A STUDY OF THE FLOW OF FLUIDS IN PIPES

By

Charles Edward Burnett

A THESIS SUBMITTED FOR THE DEGREE OF

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

The University of Tennessee

1939.

A STUDY OF THE FLOW OF FLUIDS IN PIPES

CONTENTS

	Page
PREFACE	i
CHAPTER I	
History of Piping Studies	1
CHAPTER II	
Present Day Uses of Piping	5
CHAPTER III	
Purpose of Study of Piping	7
CHAPTER IV	
Theory of Flow of Fluids	8
CHAPTER V	
Resistance of Pipe Fittings to Flow	15
CHAPTER VI	
General Formulas for Flow of Fluids	18
CHAPTER VII	
Oil Piping	26
CHAPTER VIII	
Air Piping	30
CHAPTER IX	
Water Piping	33
CHAPTER X	
Theory and Practice	37
Bibliography	39
Appendix	40
Approval	41

PREFACE

One of the most important engineering topics today is that of the "Flow of Fluids Through Pipes." The increasing importance of the piping systems in the modern power plants, in distribution systems, and in industry as a whole, causes the engineer of the present day to think of piping in a specialized nature. It is impossible to go into great detail in so short a space.

The author attempts to go into a theoretical study of the "Flow of Fluids Through Pipes," mainly that of air, oil, and water. Each one is to be taken separately and compared with whatever practical tests the writer has available. Most of the material used is that of mathematical study of piping. Data, formula and tests are obtained from various sources and an attempt to correlate them under their respective headings has been made in an attempt to justify the work done.

The average engineer, even in industry, is unfamiliar with the laws and behavior of fluids. There are many books touching on this subject in some manner or other. The problem of today is the laying out of the pipe line and adapting the information found in text books and hand books to the situation at hand. This article attempts to cover the above mentioned fluids in a general manner that some clarity of the problem at hand may be had not only to the benefit of the writer but to the reader as well.

This is not an attempt to compete with handbooks on a complete coverage of any such subject, but only to bring out an analysis of the general problem in the behavior of fluids.

The helpful suggestions and comments of Professor Roscoe Morton, Professor of Mechanical Engineering, The University of Tennessee, and the

cooperation of Mr. E. F. Biggs and Mr. Frank Ray of the Tennessee Valley Authority, have been appreciated very much in the preparation of this thesis.

Charles Edward Burnett.

CRANE CO. MADE IN U.S.A.

CHAPTER I.

HISTORY OF PIPING STUDIES

Around 312 B.C., the city of Rome began to search for another water supply than that of the river Tiber. Beginning at this time and continuing to about 130 A.D., was the aqueduct building era of the Romans. During this time about a dozen masonry aqueducts were built from the mountain springs and streams to the city. The total length of these aqueducts was around 350 miles with about 50 miles of arches for crossing the shallow valleys. The thing of interest at the time for crossing the deep valleys was the use of lead pipe that came into use.

Distribution of the water brought into play the use of pipes from the storage wells to the public fountains and bath houses. The very rich had private water connections. The fall of the Roman Empire left the uses of pipes more or less stagnant all through the middle ages.

Much work was done on hydraulics from 1425 to 1764. Most of this of course was on flow in streams and open channels.

Sir Isaac Newton, English philosopher, discussed the friction of fluids on solids. His first discussion was found to contain errors which he corrected in the 1714 edition of "Principia".

In 1718, Marquis Poleni published a book on the discharge of fluids from orifices. His conclusions in this case were sound as they were arrived at through numerous experiments.

In 1730 to 1738, there comes into the field papers by Pitot. In 1730, Pitot invented the tube which now bears his name. His description of this tube for measuring velocities appeared in one of the academy

---

- Historical Resume of the Development of the Science of Hydraulics, Oklahoma Agricultural and Mechanical College

papers in 1732. This tube has been improved and is of great importance in measuring velocities in pipes.

In 1732, Couplet made experiments on the discharge of water leading to the fountains of Versailles and showed the discrepancy existing between the actual and theoretical discharge of these pipes. These experiments brought to the attention of the hydraulic engineers the urgent need of improving the then existing theories. It is said that some of these cast iron pipes are still in use after 200 years of service.

In 1742, the work of John Bernoulli came into being. The Bernoullis extended the foundation of sound mathematical theory as a basis of hydraulic science by establishing the generalization that has come to be known as "The Bernoulli Theorm".

Highly theoretical papers written by the renowned German engineer, Euler, upon the motion of fluids, appeared in the "Memoirs of the Academy of St. Petersburg" for the years between 1768 and 1771. These papers have little practical value as he assumed a mathematical fluidity for the basis of his system.

It was Professor Michelotti of Turin and the Abbe Bossut of Paris to inaugurate a new era in hydraulics. The established the fundamental principle that formulae must be deduced from experiment and not from abstract mathematical reasoning. Bossut's experiments were chiefly on the flow of water through pipes and open channels.

In 1775, Antoine de Chezy was one of the first to put into algebraic form the effect of retarding forces on the flow of a fluid.

In 1875, J. Weisbach published a book on the flow of fluids through pipes. Various writers divide the credit for this origination of the much used pipe formula between Darcy, Weisbach, Fanning and Eytelwein.

Darcy, a French engineer, was one of the first to make a careful study of the flow of water in pipes under actual working conditions. He studied the distribution of velocities in pipes by means of pitot tubes moved about through stuffing boxes. He came to the conclusion that the roughness of the pipe walls had a great effect on the velocity of water in turbulent flow.

The work of Darcy and Bazin for the French government brought out the outstanding work of a definite relation between the roughness of the wetted perimeter and the loss of head by friction in fluids flowing in closed conduits. These two were the first to also recognize two distinct types of liquid flow: sinous and viscous.

In 1886, Hamilton Smith, Jr., assembled data on all dependable hydraulic experiments relative to the flow of water in pipes. The assembled works plus the experiments run by himself was published in 1886 and contained 400 pages.

In 1883 Osberne Reynolds made experiments by introducing threads of ink to water flowing in glass tubes. He found that there was no definite line of demarcation between sinous and viscous flow, but that of a transition period. In 1914 Lees added to the knowledge of fluid flow. Stanton and Pannell of the British Research Laboratories picked up the theoretical work of Reynolds and were the first to plot experimental data.

Kite and Kennedy in 1922 experimented with the flow of oils through pipes and further verified the curves of other experiments. Kite and Kennedy can rightly be named the forerunners of modern commercial oil pipe line computations.

During the many experiments on water there naturally followed the construction of pipe lines for the transportation of oil, gas and air. Water being the most important led the experiments, and in turn

paved the way for a better study of other fluids.

Piping for the transportation of fluids has advanced to a specialty today with large cities, industries and great distances to be connected.

Since the advent of oil piping in 1870, the piping of oil and gas has followed in experiment that of hydraulics, and much has been done on the flow of fluids.

CHAPTER II.

PRESENT DAY USES OF PIPING

The great importance of piping in modern civilization is known even to the man on the street. Its importance to the engineer is easily discernible. Without piping in the world of today, civilization would be a thing of the past. For people to live in the present day sites of large cities, great underground nets of piping are necessary. Naturally the most important to the people at large is that of the water systems. Then of course there are the gas lines to the average home with the commercial oil lines to the large industries all over the country.

The uses to which pipes are put in the present day civilization are numerous. In the petroleum industry there is the use for a special type of heavy wall tube known as the "cracking tube". The conditions under which such tubes work are most severe and frequently involve a combination of high-temperature, high-pressure, corrosion, and oxidation seldom encountered in other industrial operations.

Another use of tubes is the high pressure boilers of today. New and higher standards of boiler construction are necessary. Locomotive, marine and stationary boilers all use tubes of high steel quality, strength and ready work ability, and general all-around fitness for the important service they must render. Under this use may also be added the necessity for condenser and heat exchanger tubes.

The handling of ammonia for refrigeration purposes involves considerably more responsibility than that of maintaining the average piping system. In addition to loss of gas or liquid, the possibility of the annoying and sometimes serious consequences of escaping ammonia fumes, gives added importance to the selection of pipe for this type of service.

The use of piping for steam purposes is one of importance. Steam must be transported to a certain position to be of benefit. It must be piped to the turbines for power, or to various locations for heating and other purposes.

Today the commercial pipe lines of hundreds of miles of gas and oil lines is known to all industry. This being the solution to that of tank car transportation. Large oil and gas companies of the world own thousands of miles of such lines both large and small piping. Besides the large transportation lines from city to city there is usually a small network of gas lines in a large number of the cities. The piping of gasoline can also be considered, but not on the scale such as oil, as gasoline is usually shipped by tank car for various reasons.

Every large industry of today has a system of air pipe lines. These are used for several things, such as sprays, controls, small motors of special type, machine shop uses, plant uses and many other things. The use of such a system is usually for special work.

Although the uses of piping are many and varied, there is none more important from ancient times to the present than that of water piping. The amount of water piping in the world would be too large to even figure out. The use of water pipe lines usually limited to a certain locality such as an industry, municipality, or community. Every locality of any size has a waterworks system. These water piping systems vary in all size from the New York water system to the country home of a single water pump.

To enlarge on the uses of piping for water would be too much to put into this writing.

CHAPTER III.

PURPOSE OF STUDY OF PIPING

The author does not make any claim as to the originality of any subject touched on in this article. The main idea is that of further acquainting himself and possibly the reader with a few facts and studies of a very interesting and important topic.

By a short study of piping conditions and the flow of fluids in pipes, the author attempts not only to enlighten himself but the reader as well to a few theoretical studies with a smattering of actual tests by the P. H. and F. M. Roots Company.

To have a complete and thorough study on such a subject, it should be done in conjunction with experimentation. The author regrets the lack of time as well as equipment for such purposes.

