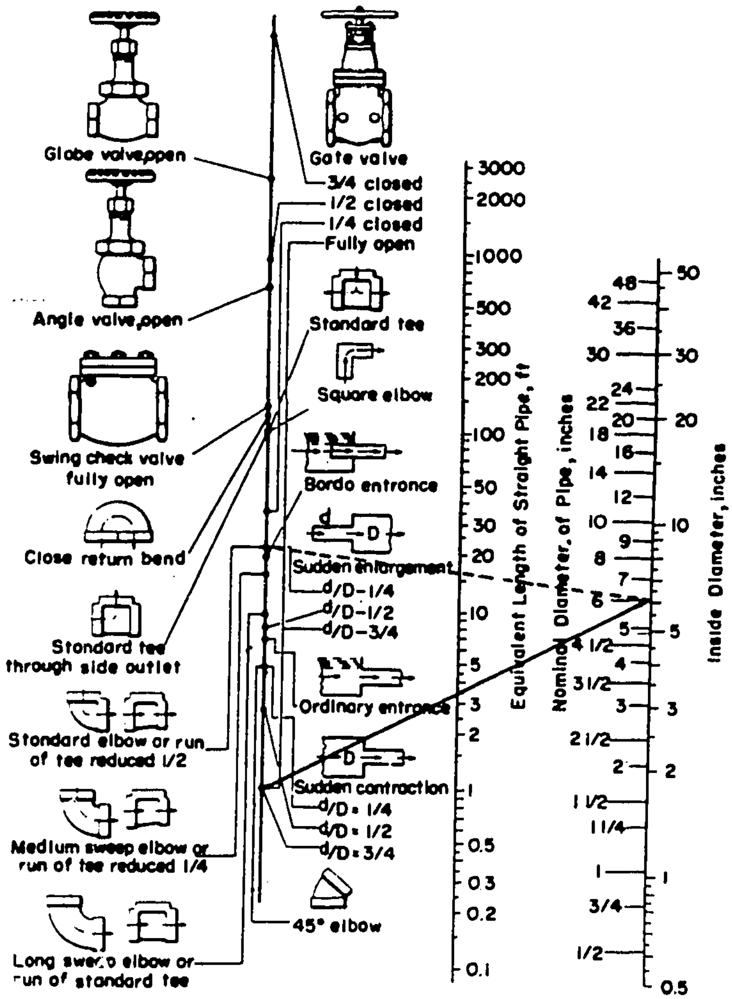
Solution:

Drop vertically at 350°F. to diagonal of 40 psig, go across horizontally to right hand scale. From this point draw a second line through 12,500 lb/hr. to dummy C. From dummy through 4 in., schedule 40 to read 7.2 psi drop/100 ft.

Example 4

If a 6" diameter pipe line contains 4 standard size elbows and 2 wide-open gate valves, determine the equivalent length of pipe for these fittings.

FRICTION LOSS IN PIPE FITTINGS



Solution:

Locate point for standard elbows. Draw a diagonal from this point to 6 inch nominal diameter scale. Equivalent length is 16 feet per elbow, therefore total equivalent length of 4 standard elbows is 4(16) = 64 feet. For gate valve (fully open), locate point and draw a diagonal to 6 inch diameter pipe. Equivalent length is 3.5 feet, therefore for 2 valves, a total of 7.0 feet. Total equivalent length of fittings in line will be 64 + 7.0 = 71 feet of 6 inch nominal diameter pipe.

Problems

1. A compressor operates at a pressure of 185.3 psig. For a 4 inch ID line and a capacity of 60 cfm, what will be the pressure drop through 600 ft. of pipe? What will be the exit pressure?

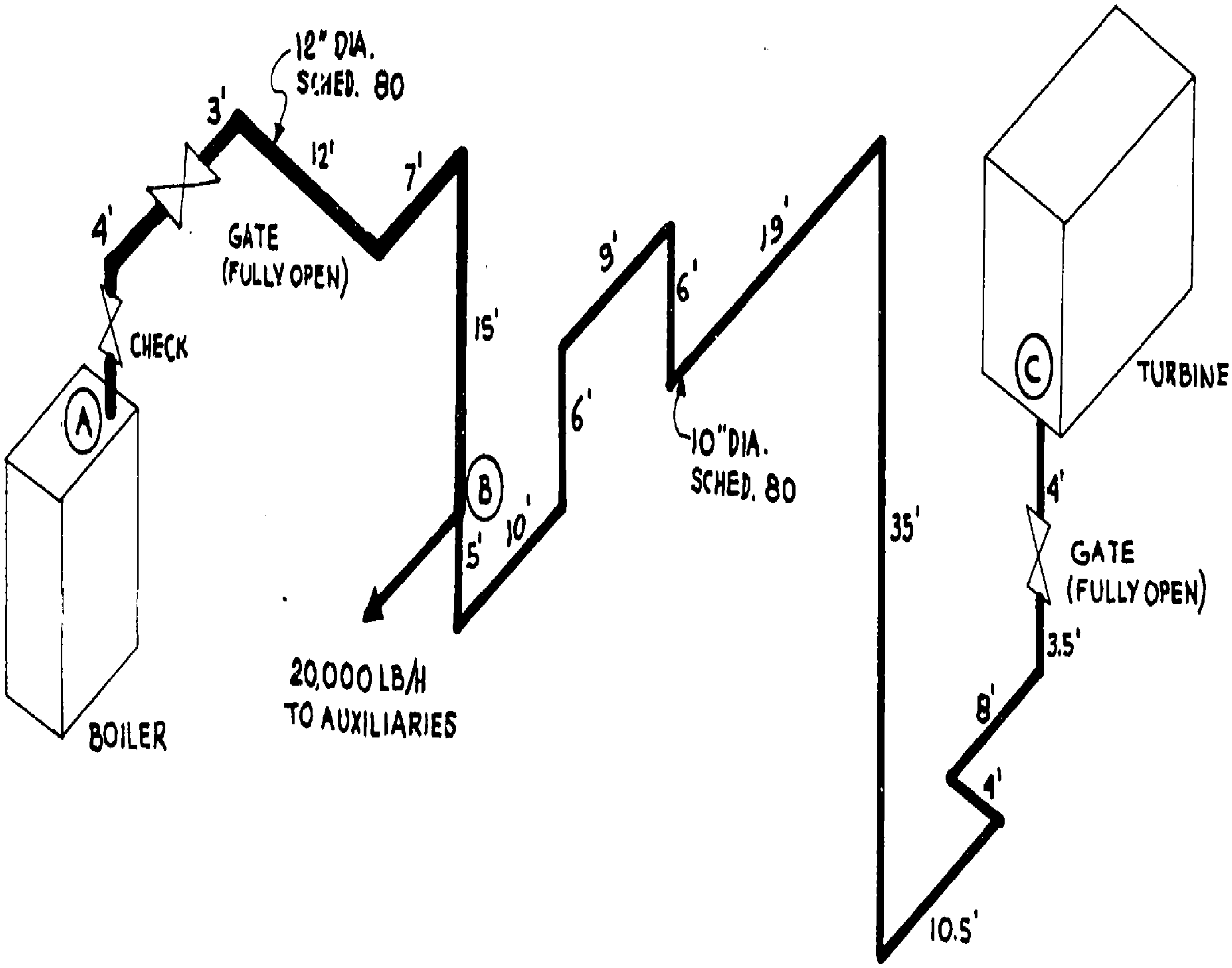
2. Steam is flowing through a 5 in. diameter schedule 40 pipe at the rate of 40,000 lb/hr. If the steam is at 500°F. and 100 psig, determine the pressure drop expected and the exit pressure if the steam flows through 50 feet of pipe.

3. A certain pipe line contains a globe valve; a gate valve, fully open; 2 - 45^{o} elbows; 2 run through standard tees; 2 standard elbows and 1 standard tee, side outlet. Determine the equivalent length of pipe if 3 inch inside diameter pipe is used.

4. In the piping system shown on the next page, the boiler is supplying 100,000 lb/hr of steam at 200 psig and $500^{o}F$. All piping is assumed to be well insulated. The pipe diameters shown are nominal and the numbers indicate the pipe lengths in feet. All elbows are long radius and check means stop check valve and gate means gate valve.

Determine: a. Pressure at point B

b. Pressure at turbine


12" DIA.
SCHED. 80
3'
12'
7'
4'
GATE
(FULLY OPEN)
CHECK
15'
9'
6'
19'
6'
10"DIA.
SCHED. 80
A
B
5'
10'
20,000 LB/H
TO AUXILIARIES
BOILER
35'
C
TURBINE
4'
GATE
(FULLY OPEN)
3.5'
8'
4'
10.5'

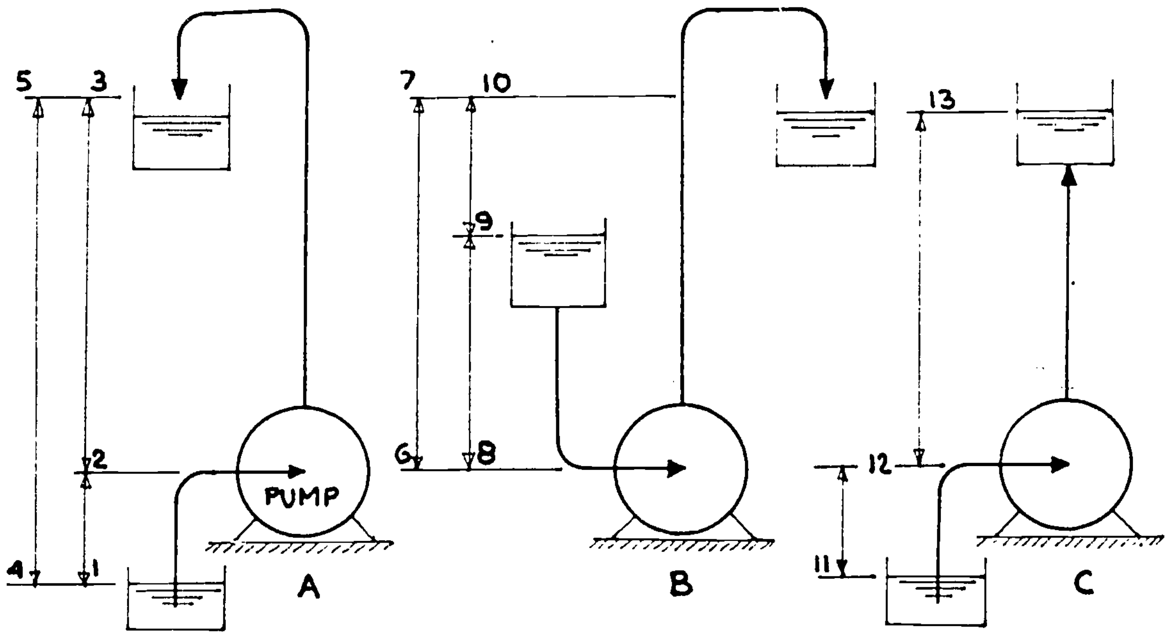
13

14

Name: Section:

Experiment No. 14 Centrifugal Pump

The following diagrams illustrate standard piping methods for pumps.



1. Using the following definitions, identify static suction lift, static discharge head and total discharge head for each of the preceeding diagrams.

A		B		C	
1-2	______	6-7	______	11-12	______
2-3	______	8-9	______	12-13	______
4-5	______	9-10	______	14-15	______

Static Suction Lift - Vertical distance in feet from supply level to pump centerline. Pump above supply.

Static Suction Head - Same as static suction lift but pump is below supply level.

Static Discharge Head - Vertical distance in feet from pump centerline to point of free delivery.

Total Static Head - Vertical distance from supply level to discharge level.

Friction Head - Pressure in feet of liquid needed to overcome resistance of pipes and fittings.

Suction Lift - Is static suction head plus suction friction head and velocity head.

Suction Head - Is static suction lift minus suction friction head and velocity head.

Discharge Head - Is static discharge head plus discharge friction head and velocity head.

Total Head - Sum of suction lift and discharge head where there is a suction head, total head is difference between discharge and suction heads.