Many engineering companies have begun to realize the lack of compiled efforts and research along such lines and have attempted to breach such lack of complete material by published pamphlets at intervals of time.

An effort is being made in this short thesis to correlate a few facts and theories along the lines of piping and flow of fluids through piping. The conflicting opinions of various authors can all be justified and probably corrected in time, but at the present only a view of such opinions will be gone over and studied. The adaptability of the theoretical to the practical will try to be shown.

CHAPTER IV.

THEORY OF FLOW OF FLUIDS

All liquids, gases and substances which change their shape and contour under the smallest forces are classed as fluids. In other words, a fluid no matter how viscous, will yield in time to the slightest stress while a solid, no matter how plastic, requires a certain magnitude of stress to be exerted before it will flow.

A solid which has its contour changed by some force is subject to tangential stresses between the particles which tend to restore it to its original shape. In a fluid these forces act only while the fluid is being changed and cease when the new change has taken place. The fluid tangential forces are proportional to its viscosity which indicates that a fluid with a high viscosity resists a change in shape with greater force than one with a lower viscosity.

One of the most important constants concerning fluids is the density, defined as the mass of unit volume of the fluid. There are two ways of determining the density of a substance. One is to measure the mass of a known volume and the other is to measure the volume of a known mass. It will be seen that, if water is used as the calibrating liquid, the determination of the density of a liquid becomes identical with the operation of determining its specific gravity, -- that is, we find by experiment the ratio of the weight of a certain volume of liquid to that of an equal volume of water at the same temperature.

The nature of the two modes of fluid motion was first demonstrated by Osborne Reynolds in a series of experiments on parallel glass tubes. As the velocity in a tube or pipe increases the point of eddy,

initiation approaches the end of the pipe first. As the velocity increases the motion of liquid in the pipe becomes sinuous throughout. The velocity at which eddy formation is first noted in a long tube in such experiments is termed the "higher critical velocity". There is also a "lower critical velocity", at which the eddies in originally turbulent flow die out. Between these two values the liquid is in an unstable state, and if moving with stream line flow may break down into turbulent motion at the slightest disturbance.

To get into the measurement of the flow of fluids, the Venturi meter, invented by Clemens Herschel in 1881, affords perhaps the simplest means of measuring the flow of a liquid. When fitted to a pipe line of diameter greater than about 2 inches, its indications are, under normal conditions, thoroughly reliable so long as the velocity exceeds 1 foot per second. The Venturi meter can be used to measure the flow of gases. Another method of measuring flow in pipes is by use of a diaphragm.

In the measurement of the flow in a pipe line, friction must be taken into consideration, as the pressure necessarily drops.

*An examination of the factors involved in the non-accelerated flow of a fluid through a pipe would indicate that the resistance or the pressure drop p/l per unit length of the pipe may depend in some way upon the diameter d, the velocity of flow, and on the density and viscosity of the fluid. In a liquid where the effect of elasticity is negligible it is difficult to imagine any other factor likely to affect the resistance except the roughness of the pipe walls, and if this roughness is proportional to the diameter, the general relationship becomes:

$$F\left(d, v, \rho, \frac{p}{l}, \mu\right) = 0$$

---

* The Mechanical Properties of Fluids

Adopting d, v, and ρ as the three independent quantities and assuming μ to remain constant gives

$$K_1 = d^x v^y \rho^x \frac{p}{l}$$

$$= l^x,\ l^y t^{-y},\ M^z l^{-3z},\ M l^{-2} t^{-2},$$

and for K, to be dimension less

$$\left.\begin{aligned} x + y - 3x - 2 &= 0 \\ -y - 2 &= 0 \\ z + 1 &= 0 \end{aligned}\right\} \text{ Whence } \left\{\begin{aligned} x &= 1 \\ y &= -2 \\ z &= -1 \end{aligned}\right.$$

and $K_1 = \frac{pd}{l\rho v^2}$

Next taking $\frac{p}{l}$ as constant while μ varies, gives

$$K_2 = d^a v^b \rho \mu$$

$$= l^a,\ l^b t^{-b},\ M^c l^{-3c},\ M l^{-1} t^{-1},$$

from which

$$\left.\begin{aligned} a + b - 3c &= 1 \\ -b &= 1 \\ c &= -1 \end{aligned}\right\} \text{ Whence } \left\{\begin{aligned} c &= -1 \\ b &= -1 \\ a &= -1 \end{aligned}\right.$$

So that the general equation takes the form

$$\psi\left\{\left(\frac{pd}{l\rho v^2}\right), \left(\frac{\nu}{dv}\right)\right\} = 1$$

$$\text{or } \frac{p}{l} = \frac{\rho \nu^2}{d}\ \phi\ \frac{\qquad}{dv} \text{ - - - - - - - - - - - (10)}$$

where the form of the functions ψ or ϕ remains to be found from experiment.

With stream-line flow, experiment shows that $\frac{p}{l}$ is proportional to v. It follows that $\phi\left(\frac{v}{dv}\right)$ must equal $\frac{kv}{vd}$, and that

$$\frac{p}{l} = \frac{k\mu v}{d^2}$$

where k is a numerical coefficient. This is Poiseulle's expression for the resistance to viscous flow, the coefficient k having the value 32.

If the flow is turbulent the pressure gradient is approximately proportioned to v^n where n is between 1.75 and 2.0. In this case $\phi\left(\frac{v}{dv}\right)$ must be such as to make $\phi\left(\frac{1}{v}\right) = v^{n-2}$, so that

$$\frac{p}{l} = \frac{\rho v^2}{d}\left(\frac{\nu}{dv}\right)^{2-n}$$

$$= k^1 \frac{\rho v^n \nu^{2-n}}{d^{3-n}} \qquad \text{---------} \qquad (11)$$

$$\text{or} \quad h = \frac{k^1 v^n \nu^{2-n}}{d^{3-n}} l \qquad \text{--------} \qquad (12)$$

where h is the difference of head at two points distant l apart, expressed as a length of a column of the fluid. This is the Reynolds formula for pipe flow.

If the foregoing assumptions are correct, on plotting observed values of $\frac{pd}{l v \rho^2}$ against simultaneous values of $\frac{\nu}{dv}$, in any series of experiments in which different liquids or pipes of different diameters are used, the points should lie on a single curve.

That this is the case for fluids so widely different as air, water, and oil, has been shown by various observers, notably by Stanton and Pannell.

(Figure 1, at the end of this chapter.)

The experimental points for both air and water lie evenly about the two curves shown, the upper referring to a rough pipe, and the lower to a smooth pipe. The agreement in the case of air can, however, only be expected to be close where the drop in pressure is so small that the effect of the change of density is negligible. For large changes of

pressure it may be shown that last formula becomes:

$$\frac{\delta p}{l} = \frac{k v_m^{l\,n} \mu^{2-n}}{d^{3-n}} \left[\frac{p_m}{CT} \right]^{n-1}$$

Here T is the absolute temperature of the gas, C is the constant obtained from the relationship $p^V = C\,T$ and v_m and P_m are the mean velocity and pressure in the pipe. The results of experiments on the flow of air through pipes by several experimenters, with diameters ranging from 0.125 in. to 0.91 ft., and at velocities from 10 to 40 ft.-sec., confirm the accuracy of this formula.

Below the critical velocity, $n = 1$, and the formula becomes:

$$\frac{p}{l} = \frac{k \mu v_m}{d^2}$$

showing that the pressure drop is now independent of the absolute pressure in the pipe, a result confirmed by experiment.

Equations (10) and (11) show that, with an incompressible fluid, if the resistance to flow varies as v^2, $\phi\left(\frac{v}{dv}\right)$ degenerates into a numerical constant. Viscosity ceases to have any direct influence on the resistance, and true similarity of flow should be obtained in all pipes at all velocities. If n is less than 2, the equations show that for similarity of flow in two pipes of different diameters, or conveying different fluids, it is necessary that $\frac{v}{vd}$ should be the same in both cases.

This has been shown to be true over a moderate range of diameters by Stanton who measured the distribution of velocity with turbulent flow across the diameters of two rough pipes of different diameters and repeated the measurements for two smooth pipes. In the rough pipes ($n = 2$) the velocity distribution (cc^1, Figure 2, end of this Chapter,) was the same in both pipes and at all velocities. In the smooth pipes ($n<2$)

identical curves were obtained only when $\frac{v}{vd}$ was the same in each pipe. Under other conditions the curves were sensibly identical from the center up to a radius of about 0.8 times the radius of the pipe, but differed appreciably at larger ratii (AA and AB, Figure 2.).

In any type of pipe the "critical velocity" at which the type of motion changes from stream-line to turbulent is obtained with a constant value of $\frac{\nu}{vd}$, and this is generally true for fluid motion under other circumstances.

As already indicated, experiment shows that the resistance to flow in a smooth pipe where n is less than 2 is not strictly proportional to any one power of the velocity, and Dr. C. H. Lees has shows that Stanton and Pannell's results for smooth pipes are very closely represented by the emperical relationship:

$$\frac{p}{l} = \frac{\rho v^2}{d} \left(a \left(\frac{\nu}{vd} \right)^{\alpha} + b \right)$$

where $\alpha = 0.35$ and a and b are constants, so that

$$\phi \left(\frac{\nu}{vd} \right) = a \left(\frac{\nu}{vd} \right)^{0.35} + b$$

In the rough pipe the ratio of friction to v^2 increases with velocity, and Stanton and Pannell suggest, for both rough and smooth pipes, an expression of the form:

$$F = \rho v^2 \left(A \frac{\nu}{vd} + K + B \frac{vd}{\nu} \right),$$

in which K depends only on the roughness of the pipe. It will be noted that this relationship is similar to the one obtained by Mr. Baristow and Booth from experiments on the normal resistance of flat plates.