14

The total head for a pump in a system may be calculated by determining the total static head, the velocity head and the friction head. The following tables may be used to evaluate:

a. Velocity head for a given flow rate (table I)

b. Pipe friction losses per 100 feet of pipe (table I)

c. Resistance of pipes and fittings to flow (table II)

To make use of table II, it is necessary to determine the "equivalent lengths of straight pipe" from an analysis of the fittings and valves in the piping system. Once this has been done, it is a simple matter to convert this friction loss to feet of water per 100 feet of pipe with the aid of table I.

I: PIPE FRICTION LOSS FOR WATER

(Wrought-iron or steel Schedule 40 pipe in good condition)

Dia, in.	Flow, gpm	Velocity, ft per sec	Velocity head, ft of water	Friction loss, ft of water per 100 ft pipe
2	50	4.78	0.355	4.67
2	100	9.56	1.42	17.4
2	150	14.3	3.20	38.0
2	200	19.1	5.68	66.3
2	300	28.7	12.8	146
4	200	5.04	0.395	2.27
4	300	7.56	0.888	4.89
4	500	12.6	2.47	13.0
4	1000	25.2	9.87	50.2
4	2000	50.4	39.5	196
6	200	2.22	0.0767	0.297
6	500	5.55	0.479	1.66
6	1000	11.1	1.92	6.17
6	2000	22.2	7.67	23.8
6	4000	44.4	30.7	93.1
8	500	3.21	0.160	0.424
8	1000	6.41	0.639	1.56
8	2000	12.8	2.56	5.86
8	4000	25.7	10.2	22.6
8	8000	51.3	40.9	88.6
10	1000	3.93	0.240	0.497
10	3000	11.8	2.16	4.00
10	5000	19.6	5.99	10.8
10	7500	29.5	13.5	24.0
10	10,000	39.3	24.0	42.2
12	2000	5.73	0.511	0.776
12	5000	14.3	3.19	4.47
12	10,000	28.7	12.8	17.4
12	15,000	43.0	29.7	38.4
12	20,000	57.3	51.1	68.1

II: RESISTANCE OF FITTINGS AND VALVES

(Length of straight pipe, ft, giving equivalent resistance)

Pipe size, in.	Std ell	Med-rad ell	Long-rad ell	45-deg ell	Tee	Gate valve, open	Globe valve, open	Swing check, open
1	2.7	2.3	1.7	1.3	5.8	0.6	27	6.7
2	5.5	4.6	3.5	2.5	11.0	1.2	57	13
3	8.1	6.8	5.1	3.8	17.0	1.7	85	20
4	11.0	9.1	7.0	5.0	22	2.3	110	27
5	14.0	12.0	8.9	6.1	27	2.9	140	33
6	16.0	14.0	11.0	7.7	33	3.5	160	40
8	21	18.0	14.0	10.0	43	4.5	220	53
10	26	22	17.0	13.0	56	5.7	290	67
12	32	26	20.0	15.0	66	6.7	340	80
14	36	31	23	17.0	70	8.0	390	93
16	42	33	27	19.0	87	9.0	430	107
18	46	40	30	21	100	10.2	500	120
20	52	43	34	23	110	12.0	560	134
24	63	53	40	28	140	14.0	680	160
36	94	79	60	43	200	20.0	1000	240

Consider the following example:

A water piping system consists of 128 feet of 2 inch schedule 40 straight pipe, 6 - 2 inch standard elbows, and 2 - 2 inch gate valves (open). System flow rate is 50 gallons per minute.

Determine total friction loss through piping in feet of water and p.s.i.

Solution:

Total equivalent length (table II)

straight pipe	= 128.0 ft.
six - 2 inch elbows @ 5.5	= 33.0 ft.
two - 2 inch gate valves @ 1.2	= 2.4 ft.
	163.4 ft.

Friction loss/100 ft. of pipe (table I) = 4.67 ft.

Friction loss/ft of pipe = .0467 ft./ft of pipe

Total friction loss (ft) = 163.4 ft. of pipe x 0.0467 ft/ft. of pipe

= 7.63 ft.

$$\text{Total friction loss (p.s.i.)} = \frac{7.63 \text{ ft. of water}}{2.31 \frac{\text{ft. of water}}{\text{p.s.i.}}} = 3.3 \text{ p.s.i.}$$

2. A pump handles 500 gallons per minute of water through 86 feet of 6 inch pipe. The pump suction is 8 feet below the centerline of pump and suction line contains one medium radius 6 inch elbow. The fluid is discharged to a point 100 feet above the pump centerline through a 5 inch line. This line contains 1 - 4 inch check valve, 2 - 4 inch globe valves and 2 - 4 inch long radius elbows. Use Schedule 40 pipe.

Determine: Total pumping head (using tables where necessary).

Name: Section:

Experiment No. 15 Fan Testing and Performance

The object of Experiment No. 15 is to develop the characteristic curves of a fan.

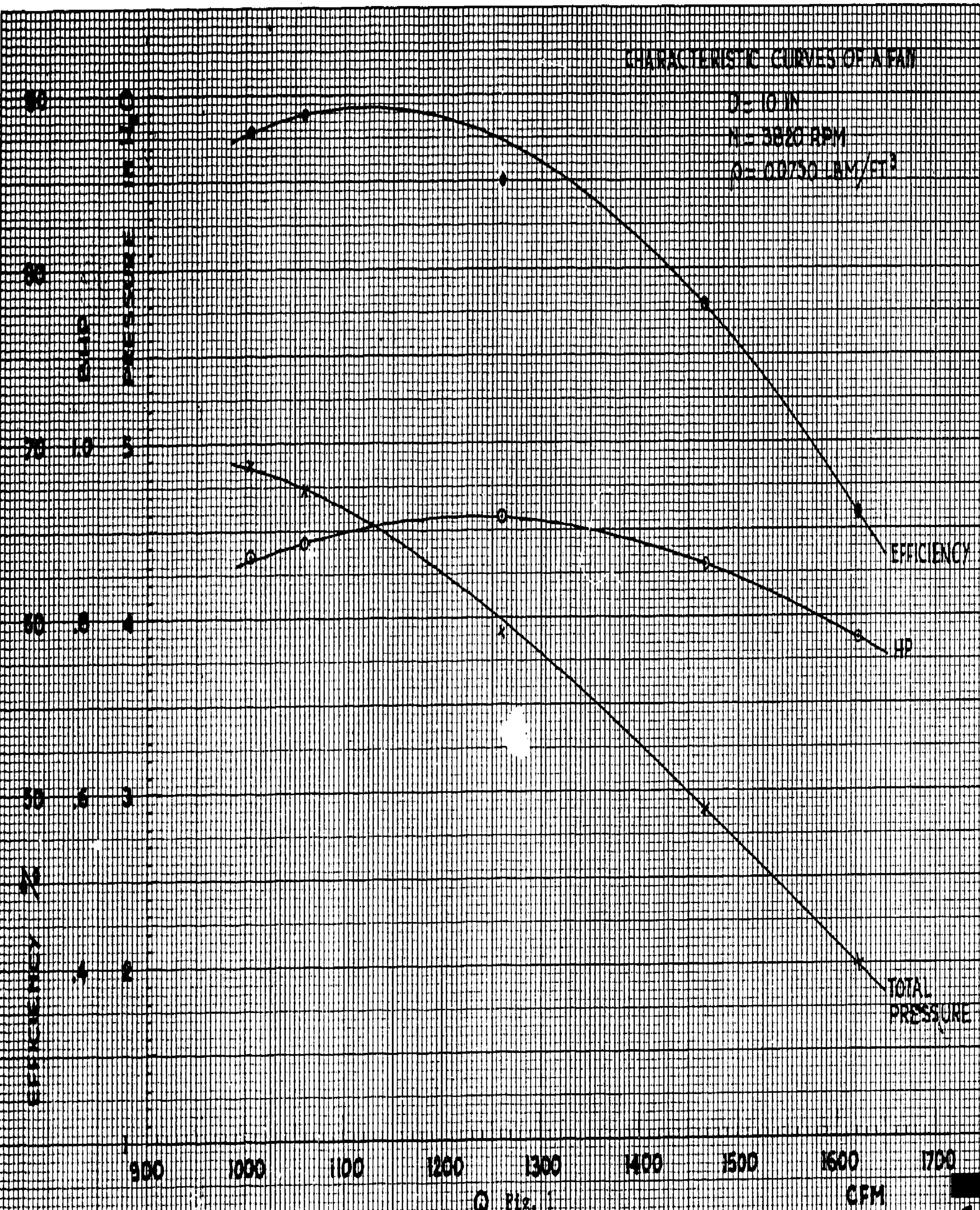
These curves can be found by testing the fan in accordance with an established test code. The usual procedure involves the variation of the resistance of the duct system from fully open to closed positions at some convenient constant speed. The resulting curves show the relation between rate of flow (abscissa) versus efficiency, power and pressure of the fan. (See Fig. 1).

Analysis of these curves gives useful information. Although the fan may operate at any point on its characteristic curve, it is apparant that it would be most economical to operate at its peak efficiency.

The question now arises as to what point on its characteristic curve would the fan operate? The point of operation can be determined for a particular fan system by finding the fan system characteristic.

The system characteristic or system resistance of a fan is the summation of all the resistances (pressure losses) within the system for any rate of flow. These losses will include frictional losses in the duct system as well as the so called minor losses due to elbows, sudden expansion, fittings, etc. The fan works against these losses, therefore, it must have sufficient output power to move the air through the duct system.

We can now establish a relationship for the system characteristic curve. Since the volume flow through the system is proportional to the velocity ($Q = AV$), and the losses are proportional to the square of the velocity (loss $= \frac{KV^2}{2g}$). We can deduce from these two equations that the pressure drop (losses) will vary as the square of volume rate of flow ($Q \propto (\Delta P)^{\frac{1}{2}}$). The resulting curve can be conveniently plotted as a parab a.



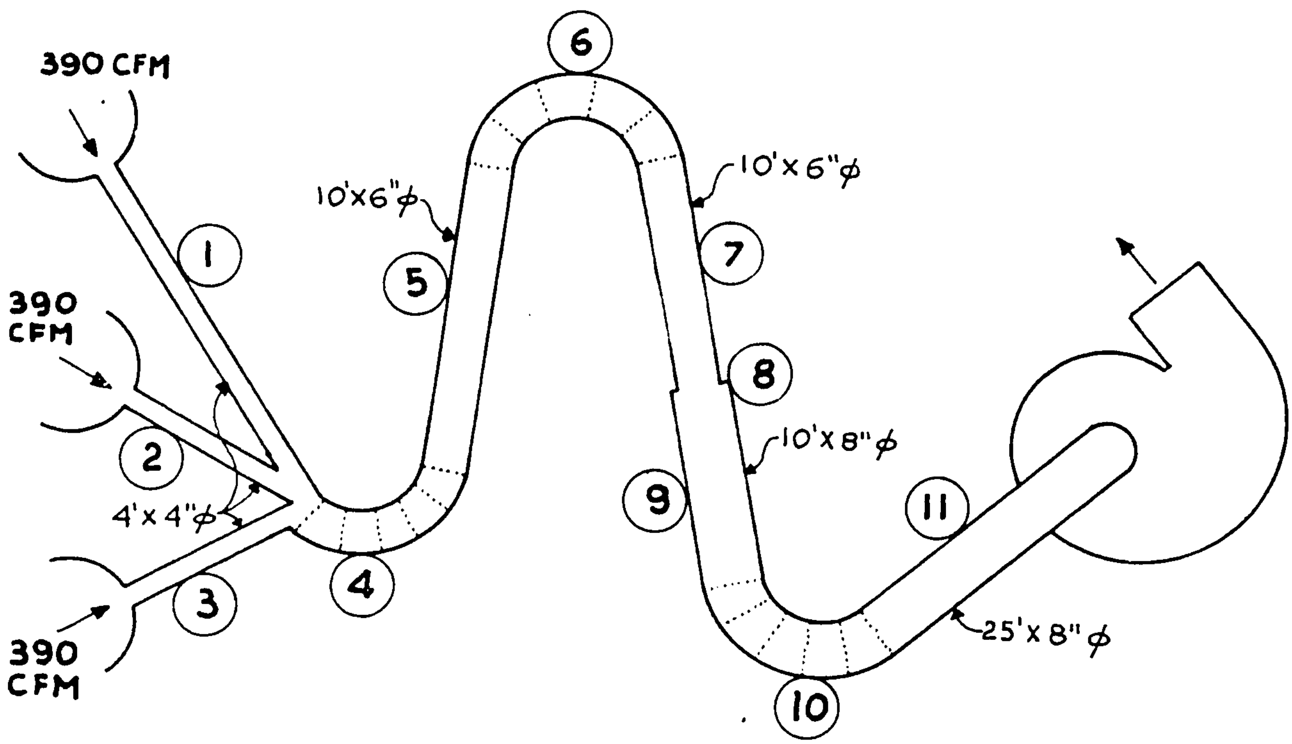
CHARACTERISTIC CURVES OF A FAN
D = 10 IN
N = 3820 RPM
ρ = 0.0750 LBM/FT3
EFFICIENCY
HP
TOTAL PRESSURE
EFFICIENCY %
BHP
PRESSURE IN H2O
900
1000
1100
1200
1300
1400
1500
1600
1700
Q
CFM