In the case of the flow of fluids there must be taken into consideration the fact that as the pipe age there are certain things that take place that cause the flow of fluids through the pipes to become harder, or in other words, an increase in friction to flow as well as

deterioration of the pipe.

Corrosion of metals may be defined broadly as the chemical action of their environment, often resulting in their deterioration or distinction. The presence of oxygen is essential for corrosion to take place in ordinary water. Oxygen alone will cause considerable corrosion in acid, neutral, or slightly alkaline water. The products of corrosion consist, mainly, of black or green ferrous hydroxide next to the metal, and reddish-brown ferric hydroxide which forms the outer layer. Naturally the formation of corrosion in pipes will retard the flow of fluid through a pipe. The friction factor used in any formula must take in consideration of this fact and as the pipe ages, the factor must be made larger to make up for the loss in flow due to this increased friction.

Symbols for Chapter IV

l = length

t = time

v = velocity

g = acceleration

ρ = density

R = force; mass x acceleration

μ = viscosity; stress x $\frac{l}{b}$

E = elasticity

ν = kinematic viscosity

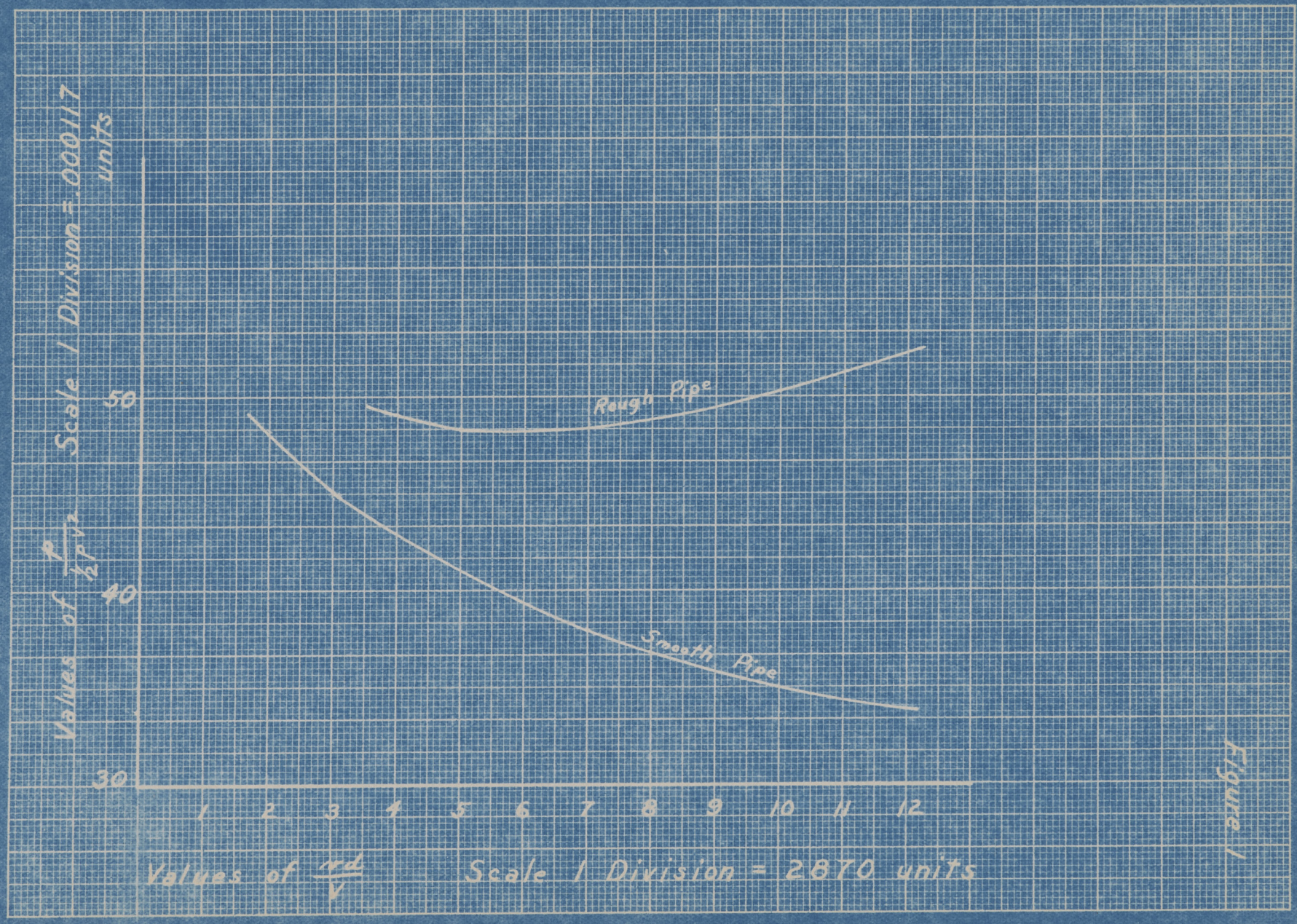

Values of $\frac{p}{\frac{1}{2}\rho V^2}$
Scale 1 Division = .00017 units
50
40
30
Rough Pipe
Smooth Pipe
1
2
3
4
5
6
7
8
9
10
11
12
Values of $\frac{\pi d}{V}$
Scale 1 Division = 2870 units

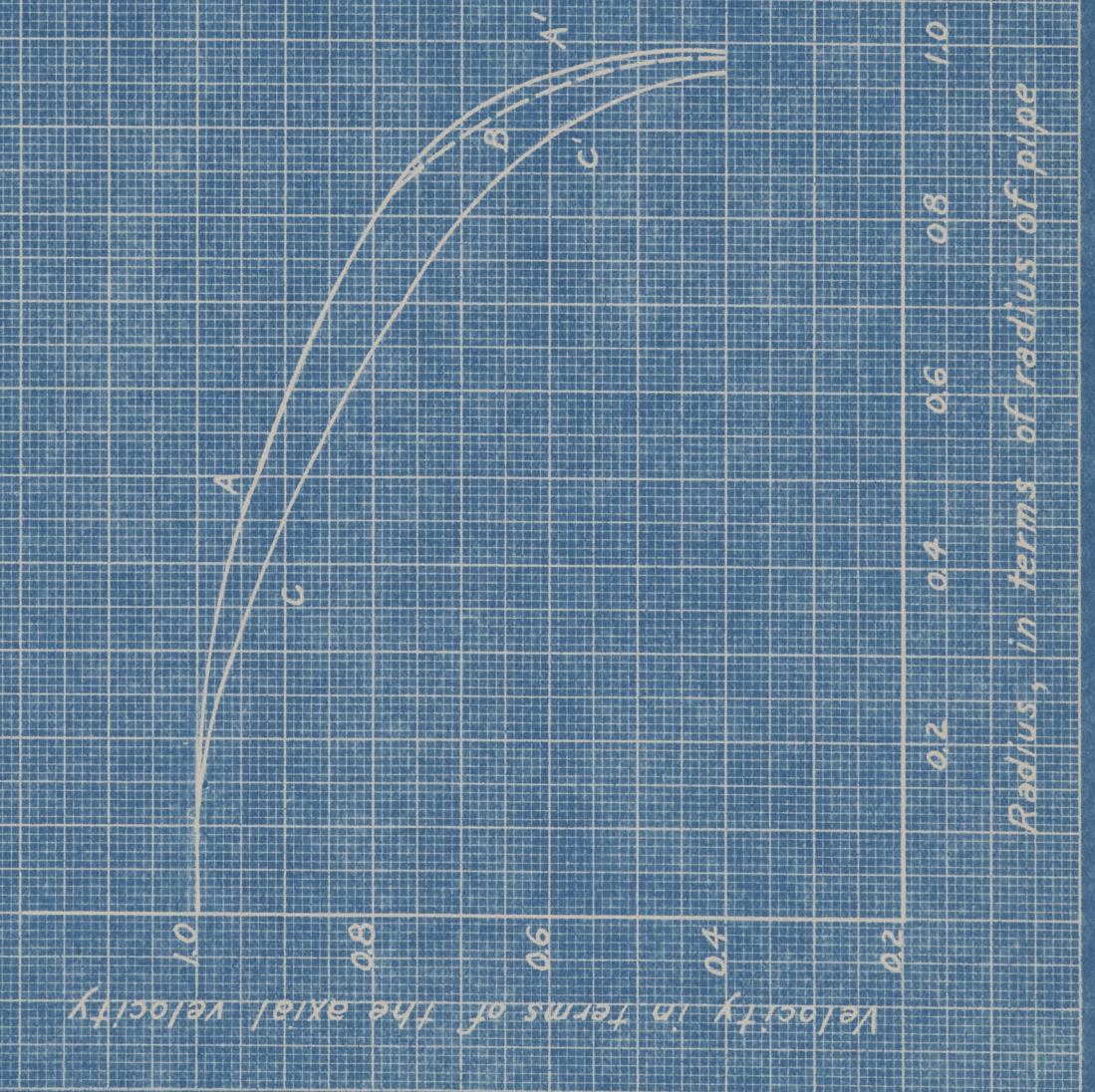
Figure 1

Figure 2

AA' velocity distribution in two smooth pipes in which v d is constant.
One pipe diameter 4.39 cm velocity at axis 1525 cm per sec
" " " 7.40 cm " " " 1017 " " "

AB smooth pipe diameter 4.39 cm " " " 541 " " "

CC velocity distribution in two rough pipes, 5.08 cm & 7.85 diameter at all velocities.



CHAPTER V.

RESISTANCE OF PIPE FITTINGS TO FLOW

The flow of a fluid in a pipe is greatly altered by the obstruction of a valve, or fitting along the pipe. When the fluid hits or passes such an obstructionthere is a change in velocity, turbulance is magnified and there is a drop in pressure. In the case of long pipe lines the drop in pressure may be of slight consequence when compared to the total drop. This is not the case of short pipe lines where the pressure drop, because of valves and fittings, becomes a major item in the total pressure drop valve.

It has been the tendency, and is usually the most practical way, to present the friction values in terms of equivalent length of the same size pipe. To give an example we may take that of the pressure drop caused by a 2 inch elbow which is equivalent to approximately the pressure drop caused by five or six feet of 2 inch pipe under the same condition of flow.

The general effect of elbows and bends on the flow of fluids in pipes is to lower the critical velocity, so that a fluid flowing streamline in a straight pipe may become turbulant upon traversing a bend or such obstruction. If a turbulence already exists in the pipe this will be altered by what ever obstruction the fluid encounters. If the fluid is turbulent in going around bends it has a tendency to rebound in a succession of straight lines forming a "rebound polygon" which tends to increase the turbulence but the fluid may resume its original condition of flow some distance along the pipe, unless the rate of flow is at the critical velocity. Typical rebound polygons

for R/d = 5 and R/d = 12 are illustrated in figure 3 at the end of this chapter.

The change of velocity alters the turbulence in the bends and elbows, and also the change in the radius of curvature, R, to the pipe diameter, d. Upon these conditions the rebound polygon depends as well as upon the properties of the fluid itself. It can thus be seen that no single value of the ratio R/d will exactly produce a minimum frictional resistance, in other words no single value of this ratio will be exactly ideal for all fluids. In the use of commercial consideration, including strength, are found to be best adapted to actual service conditions, and having frictional resistance so slight as to be negligible.

*It has been determined that the ideal radius of a bend so far as pressure drop is concerned is between 2.5 and 3 pipe diameters and that the pressure drop increases as the radius of the bend is increased, of decreased from this value. As the radius increases above three pipe diameters, the pressure drop increases, due (apparently) to the time factor of turbulence in making the direction change and is almost constant as the radius increases up to a certain point. In bends up to R/d = 5 the pressure drop increases. How far beyond this radius the curve rises was not determined. Of course, it is obvious that the larger the radius of the bend, or as the curve approaches a straight line, the lower the pressure drop. A t what radius the curve starts downward was not determined because the largest bend available for the test was one having a radius of five pipe diameters. When the radius of the bend is smaller than three pipe diameters, the pressure drop is caused by shock which increase turbulence in the connecting pipe immediately following the bend.

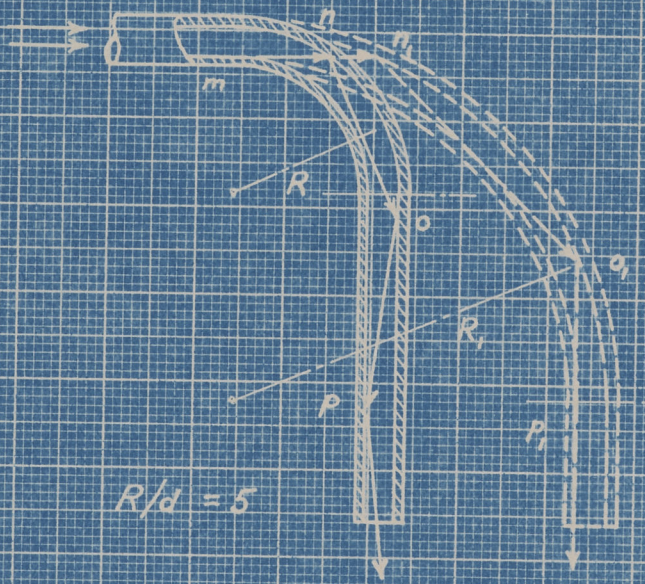
---

* Tube Turn Bulletin No. 108.

Following is a few suggestions taken from Tube Turns for equivalent lengths of pipe through several types of present day valves. The lengths are given in pipe diameters.

Valves	Pipe Diameters
Gate	5
Globe	100
Angle glove	80
Angle gate	30
Check	65
Tilting disc check	25

Figure 3



Typical Rebound Polygons

CHAPTER VI.

GENERAL FORMULAS FOR FLOW OF FLUIDS

During the past few years it has been found that certain fluid flow formulas based on the volume of the fluid without considering its viscosity at the temperature of operation are inaccurate. The use of these formulas by the engineering profession has not only resulted in the uneconomical use of pipe materials, but in a large waste of power as well. In many instances the installations that were designed for future capacities were found to be insufficient when operated at the designed capacity, while other installations could care for even larger capacities than that which they were designed for. Many investigations have shown that the inaccuracies may be attributed to the fact that the formula used had not been corrected for the viscosity of the fluid.

Many other cases of pipe design show that the designer did not take into consideration the proper size due to pressure loss caused by the bends in the system.

Laboratory experiments have been made to determine the authenticity of certain fluid flow formulas by the Engineering Department of the E. I. du Pont de Nemours Company of Wilmington, Delaware. These experiments were made under actual operating conditions and substantiate the fact that the fundamental Fanning formula is more nearly correct than others now used. This formula is written in different forms, depending on the units employed.

Some of the formula are as follows:

$$\Delta_p = 0.322\ L\ f\ S\ v^2/d$$

$$\Delta_p = 0.00517\ L\ f\ \rho\ v^2/d$$

$\Delta p = 13.4\ L\ f\ m^2 / d^5$

$\Delta p = 13.4\ L\ f\ Q^2 / d^5$

Δp = Pressure drop in lb. per sq. in.; $P_2 - P_1$

L = Length of pipe, ft.

f = Friction factor dependent on Reynolds number

ρ = Density in lb. per cu. ft. at arithmetic mean pressure equals 62.4 times S.

d = Inside diameter of pipe, inches

m = Thousands of lb. per hour.

Q = Thousands of cu. ft. per hour at density w

S = Specific gravity referred to water, = 1

v = Velocity in feet per second at density w

The Fanning formula is based on the density at working temperature which affects the viscosity of the fluid. Although the viscosity of water is little affected by the rise or fall in temperature. It is thus seen that the viscosity of the fluid at the hardest working temperature must be known.

In many cases the viscosities are referred to as Saybolt Universal, Engler or Redwood time seconds. It is necessary to convert these measurements into common unit kinematic viscosity, which in turn is expressed in centipoise units Z, which varies as the specific gravity of the fluid.

To simplify the conversion, -- a "Viscosity Conversion Chart" is referred to.* Assuming that the fluid has a Saybolt Universal viscosity of 1,000 time seconds and that the specific gravity is one; refer to "1,000 time seconds" on the Saybolt Universal viscosity

---

* Tube Turns, Inc., Bulletin No. 108

scale and read directly opposite the kinematic viscosity "2.2". To convert kinematic viscosity to centipoise units multiply by 100 times the specific gravity or 2.2 x 100 x 1 = 220 centipoises. Viscosity is also affected by extremely high pressures, but is little affected by pressure ordinarily used in commercial practice.

The value of the friction factor f in the Fanning formula is dependent on the Reynolds number and expressed as f m / DZ. This equation when plotted against the Reynolds number forming a friction factor curve shows three definite breaks, the first occurs in the viscous or stream line flow region having a value of f up to 0.14; the second occurs in the turbulent flow region where f is greater than 0.14 and less than 27 and the third occurs in the turbulent flow region where f is 27 or greater.

Where stream line flow is encountered, Poiseuille's formula is applicable:

$$\Delta p = 0.000668 \ L \ Z \ v / D^2$$

$$\Delta p = 0.034 \ L \ Z \ m / \rho \ d^4$$

symbols as before with addition of Z which is viscosity in centipoise units.

Most of the pressure drop problems occur in the turbulent region of the friction factor curve, and in order to simplify the compulation necessary for pipe size design nomographic Charts 1 to 4 are shown at end of this chapter. Charts 1 and 2 are for liquids, while charts 3 and 4 are for gases.

After a pipe has been in use for some time the inside surface may undergo a change caused by erosion or corrosion, which of course increases the friction. An increase in friction increases the pressure

drop. If the pipe has been made corrosive and erosive resistant the use of the roughness multiplication factor f_1 may be neglected. It will be noticed that f and f_1 are different, although both concern friction. In many instances the pressure at which the fluid is flowing is not in proportion to the pipe wall thickness due to present day standards, which include a thread depth safety factor.

Experiments on pipe that have been in service for a long time resulted in the use of the roughness multiplication factor f by Hazen-Williams. In this case the pressure drop found by the charts or formulas should be multiplied by a roughness multiplication factor according to the type and kind of pipe.

Contraction and expansion losses, through reducers, into branch lines or receivers of different kinds, may be determined by the following formulas:

$$\Delta_e = \rho (v-v_1)^2 / 144 \times 2g$$

$$\Delta p_c = K \rho v_1^2 / 144 \times 2g$$

$K = 0.4 \left[(1.25 - (\frac{a_1}{a}) \right]$ when a_1/a is less than 0.715

$K = 0.75 \left[(1 - \frac{a_1}{a}) \right]$ when a_1/a is greater than 0.715

a = inside area of pipe, sq. ft.

Chart number 6, on the back of the viscosity chart, gives the friction multiplication factor f_2 for determining the pressure loss through pipe coils, the equation of which is expressed as:

$$A_{p_r} = f_2 \quad \Delta_p$$

in which

Δ_p = pressure drop in straight pipe, lb. per sq. in. per ftl of pipe as determined by Charts 1, 2, 3, or 4, or by Poiseulle's formula

p_r = pressure drop in pipe coils, lb. per sq. in. per ft. of pipe.