Fig. 1

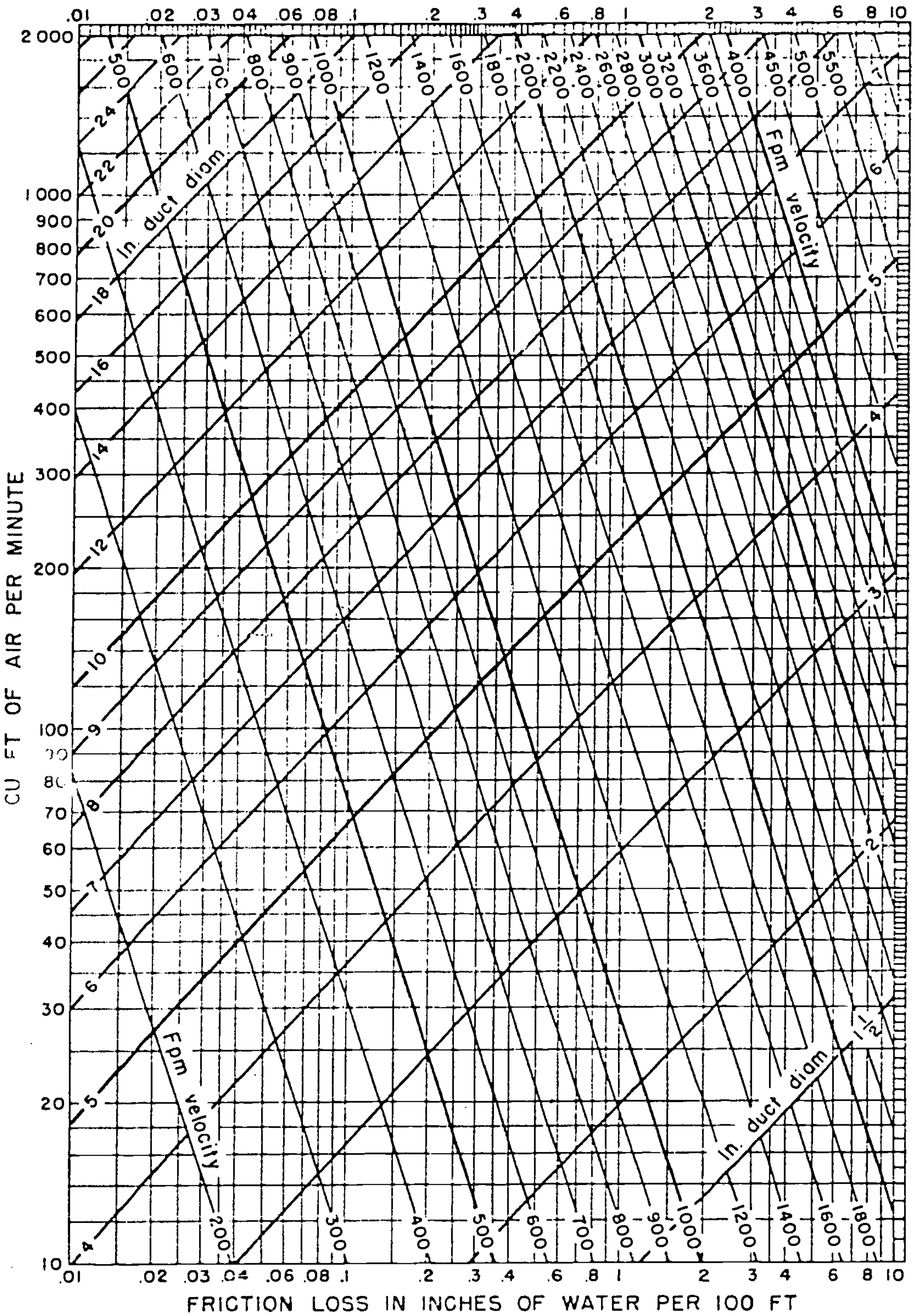
The point of operation of the fan therefore is the point of intersection between the fan characteristic pressure and the system characteristic pressure.

The following example illustrates one of the methods of finding the losses in a duct system.

Example 1: Size the following duct system. System is to be used to convey dust from grinding machines. It includes three, five piece elbows (Assume R/D = 125%). Circled numbers on diagram indicate the stations.



DUCT SYSTEM FOR GRINDING MACHINE



(Based on Standard Air of 0.075 lb per cu ft density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 ft.) Caution: Do not extrapolate below chart.

FIG. 2

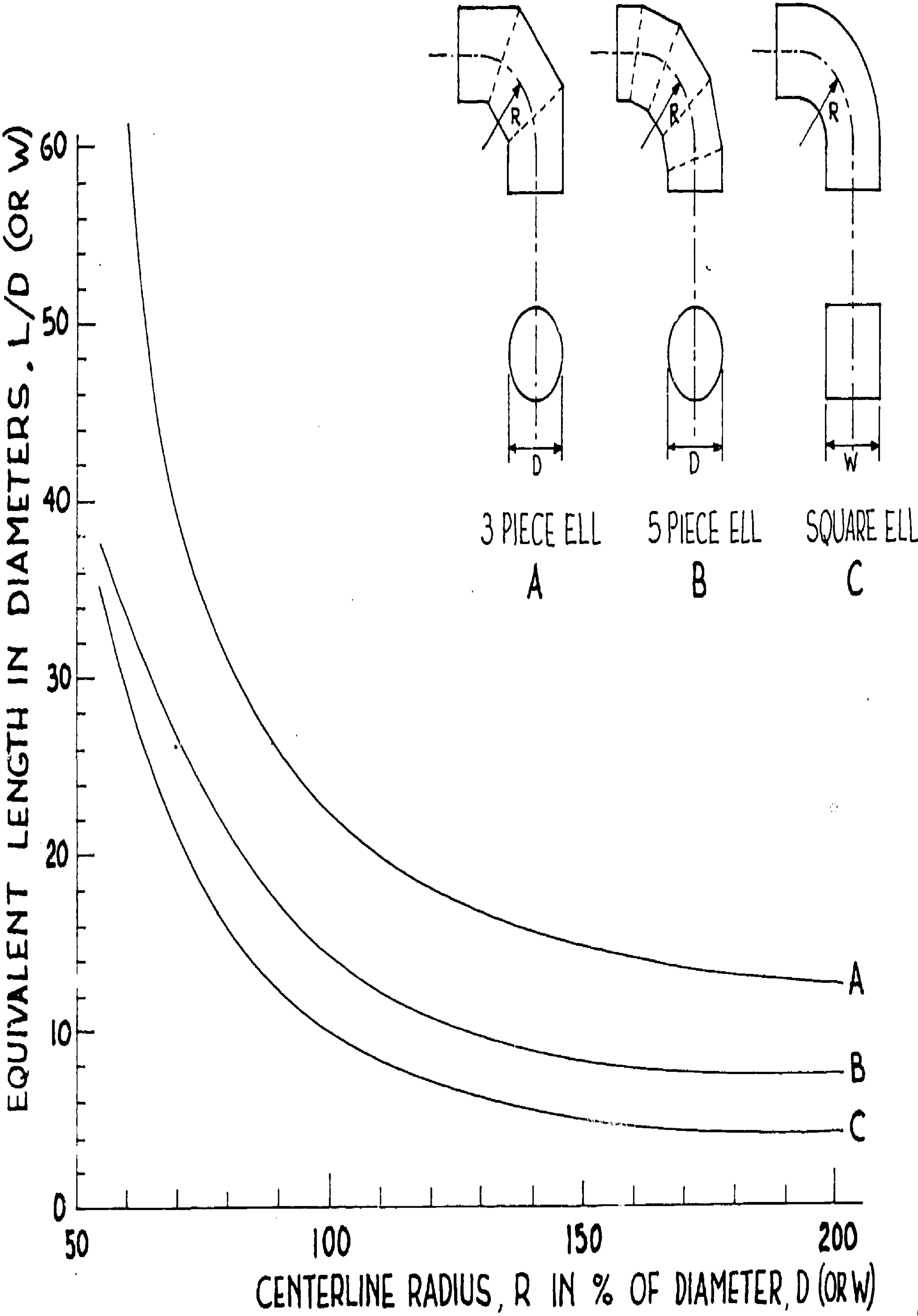

3 PIECE ELL
A
5 PIECE ELL
B
SQUARE ELL
C
R
D
W
EQUIVALENT LENGTH IN DIAMETERS, L/D (OR W)
60
50
40
30
20
10
0
50
100
150
200
CENTERLINE RADIUS, R IN % OF DIAMETER, D (OR W)

FIG. 3

Solution:

Working with various stations we calculate the losses from duct inlet to fan inlet.

At 1, 2 and 3

$Q = 390$ cfm

$D = 4$ in.

$L = 4$ ft.

From Fig. 2

$$h_{L_1} = h_{L_2} = h_{L_3} = \frac{8.5 \text{ in. } H_2O}{100 \text{ ft.}} (4 \text{ ft.}) = 0.34 \text{ in. } H_2O$$

The volume rate of flow in the remaining stations is 3(390) = 1170 cfm.

At 4, 5 piece elbow

$R/D = 125\%$

$D_3 = 6''$

From Fig. 3

$L/D = 10$

$L = 10\ (D)$

$= 10\ (6/12) = 5$ ft.

From Fig. 2

$$h_{L_4} = \frac{9.2 \text{ in. } H_2O}{100 \text{ ft.}} \times 5 \text{ ft.} = 0.46 \text{ in. } H_2O$$

At 5, D = 6 in.

$$h_{L_5} = \frac{9.2 \text{ in. } H_2O}{100 \text{ ft.}} \times 10 \text{ ft.} = 0.92 \text{ in. } H_2O$$

At 6, 5 piece elbow

$$h_{L_6} = h_{L_4} = 0.46 \text{ in. } H_2O$$

At 7, D = 6 in.

$$h_{L_7} = h_{L_5} = 0.92 \text{ in. } H_2O$$

At 8, sudden expansion

$$h_{L_8} = (V_7 - V_8)^2/(4000)^2$$

where $V_7 = Q_7/A_7 = \dfrac{1170 \text{ ft}^3/\text{min}}{(0.7854)(6/12)^2 \text{ft}^2} = 5960$ ft/min

and $V_8 = 3350$ ft/min

$$h_{L_8} = (5960 - 3350)^2 \ (4000)^2 = 0.43 \text{ in } H_2O$$

At 9, D = 8 in.

$$h_{L_9} = \frac{2 \text{ in. } H_2O}{100 \text{ ft.}} \times 10 \text{ ft.} = 0.2 \text{ in. } H_2O$$

At 10, 5 piece elbow

$$L/D = 10$$

$$L = 10\ (D)$$

$$= 10(8/12) = 6.7 \text{ ft.}$$

$$h_{L_{10}} = \frac{2 \text{ in. } H_2O}{100 \text{ ft.}} \times 6.7 \text{ ft.} = 0.134 \text{ in. } H_2O$$

At 11, D = 8 in.

$$h_{L_{11}} = \frac{2 \text{ in. } H_2O}{100 \text{ ft.}} \times 25 \text{ ft.} = 0.5 \text{ in. } H_2O$$

To find the total head we sum up all the losses. (Taking longest run).

$$h_T = 0.34 + 0.46 + 0.92 + 0.46 + 0.92 + 0.43 + 0.2 + 0.13 + 0.5$$

$$= 4.36 \text{ in. } H_2O$$

Example 2. Using the attached performance curves, find the point of operation of the fan in example 1.