The result of this equation should be multiplied by the roughness factor. To

To follow along the same lines of thinking other formula shall be brought to mind. By following several experiments it has been shown that the resistance offered to the flow of fluids through pipes follows the general formula:

$$P_1 - P_2 = \frac{4\,c\,L\,V^2}{2\,g\,D}\,\rho \qquad \text{---------(1)}$$

*This is the form of an equation that is of great use in calculating the friction drop in pressure in so-called "short lines" which in general may be considered as those conduits, pipes, or passages of uniform diameter, through which the fluid flows without changing its density more than about ten percent from any cause. Note (1) that for ordinary water lines of constant diameter this formula therefore applies for all lengths; (2) that for gas lines in which the temperature and diameter are approximately constant the formula will be accurate only when the drop in pressure is less than about ten percent of the initial absolute pressure; and (3) that for liquids, gases, or vapors flowing in pipes or tubes of uniform diameter and subject to rapid rates of heat transfer, the density may thereby be changed more in a few feet of line than it would be by friction in several miles of ordinary pipe kept at constant temperature.

*However, if the density be changed not more than about 30 percent, the formula may still be applied with a fair degree of accuracy by using the average density and the average velocity in the line.

In formula (1)

P_1 = initial pressure, lbs. per sq. in. absolute

P_2 = final pressure, lb. per sq. in. absolute

c = constant for steam flow = $f/4$

---

* Crane Company

L = length of pipe line in feet

V = velocity, ft. per second.

g = gravitational constant, 32.16 ft./sec.^{2}

D = inside diameter of pipe, feet

ρ = density of fluid, lb. per cu. ft.

f = friction factor

Professor Osborne Reynolds has shown that the coefficient "c" is dependent upon the turbulence factor or Reynolds number:

$$\text{Reynolds' number} = \frac{(\text{diameter})(\text{velocity})(\text{density})}{\text{absolute viscosity}} = \frac{DV\rho}{\mu} \quad (2)$$

$$R = \frac{(\text{diameter})(\text{velocity})}{\text{kinematic viscosity}} = \frac{dV\rho}{\mu} \quad (3)$$

As mentioned before the flow of fluids through pipes takes place under one of two conditions, viscous or turbulent flow. In the case of viscous flow the particles of the fluid move in lines parallel to each other and the velocity of the stream is maximum at the center, decreasing to zero at the inner surface of the pipe. It has been proven that the average velocity is one-half of the velocity at the center. Poisuelli's formula is used for this type of flow as follows:

$$P_1 - P_2 = \frac{32\ u\ LV}{g\ D^2} \quad \text{or} \quad \frac{143.3\ u\ LV}{d^2} \text{ lb. per sq.ft.} \quad (4)$$

u = absolute viscosity, centipoises

d = inside diameter of pipe, inches

Now that the viscous flow formula has been shown the turbulent formula will be brought to mind. The velocity of the fluid is increased to change the flow from that of viscous to that of turbulent. With turbulent flow eddy currents are set up and a mixing type of motion is started in which the average velocity is about 80 percent of that at the center.

This transition point has been mentioned before as the "critical velocity". A formula which is generally used for turbulent flow is as follows:

$$P_1 - P_2 = \frac{f L V^2}{772 d v} \text{ lb. per sq. in.} \quad (5)$$

In terms of the rate of flow, W in lbs. per minute, the equation becomes

$$P_1 - P_2 = \frac{.01214 f L v W^2}{d^5} \text{ lb. per sq. in.} \quad (6)$$

The symbols are the same as in formula (1) with the addition of:

v = specific volume, cu. ft. per lb.

d = inside diameter of pipe, inches

W = flow of steam, lbs. per minute

It is best that a check is made on the main differences in the viscous and turbulent flow formulas (4), (5), (6). The pressure drop varies as the square of the diameter in viscous flow rather than the first power as in turbulent flow; and the velocity appears only as the first power rather than the square. The friction factor "f" for viscous flow in the formula for turbulent flow is found to be equal to:

$$f = \frac{64 u v}{DV} = \frac{64 y}{DV} = \frac{64}{\text{Reynolds Number}} \quad (7)$$

this is found by equating (4) and (5) to each other.

As in formula (3), y is the kinematic viscosity.

At the end of this chapter will be found a graphical representation of formula (7).

It is best not to forget that turbulent flow has a friction factor that is dependent upon many things and must be ascertained by much research work.

*The general flow equation may be used in all conditions of fluid flow but in some cases empirecal formulas have been developed which can be presented graphically to give results which are sufficiently accurate

---

* Crane Company.

for all practical purposes. This is particularly true of water and gases and the following chapters are devoted to the description of methods for determining pressure drop values for different fluids.

CRANES
MADE IN U.S.A.

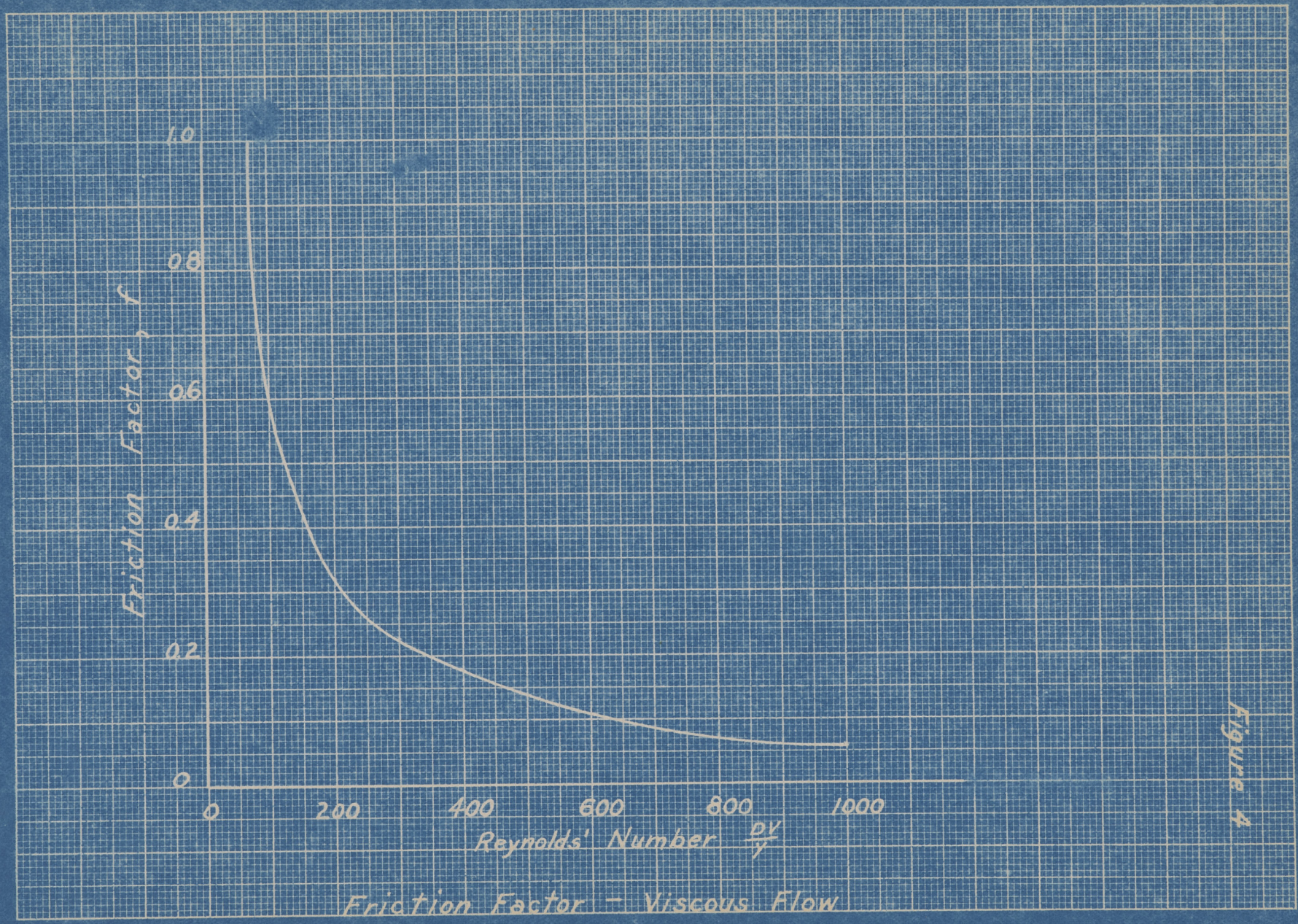


Figure 4

Friction Factor – Viscous Flow

CHAPTER VII.

OIL PIPING

One of the biggest industries in the world today is that of the petroleum industry. One of the large problems of the petroleum industry is that of transporting the oil to its destination. With the high cost of transportation in tank cars, the oil industry began the experiment of using pipe lines as far back as 1870 in West Virginia. The first few trials were total losses, due mainly to laying of the lines and leaks in the construction. As other work was done, the laying of pipe lines became a part of the oil industry. Pipes are used from the pumping of the oil from the well to its distribution over hundreds of miles of oil lines in all parts of the work. With such lines the industry became very much interested in the flow of oil through pipes.

The calculation of oil flow through pipes is much more complicated than in the case of water. Water is a fluid of well-defined and almost constant physical characteristics within ordinary temperature limits. Oil is the opposite; no two oils are exactly alike, and even any one oil is subject to important physical changes under variable temperature. The main difference between the flow of oil and water through pipes is the variable viscosity. Oil is a very complex substance. For the various reasons just mentioned, it is impossible to obtain any simple empirical equation which is universally applicable to the flow of oil in pipes. For the use of any of the formulas it is necessary to make use of various charts and tables. With the use of these charts and tables, which are obtainable from certain* handbooks, an answer is secured with a small probability of error.

---

* Piping Handbook; Walker and Crocker

Friction increases with cold oil and decreases in the summer. Deposits of paraffin in the pipes conveying crude oil reduce the effective diameter and increase the friction. Scrapers are, therefore, driven through the pipes periodically to clean away the paraffin.

As this chapter is about the solution of the flow of oil in pipes, it is appropriate that a problem or two is worked out.

*Example:

600 bbl. per hour of oil pumped through an 8-inch pipe line 10 miles long. At 60°F. the viscosity is 2,500 Saybolt Universal seconds, and the gravity is 20°A.P.I. (American Petroleum Institute.)

What is the pressure drop with the flow temperature at 60°F.?

Pressure drop formula used.

$p = p_1 \times$ specific gravity x length in miles

From Fig. 34 E, p. 172, Piping Handbook, for above conditions.

$p_1 =$ 82.5 lb. per sq. in. per mile

From table IX, p. 94. - 20°A.P.I. and 60/60° F.

specific gravity = 0.9340

Substitution:

$p = 82.5 \times 0.9340 \times 10 =$ 771 lb. per sq. in.

A check solution of the answer given above will now be worked out, using the rational formula:

$$p_x = \frac{0.0538\ f\ L\ S\ Q^2}{d^5}$$

---

* Piping Handbook; Walker and Crocker

p_x = pressure drop in lbs. per sq. in.

f = friction factor

L = equivalent length of pipe in feet

S = specific gravity = 0.9340

Q = flow in U. S. gallons per minute

d = inside diameter of pipe in inches.

$Q = \frac{600 \times 42}{60} = 420$ gallons per minute

L = 10 x 5280 - 52,800 feet

d = 8.03 inches

f = 0.057 from Fig. 15, p. 86, Piping Handbook

$$p_x = \frac{0.0538\ (0.057)(52,800)(0.9340)(176,400)}{33,400}$$

$$p_x = \frac{(467,460,000)(0.057)}{33,400} = \frac{26,645,220}{33,400}$$

$p_x = \underline{800}$ lb. per sq. in.

This answer can be noticed to be close to the preceding one.

The following empirical equation for oil flow in pipes is taken from the "Union Engineering Handbook" of the Union Steam Pump Company. The friction loss in oil pipe lines may be found by formula:

$$p = \frac{C \times Q^2}{10 \times d^5}$$

p = friction in lbs. per sq. in. per mile

C = constant, depending on character of oil

Q = barrels of oil per hour

d = diameter of pipe in inches

Using the preceding problem we have:

Q = 600 bbls. per hour

d = 8.03

C = 10.08 (20° A.P.I.; Table, Piping Handbook, p. 176.)

To correct C for being above 38 degrees - 60 degrees

$$C = 10.08 - 0.42 = 9.66 \quad (0.06 \text{ for each } 3 \text{ degrees})$$

$$p = \frac{(9.66)(600)^2}{33,400(10)} = \frac{3,477,600}{334,000}$$

$$p = 10.4 \text{ lbs. per sq. in. per mile}$$

Checking this answer by the table in Piping Handbook, Walker and Crocker, table XVIII on page 176. For an 8-inch pipe with 600 bbls. per hour, the friction of oil is given as 9.9 lbs. per square inch per mile.

Thus it can be seen that with a ten mile line and a drop of approximately 10 lbs. per square inch per mile there would be around 100 lbs. per square inch for such a line.

CHAPTER VIII.

AIR PIPING

When air flows through a pipe with a relatively small drop in pressure, the pressure, density, and velocity of the gas remains nearly constant as it traverses the pipe. When the pressure drop is considerable, however, the gas expands due to the pressure drop as it traverses the pipe, and while its density is decreasing its velocity is increasing. Thus it is noted that there are two conditions of flow in the case of air that has to be dealt with.

The following is the working of a problem by a formula and then checking the tables*for air, with the answer.

Use the following symbols in this chapter only:

P = pressure in ounces per square inch

L = length of pipe in feet

Q = quantity in cubic feet per minute

D = diameter of pipe in inches

V = velocity in feet per second

* $Q = 0.327\ V\ D^2$

D = 9 inches

V = 50 feet per second (velocity in table--per minute)

$Q = 0.327\ (50)(81) = 0.327\ (4050)$

Q = 1324 cubic feet per minute

Taking this answer of 1324 cubic feet per minute. Checking the table, sheet 5.*

---

* P. H. and F. M. Roots Company

Taking the column for the 9 inch pipe and the line for the point where it is crossed by the velocity of 3000 feet per minute (50 ft. per second). From this point and checking column one there is found the answer of 1300 cubic feet per minute.

Formula	*Table (Sheet 5)
1324 c.f.m.	1300 c.f.s.

Taking another problem on air, this time on the pressure drop. Using the following formula:

* $P = \frac{LV^2}{25000\ D}$ or $P = \frac{L \times 9.3\ Q^2}{25000\ D^5}$

L = 100 feet

V = 80 feet per second (4800 feet per minute)

D = 20 inches

$P = \frac{100 \times 6400}{25000 \times 20} = \frac{640{,}000}{500{,}000} = \frac{6.4}{5}$

P = 1.25 ounces

Formula	* Table (Sheet 6)
1.25 ounces	1.3 ounces

In the Appendix will be found several blueprints made by the P. H. and F. M. Roots Company. The first four blueprints are a study of the friction losses of free air blowing through several sizes of pipes. Numbers 1 and 2 are a study of friction loss with 5000 cubic feet per minute of air blowing and exhausting. Numbers 3 and 4 show the same problems with an increase of air to 7500 cubic feet per minute.

The conditions of the set-up were not given and check on the points can not be made, but the formula used is given below.

---

* P. H. and F. M. Roots Company

$$D = P_i \left(1 - \sqrt{1 - 16.8\, SQ_i^2\, f\, \frac{L}{T_i\, d^5}} \right.$$

D = friction drop pounds per square inch

Q_i = volume entering the pipe

P_i = pressure of air entering the pipe, pounds per square inch abs.

T_i = temperature of air entering pipe

L = length of pipe in feet

d = inside diameter of pipe, inches

f = coefficient of friction (use 0.0001)

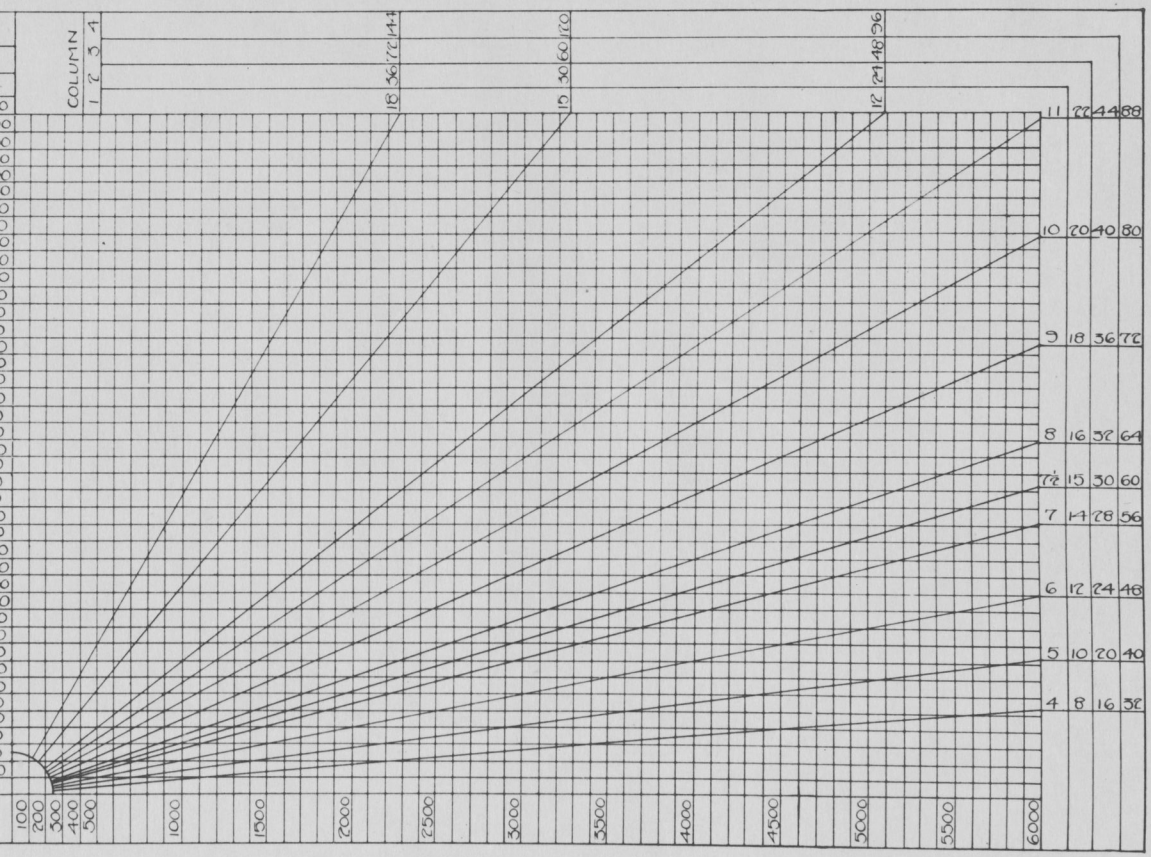
S = specific gravity

GRAVES AIRESEARCH MADE IN U.S.A.