Solution: Point of operation will be the intersection of system characteristic curve and fan characteristic curve (shown in Fig. 4). We now can proceed to develop the system characteristic.

$$Q \propto (\Delta P)^{\frac{1}{2}}$$

$$Q = C\ (\Delta P)^{\frac{1}{2}}$$

Using the total frictional loss for the given flow rate (example 1) we can determine the constant C.

$$C = Q/\ (\Delta P)^{\frac{1}{2}} = 1170/(4.36)^{\frac{1}{2}} = 560.3$$

We can use this relationship to get some additional points for the curve.

$$\Delta P = (Q/C)^2 = (Q/560.3)^2$$

Proceeding in this manner, we established the following table:

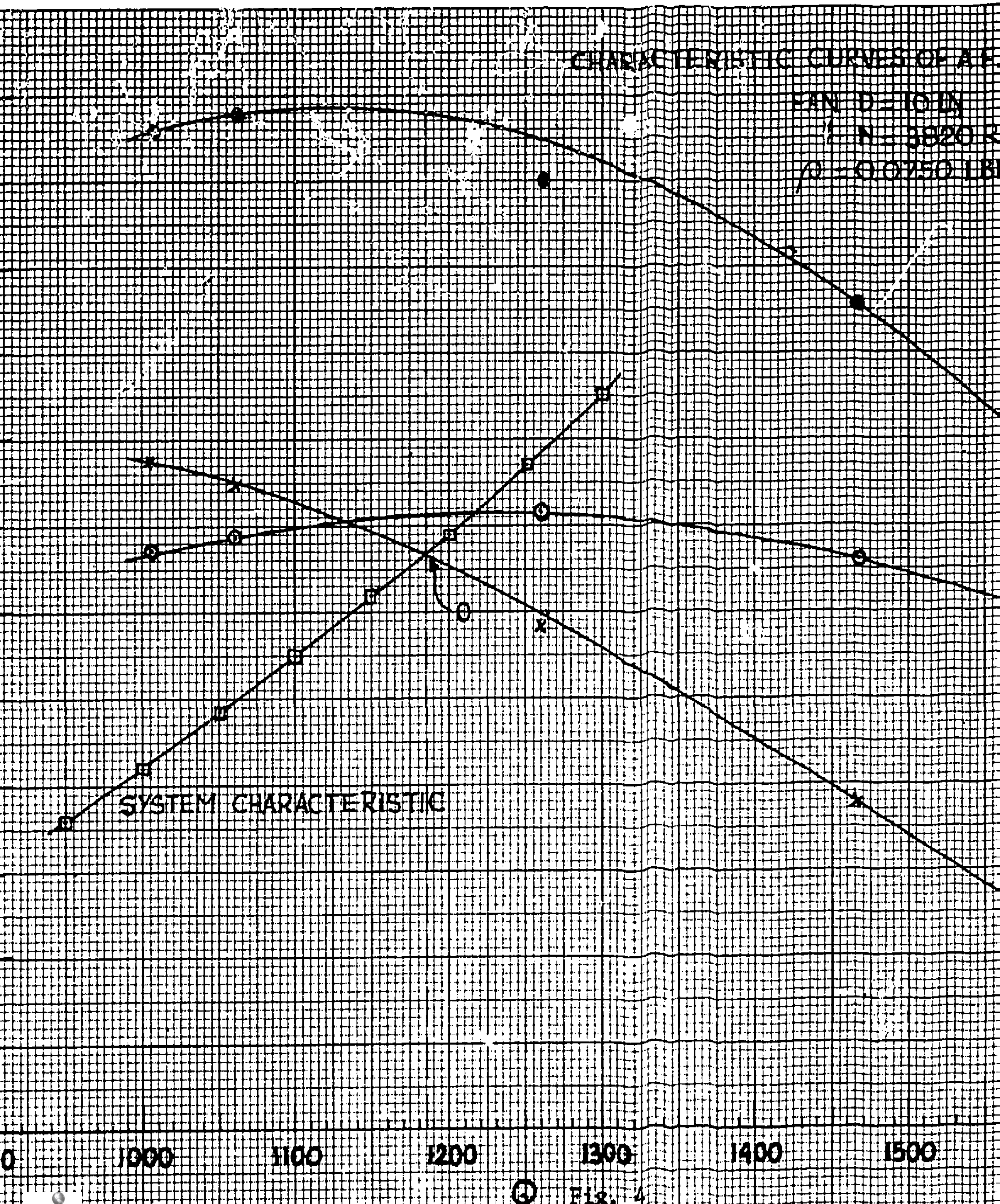
Q	P	Q	P
1300	5.38	1100	3.85
1250	4.98	1050	3.51
1200	4.59	1000	3.18
1150	4.21	950	2.87

Plotting these points on the same graph (Fig. 4) we find the point of operation of the fan (point O). At this point, the system characteristic and fan characteristic intersect.

$$P = 4.3 \text{ in. } H_2O$$

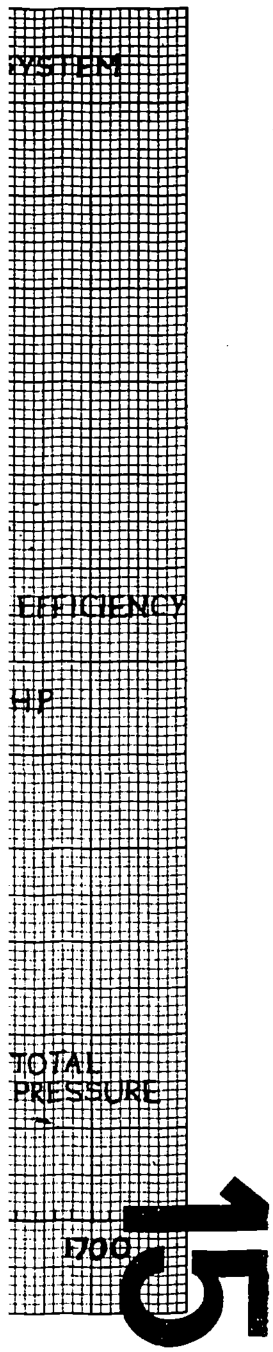
$$Q = 1185 \text{ cfm}$$

$$\eta = 89\%$$



CHARACTERISTIC CURVES OF A F
FAN D = 10 IN
N = 3820 R
ρ = 0.0750 LB
SYSTEM CHARACTERISTIC
O
1000
1100
1200
1300
1400
1500
Q

Fig. 4


YSTEM
EFFICIENCY
HP
TOTAL
PRESSURE
1700
15

Problems:

1. A fan having an outlet area of 4 ft^2, delivers 10,000 ft^3/min. air (ρ=0.0754 lbm/ft^3). The fan develops 3 in. of water total pressure and the input power is 4 HP.

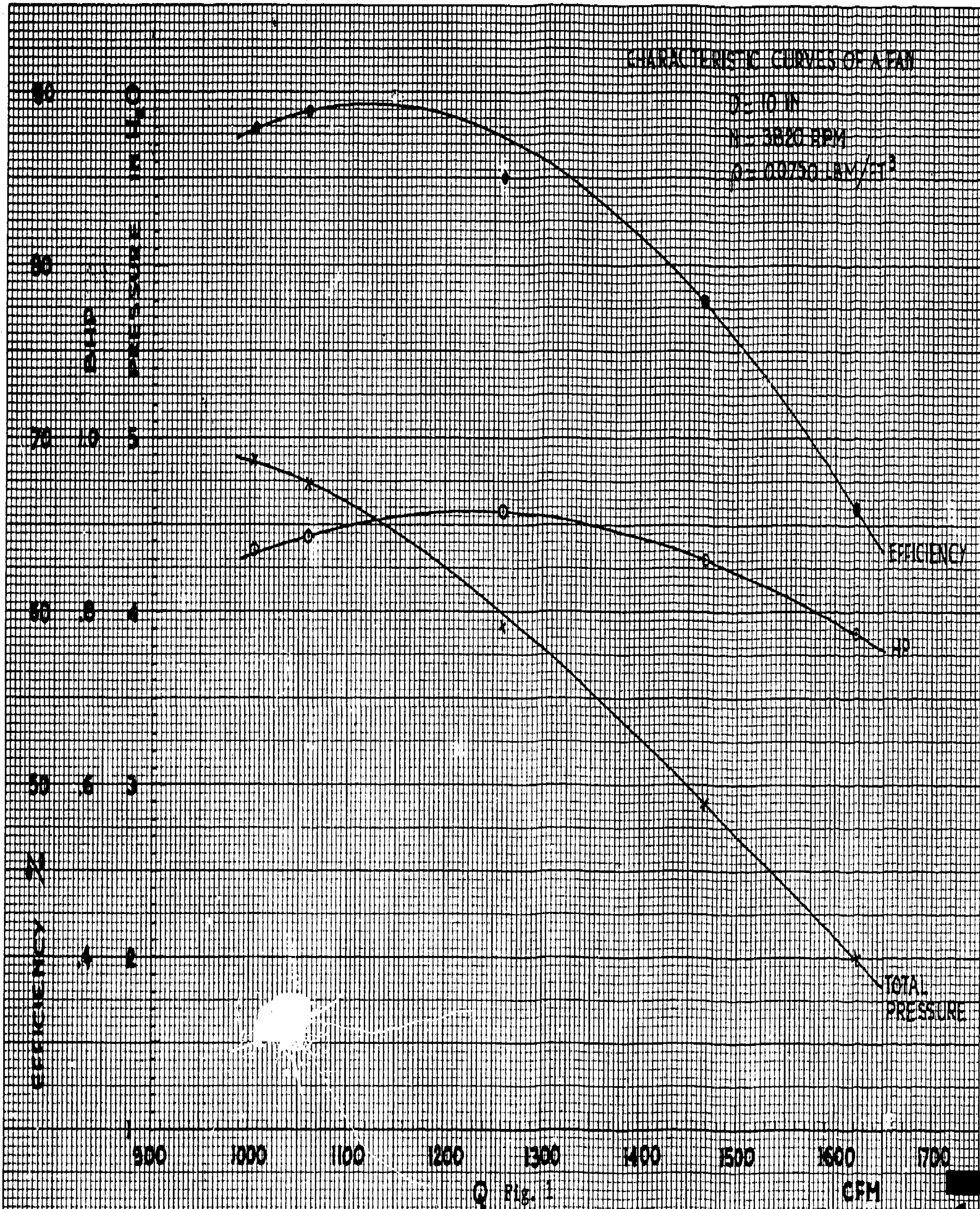
   Determine the fan total and static efficiencies.

2. Assume we want to use the fan on the following page for a duct system that handles 1225 cfm while developing 3.5 in. of water total pressure.

   a. Draw the system characteristic curve.

   b. Determine the volume flow rate, HP and efficiency.

   c. It can be seen in part (b) that the point of operation is not at 1225 cfm and 3.5 in. of water. What can be done to obtain this?

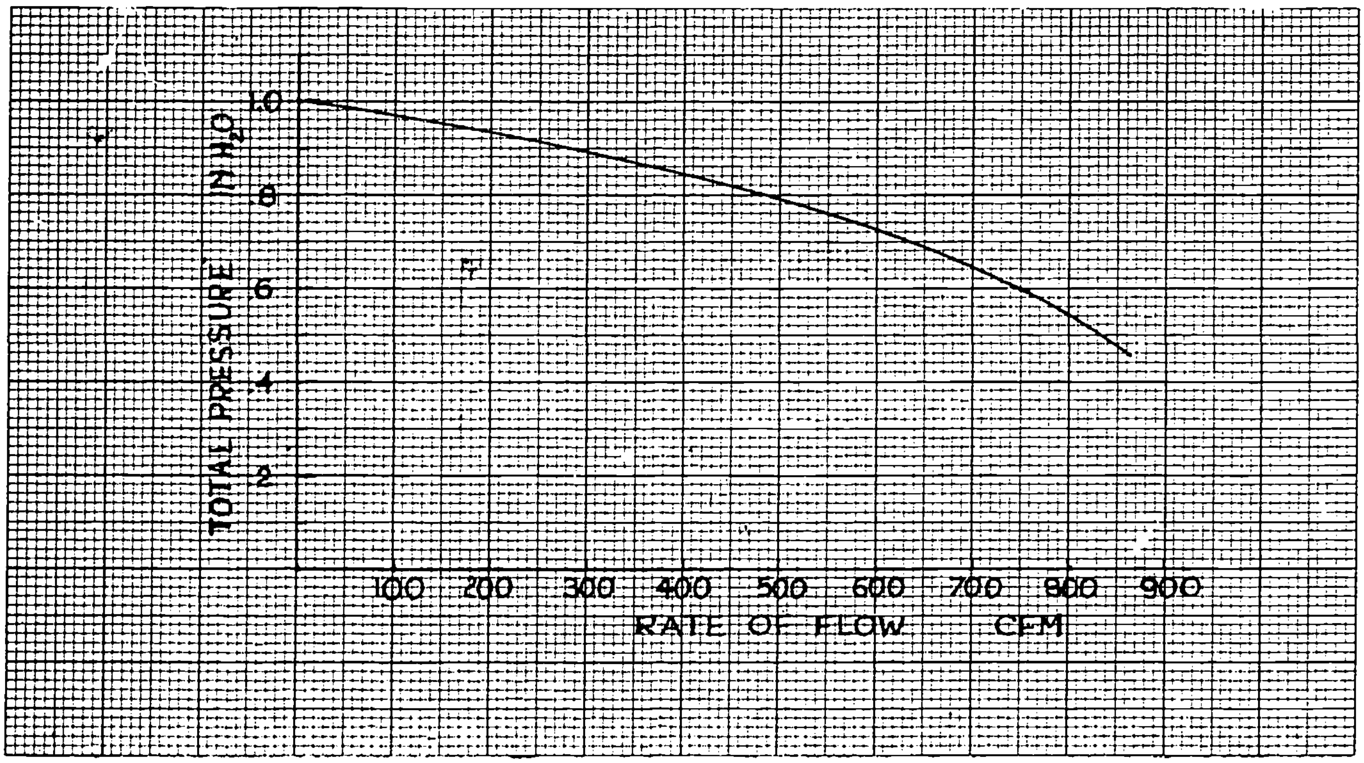


CHARACTERISTIC CURVES OF A FAN
D = 10 IN
N = 3820 RPM
ρ = 0.0750 LBM/FT³
EFFICIENCY %
BHP
PRESSURE IN H₂O
EFFICIENCY
HP
TOTAL PRESSURE
900
1000
1100
1200
1300
1400
1500
1600
1700
Q
CFM

Fig. 1

3. Assume a particular fan has a system characteristic as shown. (The system is designed to develop 0.6 in. of water at 750 cfm).

If the system total pressure is increased to 0.8 in. of water based on a flow rate of 750 cfm what would be the new operating point?



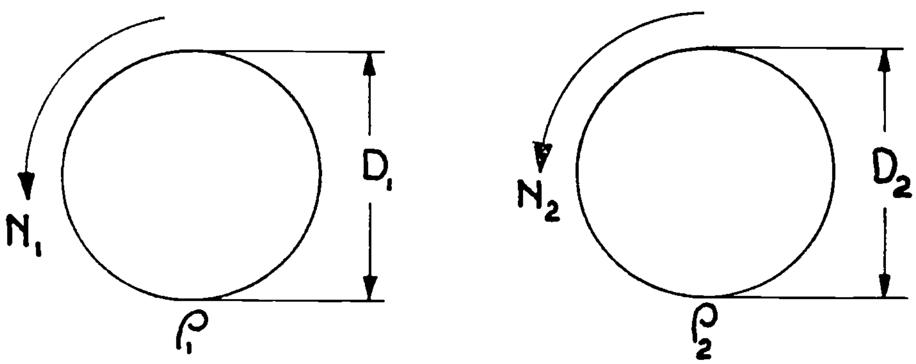
Name: Section:

Experiment No. 16 Fan Laws

Fan companies manufacture a line of fans in a single design that are geometrically similar. The manufacturer usually tests one of the fans in the series and the performance curves or data generated from these tests are available in fan catalogs.

Assume we want to use one of the fans in this series for a particular job. How do we go about making the engineering decision as to what size fan to use to satisfy the job requirements? The problem can be solved by applying the fan laws. Application of these laws allows us to obtain sufficient data for any fan in the particular series.

A discussion and derivation of the fan laws can be found in experiment 16. A more practical form of these relationships is summarized below.



where N = rpm, D = diameter, ρ = density

$C^2 = (D_2/D_1)^2$

R = Tip speed factor $= \dfrac{\pi D_2 N_2}{\pi D_1 N_1}$

$K = \rho_2 / \rho_1$

The fan laws can now be written

$$Q_2 = Q_1\ (C^2 R) \qquad (1)$$

$$P_2 = P_1\ (K\ R^2) \qquad (2)$$

$$HP_2 = HP_1\ (K C^2 R^3) \qquad (3)$$

These laws apply to fans having the same geometric shape and operating at the same point of rating (operating at corresponding points on their performance curves, therefore having the same efficiency - usually maximum).

Example 1 - Converting fan performance data:
Assume we have the following catalog data for a 40 ¼" diameter fan ($\rho = 0.0750$ lbm/ft^3)

Q, cfm	V, ft/min	N, rpm	HP	Pstatic, in H_2O
37,?80	4,000	1,341	35.6	3
26,100	2,800	1,042	18.4	3
18,640	2,000	864	11.2	3
13,980	1,500	773	7.76	3
13,050	1,400	761	7.27	3

Using the Fan Laws and the data available for the 40 ¼" fan, we want to generate the performance curves for a similar fan with the following data:

fan diameter = 10 in

fan rpm = 3,820

$\rho = 0.0750$ lbm/ft^3

Solution: Working with the first point data

$D_1 = 40\frac{1}{4}$ in $D_2 = 10$ in

$N_1 = 1341$ rpm $N_2 = 3820$ rpm

$HP_1 = 35.6$ $\rho_2 = 0.0750$ lbm/ft^3

$Q_1 = 37280$ cfm

$V_1 = 4000$ ft/min

$\rho_1 = 0.0750$ lbm/ft^3

$$C^2 = (D_2/D_1)^2 = (10/40.25)^2 = 0.0617$$

$$K = (\rho_2/\rho_1) = 1$$

$$R = \frac{D_2N_2}{D_1N_1} = \frac{(10)(3820)}{(40.25)N_1} = \frac{949}{N_1} = \frac{949}{1341} = 0.707$$

$$R^2 = (0.707)^2 = 0.500$$

$$R^3 = (0.707)^3 = 0.353$$

$$C^2R = 0.0617(0.707) = 0.0435$$
$$C^2R^3 = 0.0617(0.353) = 0.0218$$

Using first law

$$Q_2 = Q_1 \; (C^2R)$$
$$= 37280 \; (0.0435)$$
$$= 1622 \text{ cfm}$$

Using second law

$$P_2 = P_1 \; (KR^2)$$

To find P_2, we must first find the total pressure P_1

$$P_{T_1} = P_{s_1} + P_{v_1}$$

where P_s is the static pressure and P_v is the velocity pressure

$$P_{v_1} = \frac{V^2}{2g} = \frac{V^2 ft^2/min^2}{64.4 ft/sec^2} \times \frac{min^2}{3600 sec^2} \times \frac{12 in}{ft} \times \frac{0.0750}{62.4}$$
$$= \frac{V^2}{16 \times 10^6} = \frac{(4000)^2}{16 \times 10^6} \text{ in } H_2O$$

$$P_{v_1} = 1.0 \text{ in } H_2O$$

$$P_{T_1} = 3 \text{ in } H_2O + 1 \text{ in } H_2O$$
$$= 4 \text{ in } H_2O$$

$$P_2 = 4 \text{ in } H_2O \quad (1)(0.500)$$
$$= 2 \text{ in } H_2O$$

Using third law

$$HP_2 = HP_1 \; (KC^2R^3)$$
$$= 35.6 \; (1)(0.0218)$$
$$= 0.776 \text{ HP}$$

Total efficiency

$$\eta_T = \frac{Q(P_T)}{6356(BHP)}$$

where Q is in cfm

P_T is in inches of H_2O

$$\eta_T = \frac{1622(2)}{6356(.776)} = 65.8\%$$

This procedure is now repeated for the second set of data.

$D_1 = 40\frac{1}{4}$ in

$Q_1 = 26100$ cfm

$V_1 = 2800$ ft/min

$N_1 = 1042$ rpm

$HP_1 = 18.4$

$P_{s_1} = 3$ in H_2O

$\rho_1 = 0.0750$ lbm/ft^3

$D_2 = 10$ in

$N_2 = 3820$ rpm

$\rho_2 = 0.0750$ lbm/ft^3

$$C^2 = 0.0617$$
$$K = 1$$
$$R = \frac{949}{N_1} = \frac{949}{1042} = 0.911$$
$$R^2 = (0.911)^2 = 0.830$$
$$R^3 = (0.911)^3 = 0.756$$
$$C^2R = (0.0617)(0.911) = 0.0562$$
$$C^2R^3 = (0.0617)(0.756) = 0.0466$$

$$Q_2 = 26100\ (0.0562) = 1467 \text{ cfm}$$

$$P_{v_1} = \frac{V^2}{16\text{x}10^6} = \frac{(2800)^2}{16\text{x}10^6} = 0.49 \text{ in } H_2O$$

$$P_{T_1} = P_{s_1} + P_{v_1}$$
$$= 3 + 0.49 = 3.49 \text{ in } H_2O$$

$$P_2 = 3.49 \text{ in } H_2O\ \ (1)(0.830)$$

$$P_2 = 2.90 \text{ in } H_2O$$

$$HP_2 = HP_1\ (KC^2R^3)$$
$$= (18.4)(1)(0.0617)(0.756)$$

$HP_2 = 0.858$

$\eta_T = \frac{(1467)(2.90)}{6356(.858)}$

$= 78\%$

Working with the five points given in the data sheet, we can generate the following table for the 10 in fan at 3820 rpm and 0.0750 lbm/ft^3 density.

Q, cfm	P_{total}, in H_2O	HP	η_{total},	RPM
1622	2	0.776	65.8	3820
1467	2.90	0.858	78	3820
1262	3.92	0.915	85.1	3820
1060	4.74	0.885	89.3	3820
1005	4.87	0.872	88.3	3820

We now have sufficient data to plot the characteristic curves of the 10 in fan (Fig. 1).

Example 2 - It is necessary to use one of the fans in this series to deliver 60,000 cfm of air with a total pressure of 12.5 in H_2O. Determine size of fan and rpm necessary to accomplish this.

Solution: Though you may choose any size fan you wish it is best to check the manufacturers catalog and restrict your choice to the sizes available in the series. To simplify the problem, we will limit our selection to 50, 55 and 60 in diameters.