SHEET NO. 1

PIPE DIAMETER IN INCHES

CUBIC FEET PER MINUTE			
COL 1	COL 2	COL 3	COL 4
4000	16000	64000	256000
3900	15600	62400	249600
3800	15200	60800	243200
3700	14800	59200	236800
3600	14400	57600	230400
3500	14000	56000	224000
3400	13600	54400	217600
3300	13200	52800	211200
3200	12800	51200	204800
3100	12400	49600	198400
3000	12000	48000	192000
2900	11600	46400	185600
2800	11200	44800	179200
2700	10800	43200	172800
2600	10400	41600	166400
2500	10000	40000	160000
2400	9600	38400	153600
2300	9200	36800	147200
2200	8800	35400	140800
2100	8400	33600	134400
2000	8000	32000	128000
1900	7600	30400	121600
1800	7200	28800	115200
1700	6800	27200	108800
1600	6400	25600	102400
1500	6000	24000	96000
1400	5600	22400	89600
1300	5200	20800	83200
1200	4800	19200	76800
1100	4400	17600	70400
1000	4000	16000	64000
900	3600	14400	57600
800	3200	12800	51200
700	2800	11200	44800
600	2400	9600	38400
500	2000	8000	32000
400	1600	6400	25600
300	1200	4800	19200
200	800	3200	12800
100	400	1600	6400

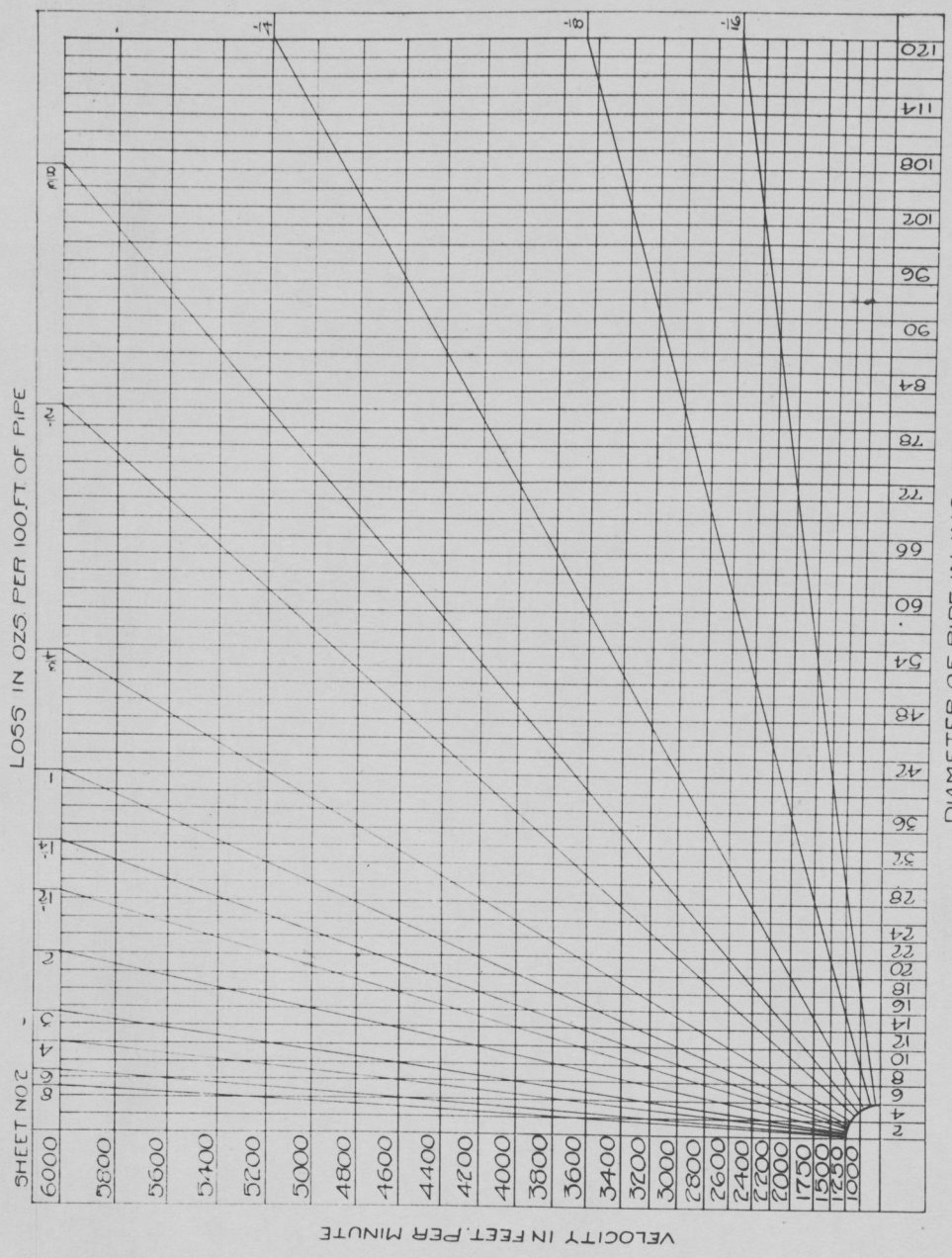


VELOCITY IN FEET PER MINUTE

Air Velocities

Sheet 5

Sheet 6



Pipe Friction for Air

CHAPTER IX.

WATER PIPING

The author realizes the importance of water piping and does not, in this small chapter, try to delve deeply into such a subject, but only to touch lightly as it pertains to the flow of fluids.

Many emperical formulas have been developed for the flow of water in pipes. Many of these formulas vary considerable due to the difficulty of setting up a roughness factor. The roughness of the surface causes the friction factor to increase and thus increases the loss in pressure.

The discussion following could be applied to all fluids except where there are large changes in densities. *Since three fundamental differences in the respective laws governing flow with stream-line and turbulent motion, loss of head for the two types of flow will be discussed separately. In all cases, loss of head due to friction is independent of pressure.

*If stream line flow exists, the loss of head due to friction is independent of the degree of roughness of the conduit surfaces. It varies directly as the length of pipe and the velocity and viscosity of the fluid, and inversely as the cross-sectional area of the stream and the fluid density. Again we have Poiseuille's Law.

$$h_f = 0.994 \frac{\mu}{\rho} \frac{lv}{d^2} \qquad \text{----------(1)}$$

h_f = frictional loss

l = length, feet

d = diameter, feet

v = velocity, ft. per sec.

---

* Hydraulics, King and Wisler.

μ = viscosity, English units

ρ = density, lbs. per cu. ft.

In the case of turbulent flow, there are certain laws based on observation and experiment. A few of the laws which appear to govern fluid friction are as follows:

(a) Frictional loss increases with roughness of the conduit surface. K = roughness coefficient.

(b) Frictional loss is directly proportional to the area of the wetted surface.

(c) Frictional loss varies inversely as some power of the diameter.

(d) Frictional loss varies directly as some power of the velocity.

(e) Frictional loss increases with the viscosity of a fluid and decreases as the density increases.

The loss of head for a fluid of given viscosity and density can be written in the form

$$h_f = K \times dl \times \frac{1}{d^x} \times v^n \quad \text{---------- (2)}$$

substituting K^1 and m for K and X-1 respectively,

$$h_f = K^1 \frac{1}{d^m} v^n \quad \text{---------- (3)}$$

In an account of experiments on the flow of water in pipes published by Darcy, he expressed the Chezy formula in the form,

$$h_f = f \frac{1}{d} \frac{v^2}{2g} \quad \text{---------- (4)}$$

It will be observed that the formula (4) can be obtained from formula (3) by writing $n = 2$ and $m = 1$. The value of f is obtained from tables.*

Some American engineers prefer to use the Chezy formula in the form published by Fanning, as follows:

$$h_f = F \frac{1}{r} \frac{v^2}{2g} \quad \text{---------- (5)}$$

* Hydraulics, King and Wisler, page 165.

in this formula $F = 1/4\ f$ of the formula (4)

r = hydraulic radius.

These formulas as given and the reference to the tables are to be used only for water as it occurs in the natural state. In any treatment of the subject of fluid friction the influences of viscosity and density must be given consideration.

Inasmuch as the coefficients of friction vary considerably and according to various preferences, the answers to any one problem will not check exactly. Following will be given as simple illustration to show the computation of a frictional loss. Using the Darcy formula:

$$h_f = f \frac{l}{d} \frac{v^2}{2g}$$

Problem: New cast iron pipe

l = 1200 feet

d = 6 inches

Q = 1.5 cu. ft. per second.

To find velocity

$$v = \frac{Q}{a} = \frac{1.5}{0.196} = 7.65 \text{ ft. per second.}$$

Substitution and table for f *

$$h_f = 0.022 \frac{1200}{1/2} \times \frac{58.5}{64.4}$$

$$h_f = 0.022 \times 2400 \times 0.91$$

$$h_f = 48.04 \text{ ft.}$$

Checking accepted answer 48 ft. *

In most cases of corrosion in ordinary natural water, the amount of dissolved oxygen present is the controlling factor. In closed water systems, the oxygen concentration is limited and practically determines the corrosion rate. This important fact has been established not only

---

* Hydraulics, King and Wisler

TX4

by laboratory experiments but also by a considerable amount of practical experience and investigative work. It has been shown in many plants that a saving can be obtained removing dissolved oxygen from the water to avoid this corrosion.

CRANE
MADE IN U.S.A.

CHAPTER X.

THEORY AND PRACTICE

Our present knowledge of fluid friction has been derived largely through experimental investigation and this has resulted in the development of a large number of emperical formulas. The underlying principles have tried to be brought out in the chapter on the theory of fluid flow. It is impossible to go through all the formulas in use today, but the basic fundamentals for all of these formulas are the same.

In recent years a great many researches have been made into the mechanical properties of fluids by physicists and engineers. These researches have been of the utmost importance to the engineers of this country. The most important and complete experiments have been made on water. Most of the formulas used in this line of work are very accurate, depending on the friction factor. Such is not the case for air and oil due to other factors entering into each case brought to mind.