1) Assume D = 50 in

Assuming a constant tip speed process

$D_1 = 10$ in, $D_2 = 50$ in, $Q_2 = 60,000$ cfm

$R = \frac{D_2 N_2}{D_1 N_1} = 1$

$C^2 = (D_2/D_1)^2 \quad (50/10)^2 = 25$

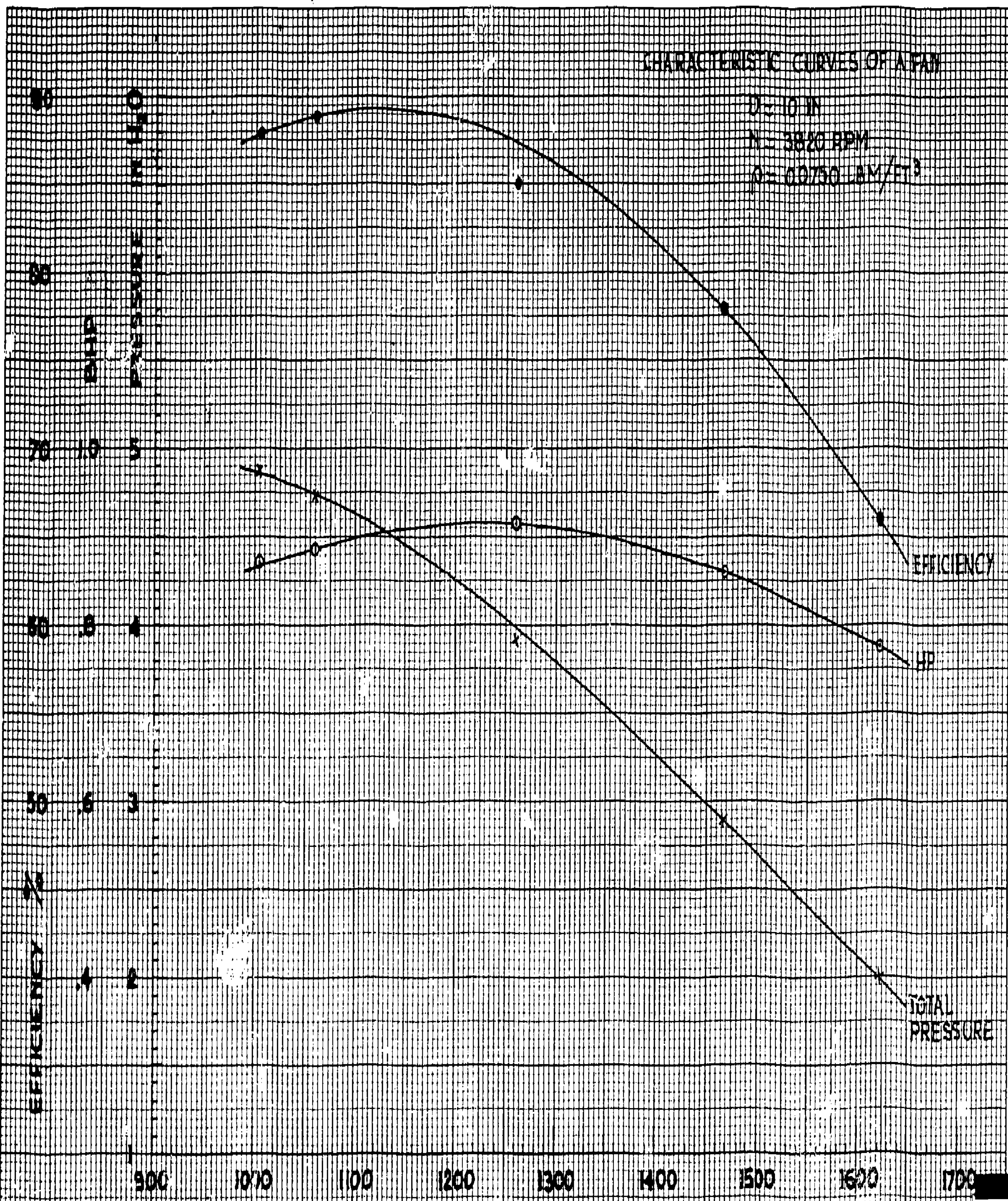

CHARACTERISTIC CURVES OF A FAN
D = 10 IN
N = 3820 RPM
ρ = 0.0750 LBM/FT³
EFFICIENCY
HP
TOTAL PRESSURE
EFFICIENCY %
BHP
PRESSURE IN H₂O
900
1000
1100
1200
1300
1400
1500
1600
1700
Q
CFM

Fig. 1

$$Q_2 = Q_1 \ (C^2R)$$

$$Q_1 = \frac{Q_2}{C^2R} = \frac{60,000}{25} = 2400 \text{ cfm @ } 12.5 \text{ in } H_2O$$

The tip speed of the 10 in fan will be

$$T_{s_1} = \text{tip speed} = \frac{\pi DN}{12} = \frac{(10\text{in})3820 \text{ rev/min}}{12 \text{ in/ft}}$$
$$= 10,000 \text{ ft/min}$$

We now try to find the system characteristic.

$$Q \propto (\Delta P)^{\frac{1}{2}} \text{ (See experiment No. 15)}$$

or $$Q = C \ (\Delta P)^{\frac{1}{2}}$$

Using the total pressure drop and the corresponding flow rate, we can determine the constant C.

$$C = Q/(\Delta P)^{\frac{1}{2}}$$
$$= 2400/(12.5)^{\frac{1}{2}}$$
$$= 678.9$$

Since we have established the value of the constant the equation can be written

$$\Delta P = (Q/C)^2$$
$$= (Q/678.9)^2$$

Proceeding in this manner, we establish the following table:

Q, cfm	P, in H_2O
1600	5.55
1500	4.88
1400	4.25
1300	3.65
1200	3.12
1100	2.65
1000	2.2

These values can be plotted and point of operation determined for the 50 in fan (Fig. 2).

2) Assume $D = 55$ in

Assuming constant tip speed process

$D_1 = 10$ in $\qquad D_2 = 55$ in

$Q_2 = 60{,}000$ cfm

$$R = \frac{D_2 N_2}{D\ N_1} = 1$$

$$C^2 = (D_2/D_1)^2 = (55/10)^2 = 30.25$$

$$Q_2 = Q_1\ (C^2 R)$$

$$Q_1 = \frac{Q_2}{C^2 R} = \frac{60{,}000}{30.25} = 1983 \text{ cfm @ } 12.5 \text{ in } H_2O$$

$$Q \propto (\Delta P)^{\frac{1}{2}}$$

$$1983 = C\ (12.5)^{\frac{1}{2}}$$

$$1983 = C\ 3.535$$

$$C = 561$$

Q, cfm	P
1600	8.13
1500	7.15
1400	6.24
1300	5.37
1200	4.58
1100	3.84
1000	3.17

These values can be plotted and point of operation determined for the 55 in fan (Fig. 2).

3) Assume $D = 60$ in

Assuming constant tip speed process

$D_1 = 10$ in $\qquad\qquad D_2 = 60$ in

$$R = \frac{D_2 N_2}{D_1 N_1} = 1 \qquad\qquad Q_2 = 60{,}000 \text{ cfm}$$

$$C^2 = \left(\frac{D_2}{D_1}\right)^2 = \left(\frac{60}{10}\right)^2 = 36$$

$$Q_2 = Q_1 \; (C^2 R)$$

$$Q_1 = \frac{Q_2}{C^2 R} = \frac{60{,}000}{36} = 1667 \text{ cfm @ } 12.5 \text{ in } H_2O$$

$$Q \propto (\Delta P)^{\frac{1}{2}}$$

$$Q = C \; (\Delta P)^{\frac{1}{2}}$$

$$1667 = C \; (12.5)^{\frac{1}{2}}$$

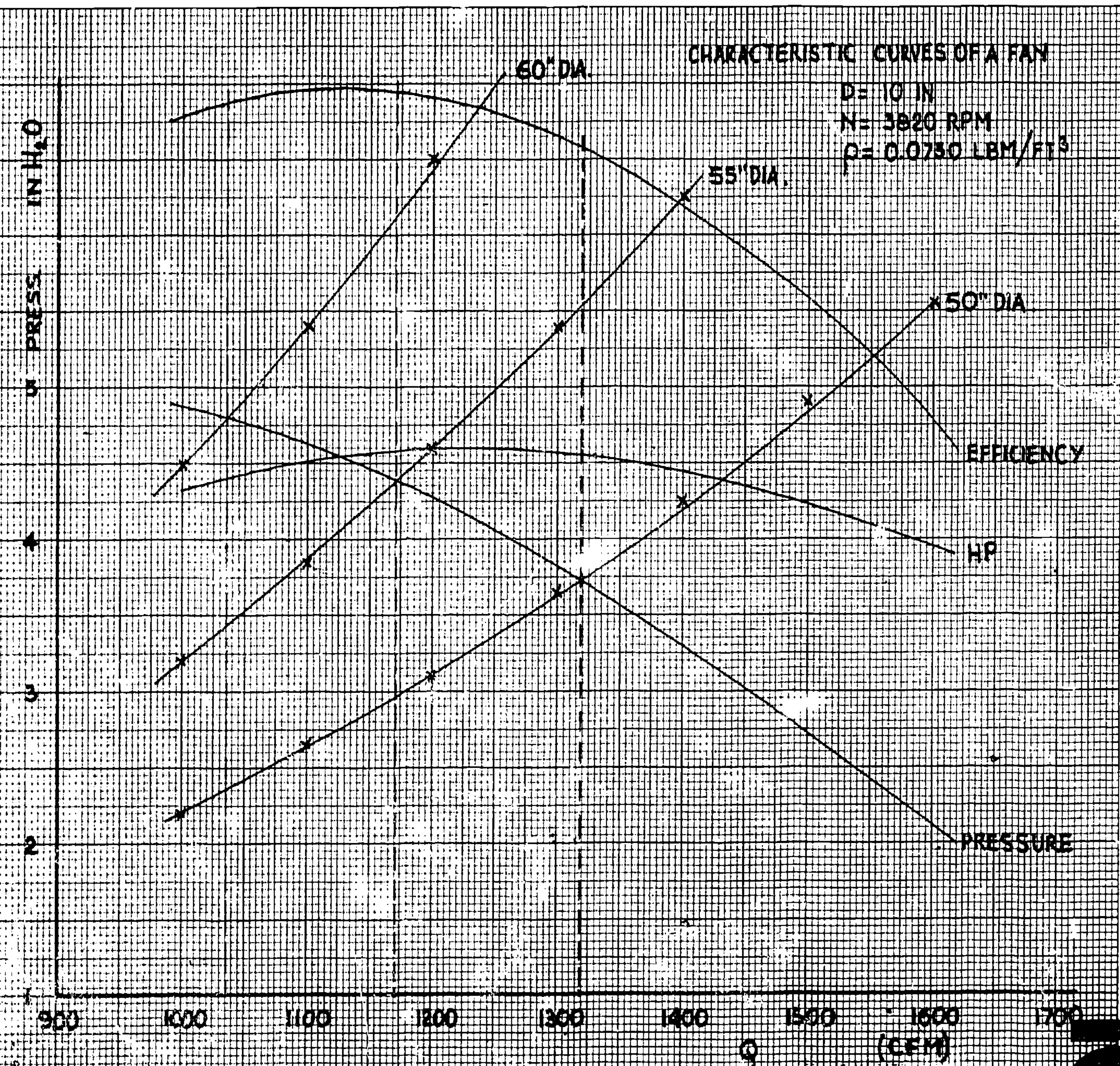
$$1667 = C \; 3.535$$

$$C = 472$$

Q, cfm	P
1600	11.5
1500	10.1
1400	8.81
1300	7.57
1200	6.45
1100	5.43
1000	4.49

Plotting the characteristic curves of the three fans, we establish the following results: (Fig. 2)

Diameter, in	P, in H_2O	η, efficiency %	Q, cfm
50	3.7	86	1320
55	4.4	89.5	1170
60	4.8	89	1035


CHARACTERISTIC CURVES OF A FAN
D= 10 IN
N= 3820 RPM
ρ= 0.0730 LBM/FT³
60" DIA.
55" DIA.
50" DIA.
EFFICIENCY
HP
PRESSURE
PRESS. IN H₂O
4
3
2
900
1000
1100
1200
1300
1400
1500
1600
1700
Q
(CFM)

At this point, the engineering decision must be made as to which one of these fans to pick. Various considerations enter this decision making process. Questions must be asked, such as the number of hours per year the fan is anticipated to operate? How many fans of these requirements needed? How important is the job?

The answers to these questions are obviously important. For example if the fan will see heavy use it would be worthwhile to optimize the efficiency. If the job is important and you need a large quantity of these fans, it may be worthwhile to ask the manufacturer to build a more efficient special size.

The following general guidelines could be of some use.

1. Try to pick a fan operating at or near maximum efficiency. This would be most economical in its energy consumption.
2. Somewhat to the right of maximum efficiency will enable us to use a smaller size fan for a given capacity.
3. Far to the right of this point the efficiency and pressure would be too low.
4. Far to the left of this point the fan becomes too large and operation could be in an unstable and noisy region.

With these guidelines in mind, our selection would be the 55 inch diameter.* By use of the fan laws, we now try to find the rpm.

$$P_2 = P_1 \; (K \; R^2)$$

where

$$K = \rho_2/\rho_1 = 1$$

$$R = \frac{\pi D_2 N_2}{\pi D_1 N_1}$$

* 55" fan approximate [illegible] cheaper than 60" fan.

$$P_2 = P_1 \frac{(\pi D_2 N_2)^2}{(\pi D_1 N_1)^2}$$

where $\pi DN = T_s$ = tip speed

$$(P_2/P_1)^{\frac{1}{2}} = T_{s_2}/T_{s_1}$$

We substitute this in the system characteristic equation

$$Q_2/Q_1 = (P_2/P_1)^{\frac{1}{2}} = \frac{T_{s_2}}{T_{s_1}}$$

where T_{s_1} = 10,000 ft/min

Q_1 = 1170 cfm

Q_2 = 1983 cfm

$$T_{s_2} = \frac{1983}{1170}\ (10{,}000)\ \text{ft/min}$$

$$= 16{,}950\ \text{ft/min}$$

$$T_{s_2} = \pi D_2 N_2$$

$$N_2 = \frac{T_{s_2}}{D_2 \pi}$$

$$= \frac{16950\ \text{ft/min}\ (12\ \text{in})}{(55\ \text{in})\ \pi\ (\text{ft})}$$

$$= 1178\ \text{rpm}$$

Example 3 - What HP would the 55 in fan draw at the selected speed?

10 in fan	55 in fan
$D_1 = 10$ in	$D_2 = 55$ in
$N_1 = 3820$ rpm	$N_2 = 1178$ rpm
$BHP_1 = 0.91$ (from graph)	$BHP_2 = ?$

Using the third fan law

$$HP_2 = HP_1 \; (KC^2 \; R^3)$$

$$K = 1$$

$$C^2 = (D_2/D_1)^2 = (55/10)^2 = 30.25$$

$$R = \frac{\pi D_2 N_2}{\pi D_1 N_1} = \frac{55 \; (1178)}{10 \; (3820)} = 1.696$$

$$R^3 = (1.70)^3 = 4.88$$

$$HP_2 = 0.91 \; (1) \; (30.25) \; (4.88)$$

$$= 134 \text{ HP}$$

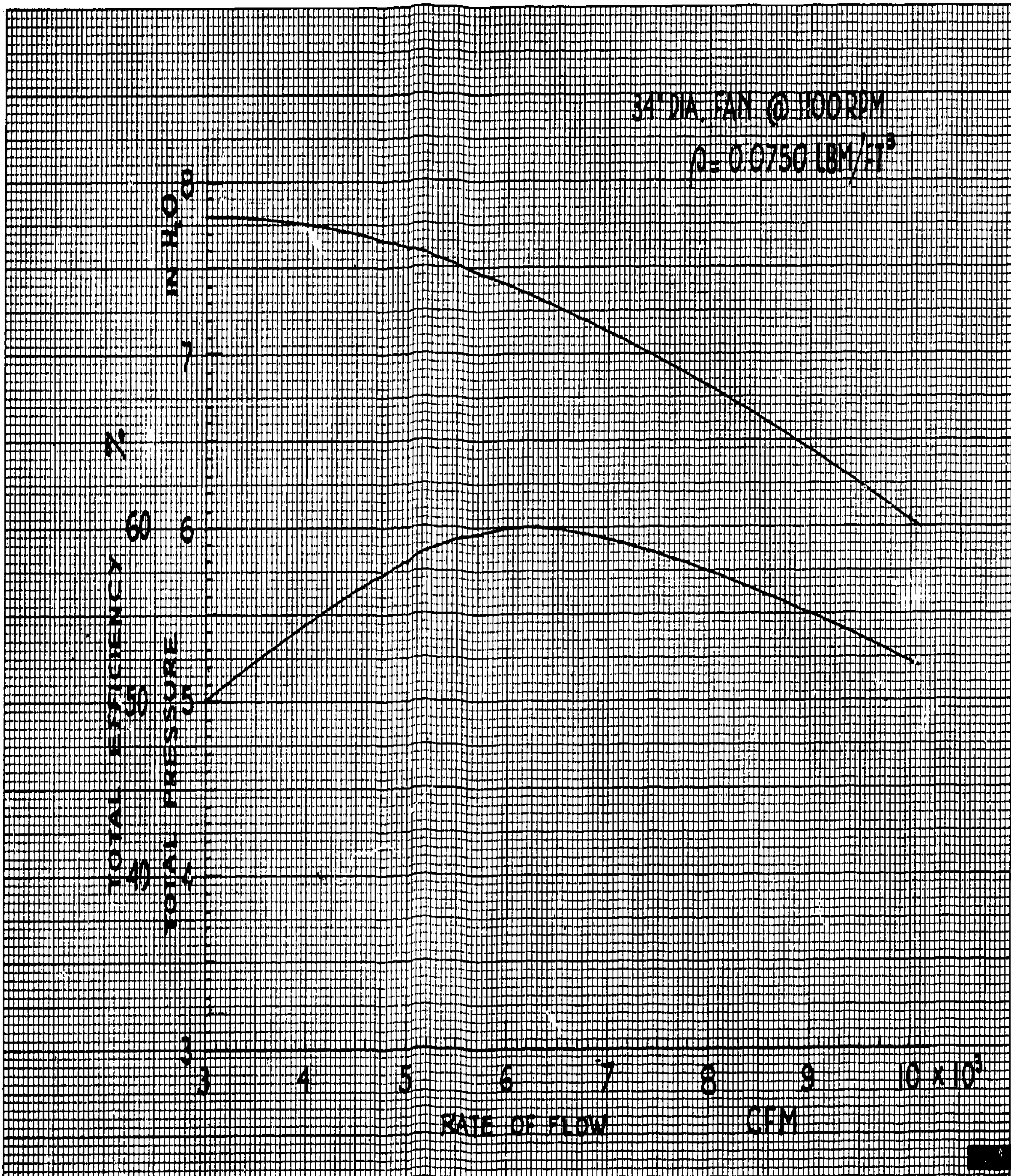
or

$$BHP = \frac{Q \; P_T}{6356 \; (\eta)}$$

$$= \frac{(60{,}000) \; (12.5)}{6356 \; (0.895)}$$

$$= 132 \text{ HP}$$

Problem 1 - (a) Using the attached performance curves, calculate the size of fan required and at what speed it would be necessary to run it for delivery of 1544 cfm of air with a total pressure of 5.45 in H_2O, ρ = 0.0750 lbm/ft. (Limit your selection to one of the following diameters: 18" or 20"); (b) What HP would your selected fan draw?



34" DIA. FAN @ 1100 RPM
ρ = 0.0750 LBM/FT³
TOTAL EFFICIENCY %
TOTAL PRESSURE IN H2O
8
7
6
5
4
3
60
50
40
3
4
5
6
7
8
9
10 x 10³
RATE OF FLOW
CFM

Name: Section:

Experiment No. 17A Engine Efficiency

1. Most internal combustion engines operate on the four or two stroke cycle principal and are either single or double acting. Define each.

2. What type of engine are you studying and how was it determined?

3. The sum of the moments of the forces on the brake about the center of the flywheel gives us the torque FL in equation number one. Since 2π and 33,000 are constants, the equation can be simplified to

$$\text{a) B.H.P.} = \frac{TN}{5250} \qquad \text{b) B.H.P.} = \frac{TN}{63{,}000}$$

What units must torque have in order to satisfy each equation?

a) b)

4. The brake arm on a dynamometer is 26 inches in length and exerts a tare weight of 25 pounds on our scale. A gross weight of 125 pounds is needed when an engine attached to this dynamometer is running at 1500 rpm. What horsepower is being developed?

5. A flow meter connected to an engine running at 1800 rpm and developing 12 H.P. shows a fuel flow rate of 60 grams per minute. Determine the specific fuel consumption in lb./HP-hr.

6. The heating value of a fuel is the amount of heat given up by the products of combustion. When most fuels burn, the hydrogen in the fuel combines with oxygen and forms water. What happens to this water after combustion, determines whether we have what is known as a higher or lower heating value.
What is the difference between these two heating values?

7. A four cycle, 4 x 4 inch, 2 cylinder gasoline engine running at 2000 rpm develops 105 H.P. when using 62 pounds of fuel per hour. The fuel has a heating value of 18,900 Btu/lb.
What is the thermal efficiency of this engine?

8. Using the data given below, plot two curves. Thermal efficiency and specific fuel consumption as ordinate versus B.H.P. as abscissa.

B.H.P.	Eff.	S.F.C.
109.5	37.5	.355
89	32.5	.450
74	33.5	.430
45.5	27.0	.560
15	17.5	.750

a. At what load is the engine most economical? Why?

b. What reasons can you give for the points falling where they do at 89 H.P.?

Name: Section:

Experiment No. 17B Ignition Timing

1. In most spark ignition engines, half of the pressure rise due to the combustion of the fuel occurs before top dead center. Since the rate at which each type of fuel will burn varies with the fuel, would you retard or advance the spark for an optimum spark setting when using a slow burning fuel. Why?

2. A major factor affecting the optimum spark setting is the interval of time required for the mixture to ignite and expand. As an engine speed is increased, what must be done to the spark setting? How is this done automatically?

3. The cylinder of an engine takes in only a part of the full charge when operating at part throttle conditions. Would you advance or retard the spark when this condition exists? Why?

4. What affect would retarding the spark have on an engine when running at a particular throttle setting?

5. a. Turn on the power to the Megatech engine (no fuel), turn the engine over by hand. Determine with a timing light the approximate distance the piston must travel from the 20° advanced position to top dead center.

   b. How else may this distance be determined?

6. The following results were obtained while testing a 6 cylinder automotive engine.

Speed	BHP	Spark Advance BTDC
3,000	90.2	10°
3,000	106.2	20°
3,000	115.3	30°
3,000	116.	40°
3,000	110.7	50°
3,000	103.	60°

Plot a curve of spark advance as abscissa versus HP as ordinate and determine the spark setting to be used for the greatest output.

Name: Section:

Experiment No. 17C Air-Fuel Ratio

A mixture that contains the chemically correct amount of air to support complete combustion of the fuel supplied to an engine is called the stoichiometric (or ideal) air-fuel ratio. A "lean-mixture" is one in which the amount of air used to complete the combustion process is greater than the ideal (excess air), whereas a "rich mixture is one in which the amount of air used is less than ideal (deficient air)". In a typical spark-ignition engine the fuel-air ratio for best power is about 7 percent greater than the stoichiometric ratio, whereas the ratio for maximum economy is 5 to 10 percent less than the stoichiometric.[1.] The stoichiometric ratio is about 0.067 pounds of fuel per pound of air.

For any engine the amount of air that can be drawn into the cylinder per unit of time is affected by the volumetric efficiency. However, the power developed depends on the efficiency of the engine and the energy input in the form of fuel. It should be noted, that as the volumetric efficiency decreases the amount of fuel injected must also decrease if the proper air-fuel ratio is to be preserved. As a consequence, the power output of the engine will decrease. (A complete discussion of the factors influencing volumetric efficiency are beyond the scope of this experiment).

Part A

An engine on test develops 100 horse power running at its rated speed and uses 13.52 pounds of air per minute. The lower heating value of the fuel is 19,000 Btu/lb_f. The air-fuel ratio is stoichiometric, and is varied from 70% to 140% in 10% increments during the test.

1. For each incremental value of the air-fuel ratio, calculate the efficiency using the following equation:

$$\text{efficiency} = \frac{\text{H.P. x 42.4 Btu/hp. min}}{w_f\text{(lbf/min) x L.H.V. (Btu/}lb_f)}$$

1. Tuve and Domholdt. "Engineering Experimentation - McGraw-Hill, 1966.

17

2a. Show necessary calculations and enter result in appropriate table.

2b. Results

Air-Fuel Ratio % of Ideal	Efficiency
70	
80	
90	
100	
110	
120	
130	
140	

3. Plot results using percent of ideal air-fuel ratio as abscissa and efficiency as ordinate.

Part B

The following data was accumulated during a test of a four stroke single cylinder engine with a 3¼" bore and 4½" stroke. The air-fuel ratio was 0.075 pounds of fuel per pound of air during the test and the engine speed was varied from 800 rpm to 1600 rpm. The temperature of intake air was 100°F.

1. Using additional data provided below, calculate the volumetric efficiency and the actual pounds of fuel used per minute and enter results in the following table. (Show necessary calculations).

R.P.M.	I.H.P.	lb air/min	lb fuel/min	Volumetric Efficiency
1600	7.7	.746		
1400	7.0	.680		
1200	6.6	.653		
800	4.7	.460		

2. Plot results with air capacity in lb air/min as abscissa versus volumetric efficiency and I.H.P. as ordinate.

Name: Section:

Experiment No. 17E Compression Ratio

1. How would you determine the compression ratio of an engine when no manufacturers specifications are available?

2. What major factor limits the compression ratio for any given engine? Explain.

3. Early automotive engines operated with 3 or 4 to 1 compression ratios. Todays engines with higher cylinder pressures and temperatures are in the 7 to 10 range. What technological advances have made these higher compression ratios possible?

4. What methods would you use to; (a) increase and (b) decrease the compression ratio for a given engine?

a.

b.

5. The clearance within an engine is usually expressed as a certain percentage of the volumetric displacement. If the volumetric displacement is the volume displaced by the piston as it travels through one stroke, calculate the compression ratio of a 4 stroke, 4 cylinder, 3.75 by 4 inch gasoline engine running at 3,000 rpm and having 11 percent clearance.

6. a. The ideal air cycle efficiency is found by the equation:

$$\eta = 1 - \frac{1}{(V_1/V_2)^{k-1}}$$

When k is equal to 1.4, we are compressing ideally without any loss of heat. When k is 1.33, the ideal compression process is approaching more closely that of the actual engines where heat losses occur.

Calculate the ideal efficiencies for compression ratios of 4, 5, 6, 7, and 8 when k = 1.4 and compare them with the efficiencies for k = 1.3.

6. b. What variables in the actual engine would drop considerably your ideal values?

18a

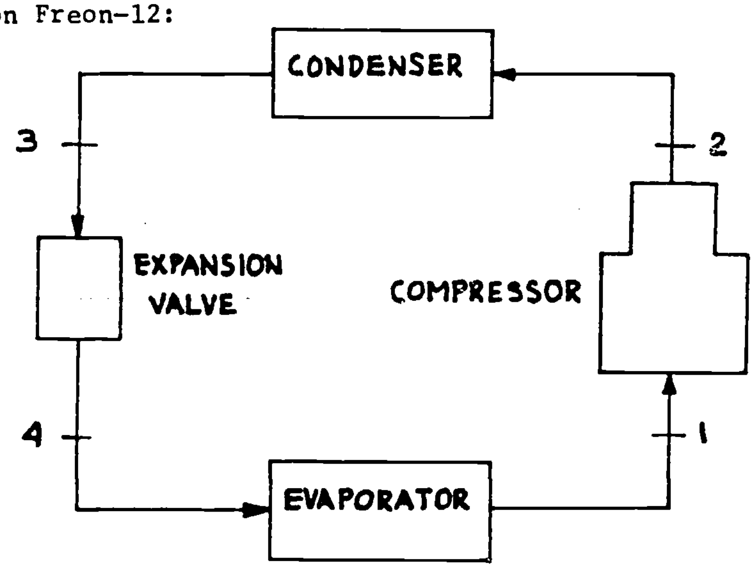
Name:

Section:

Experiment No. 18a

Vapor Compression Systems

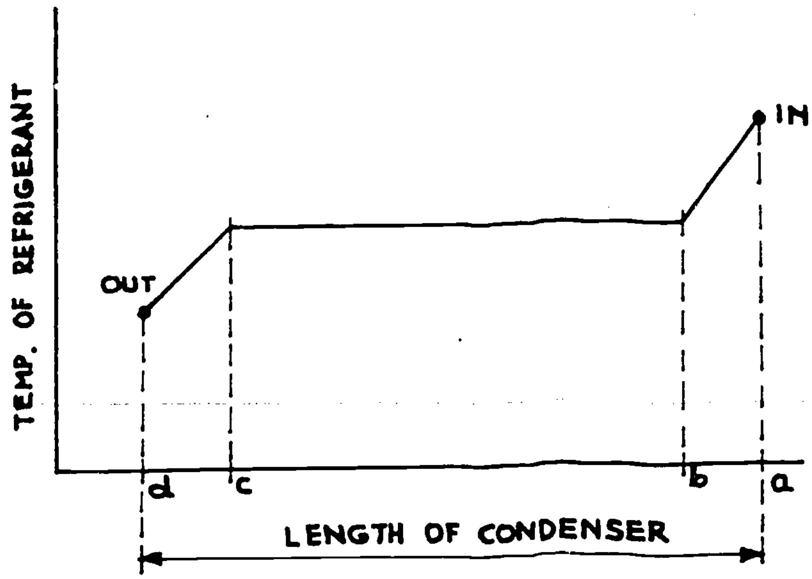
The following information is given for a simple vapor compression system operating on Freon-12:



1. Fill in following data sheet:

STATE POINT	T °F	P PSIA	H BTU/LB	CONDITION OF FLUID
1	20	25		
2	140	120		
3	85	120		
4	2.23	25		

2. The following plot indicates the condition of the refrigerant as it passes through the condenser:



Considering the information from the data sheet, determine the following for the condenser:

a. The sensible drop in temperature (^{o}F) of superheated vapor.

b. Change in enthalpy (Btu/lb) during latent state.

c. Number of degrees of subcooling (^{o}F).

3. Locate the state points on the accompanying P-H diagram and determine for a flow rate of five pounds per minute, the following:

   a. Work of compression (H.P.)

   b. Refrigeration effect (tons)

   c. Heat rejected to condenser (Btu/min)

18b

Name: Section:

Experiment No. 18b System Tonnage

An air conditioning system, consisting of a water cooled condensing unit and coil, was installed in a commercial establishment based on a calculated cooling load of 120,000 Btu/hr. It soon became apparent that either the load had been calculated incorrectly or an under-sized unit had been selected, since the load requirements for the area were never satisfied. To determine where the error lay, a series of independent tests were conducted on the system and the following data was accumulated:

Air Side:

Reading	Dry Bulb °F		Wet Bulb °F		Velocity of Air
	In	Out	In	Out	ft/min
Initial	82	57	70	55	2,000
Middle	81	58	71	56	2,100
Final	83	59	72	57	1,900

Duct Diameter = 16 inches I.D.

Water Side:

	Condenser Water Temp.	
	In	Out
Initial	50	60
Middle	52	62
Final	51	61

Flow Rate: estimated at 3 gall/min-ton based on ten ton unit.
K = 0.86 for water side calculation.

PAGE 186, CHART A-4, "PRESSURE-ENTHALPY DIAGRAM"
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1. Fill in the following data sheet and compute the tonnage from both air and water side:

	Return Air	Air Off Coil
Dry Bulb (^oF)		
Wet Bulb (^oF)		
Enthalpy (Btu/lb)		
Moisture Content (lb/lb)		
Density of Air (lb/ft^3)		
Relative Humidity (%)		

Average air velocity ________ ft/min

Tonnage from air side ________ tons

Tonnage from water side ________ tons

Show all calculations:

a. Volume flow rate of air (ft^3/min)

b. Mass flow rate of air (lb/min)

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c. Tonnage from air side

d. Tonnage from water side

2. Answer the following questions:

   a. Is there a significant difference between the values calculated for tonnage by these two methods?

   b. If so, which technique would you employ and why?

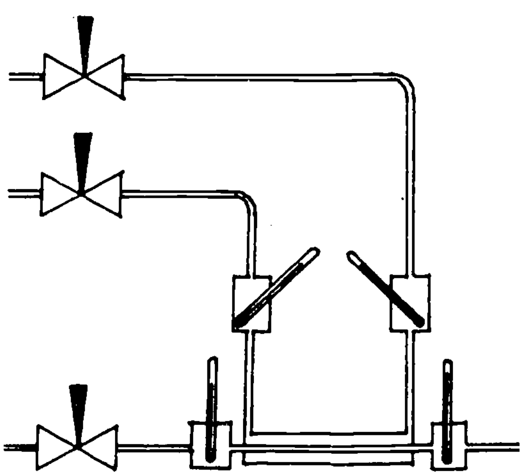
   c. In your opinion, was the load calculation correct? Why?

Name: Section:

Experiment No. 19 Heat Exchangers

1. Which two flow-types of heat exchanger are studied in this experiment?

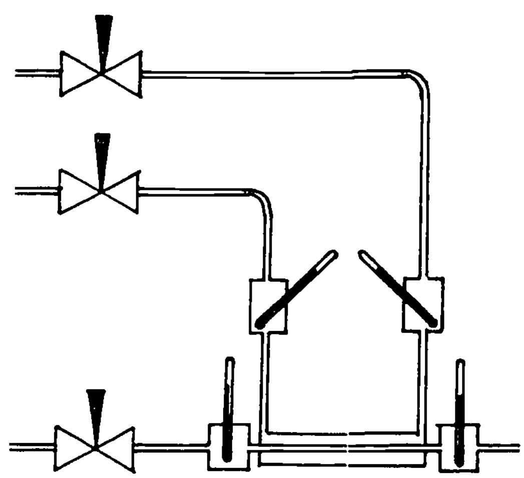
2. In the following diagrams indicate:
   a. Flow directions of hot and cold water.
   b. Which valves meter hot and cold water flow rates.
   c. The temperature measured by each thermometer (t_{hi}, t_{co}, etc.).
   d. The equations for Δt_1 and Δt_2.



PARALLEL FLOW

$\Delta t_1 =$

$\Delta t_2 =$



COUNTER FLOW

$\Delta t_1 =$

$\Delta t_2 =$

3. Given the quantities $\dot{Q}$, $\dot{m}_h$, $C_{ph} = C_{pc}$, Δt_h and Δt_c, write the equation for the cold water flow rate:

4. Given the quantities $\dot{Q}$, A_3 and Δt_{lm}, write the equation for the overall heat transfer coefficient based on A_3:

5. If the hot water temperature is 170^{o}F., and the inside diameter of the hot water tube is 0.315 inches, what is the minimum hot water flow rate (lbm/hr) for turbulent flow?

6. The fluid properties are based on the average fluid temperatures, write the equations for these temperatures:

7. What are the dimensions of the heat capacity rate, $\dot{m}\,C_p$?

8. If the heat capacity rates are equal on the hot and cold sides, what is the relationship between Δt_h and Δt_c?

9. List some possible areas in the exchanger where heat flow may cause errors.

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Name:

Section

Experiment No. 20

Heat Conduction

1. What are the values for thermal conductivity of copper, iron, and aluminum in the literature?

2. Describe an experimental method of determining the thermal conductivity of a metal (include sketch).

3. Describe with the aid of a sketch the principle of operation of a heat pipe.

4. Using book values for the thermal conductivity, k, and giving the rate of heat transfer through the copper rod a value of one, what are the heat transfer rates for the aluminum and iron rods?

5. By what factors would the diameters of the iron and aluminum rods be enlarged to give the same rate of heat transfer as the copper rod?

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6. What are the units of the integral in equation No. 5?