*Many excellent books have been published on Hydraulics, Thermodynamics, Compressed Air, Ventilation, and other sciences, which explain these laws from different standpoints. When laying out a pipeline, or adapting the laws to some other simple, everyday problem, however, most textbooks and handbooks are confusing because of the large amount of superfluous information contained in them.

The above paragraph gives an idea of what an industrial plant has to say about the knowledge of the behavior of fluids. Probably every large industrial plant has experiments along the lines of their most important problems.

As each problem is approached and attacked by the engineers of the world today the subject of the "Flow of Fluids in Pipes" becomes more

---

* P. H. and F. M. Roots Company

practical and easier to solve. The work of yesterdays engineers and physicists is not forgotten, as it is upon their basic fundamentals that the problems of today are solved.

Experimentation is the only true method of investigating a subject and this must be done constantly to check the mathematical theory. The theoretical leads to the practical.

Bibliography

The Mechanical Properties of Fluids

A Collective Work

Industrial Oil Engineering

By J. R. Battle

The Flow of Fluids

By Tube Turns, Incorporated.

Flow of Fluids in Pipes

By Crane Company

Engineering Tables

By The P. H. and F. M. Roots Company

Piping Handbook

By Walker and Crocker

Oklahoma Agricultural and Mechanical College Bulletin

Hydraulics

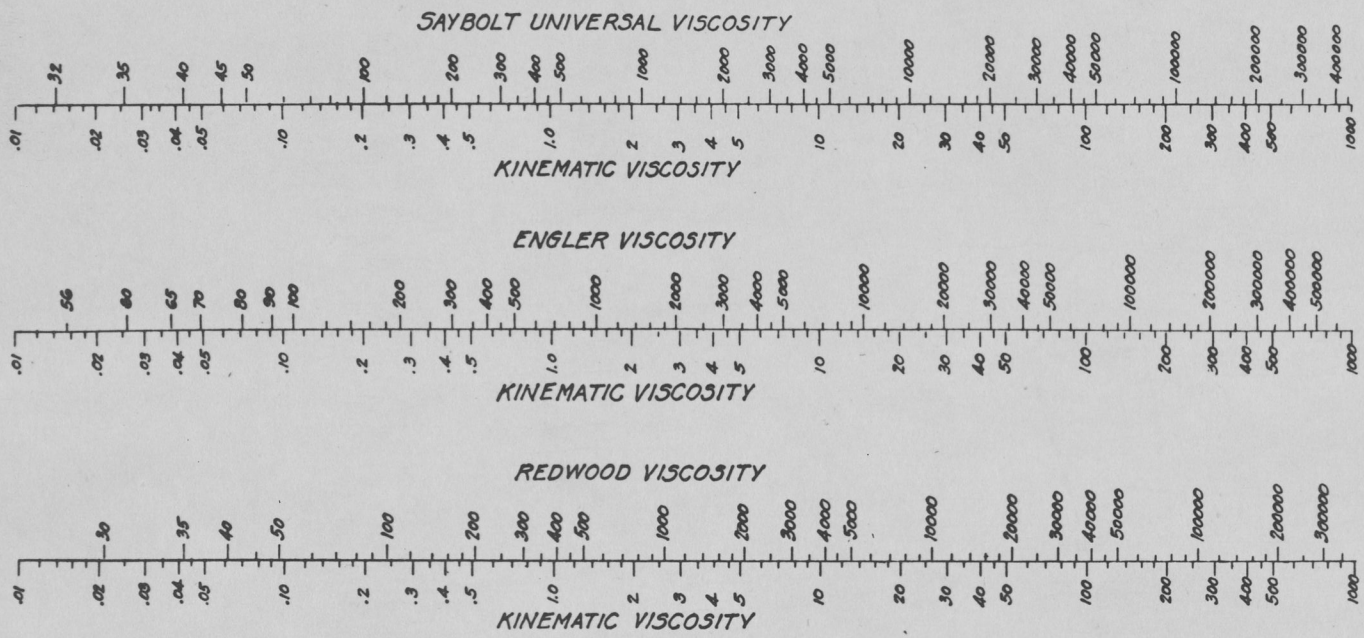
By King and Wisler

Corrosion - Causes and Prevention

By Frank N. Speller

APPENDIX

CHART Nº 7
VISCOSITY CONVERSION CHART



THIS CHART CONSTRUCTED WITH THE FOLLOWING FORMULAS USED BY THE UNITED STATES BUREAU STD'S.

SAYBOLT UNIVERSAL VISCOSITY:

$$k = .0022SU - \frac{1.8}{SU}$$

ENGLER VISCOSITY:

$$k = .00147E - \frac{3.74}{E}$$

REDWOOD VISCOSITY:

$$k = .0026R - \frac{1.715}{Rw}$$

IN WHICH:

k = KINEMATIC VISCOSITY
SU = SAYBOLT TIME SECONDS
E = ENGLER TIME SECONDS
Rw = REDWOOD TIME SECONDS

TO CONVERT KINEMATIC VISCOSITY INTO CENTIPOISE UNITS "Z" MULTIPLY BY 100 TIMES THE SPECIFIC GRAVITY OF THE FLUID, OR $Z = k \times 100 \times Sp.Gr.$

CONVERTING BAUME DEGREES INTO SPECIFIC GRAVITY BY THE AMERICAN PETROLEUM INSTITUTE (API) FORMULA:

FOR FLUIDS LIGHTER THAN WATER:

$$Sp.Gr. = \frac{141.5}{131.5 + \text{BAUME DEGREES}}$$

FOR FLUIDS HEAVIER THAN WATER:

$$Sp.Gr. = \frac{145}{145 - \text{BAUME DEGREES}}$$

F.L. Snyder

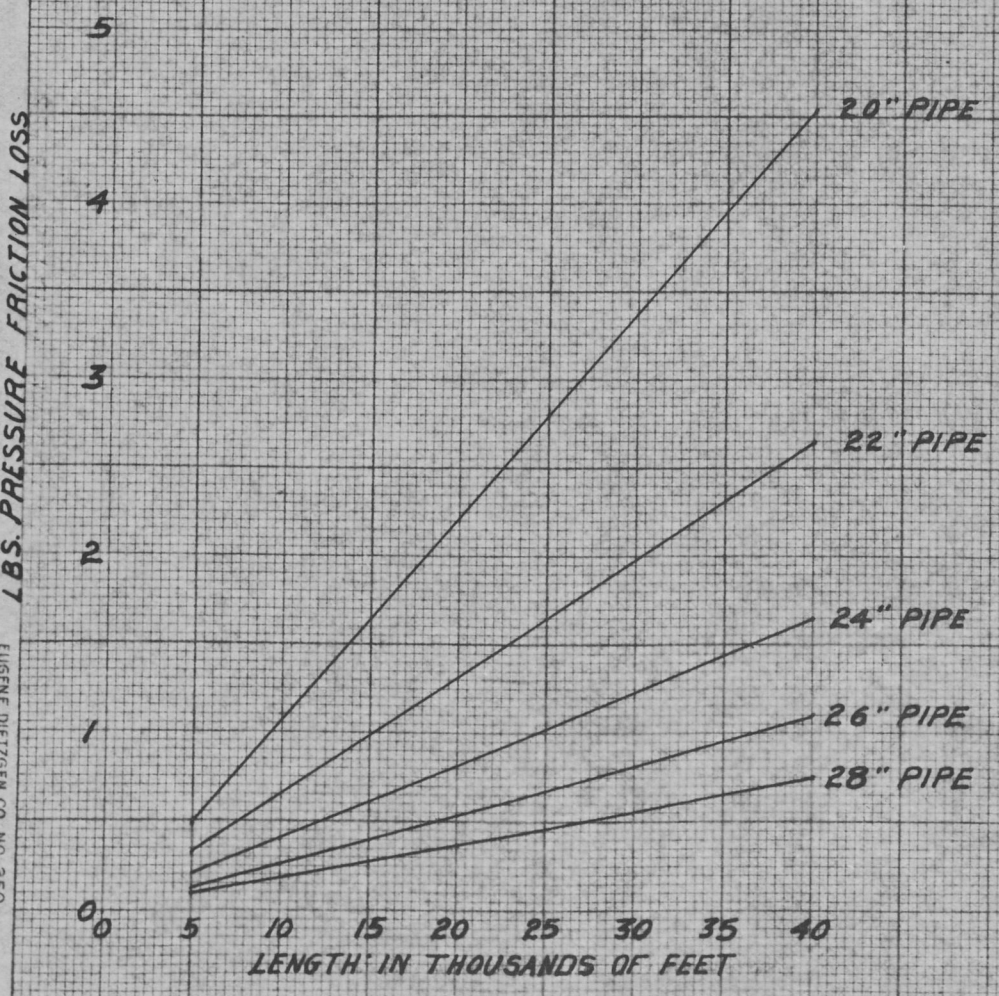
Sheet 7

FRICTION LOSS
WITH 5000 C.F.M. FREE AIR BLOWING

BAR.-10.6 #/in²

FORMULA USED $D = P_2 \left(1 - \sqrt{1 - 6.85 Q_1^2 f \frac{L}{T_1 d^5}}\right)$

D = FRICTION DROP LBS. / SQ. IN.
Q_1 = VOL ENTERING PIPE
P_2 = PRESS. OF AIR ENTERING PIPE LB / SQ. IN. ABS.
T_1 = TEMP. OF AIR ENTERING PIPE
L = LENGTH OF PIPE, FT.
d = INSIDE DIA. OF PIPE, IN.
f = COEFFICIENT OF FRICTION (USE 0.0001)
S = SPEC. GRAVITY OF GAS REFERRED TO AIR.

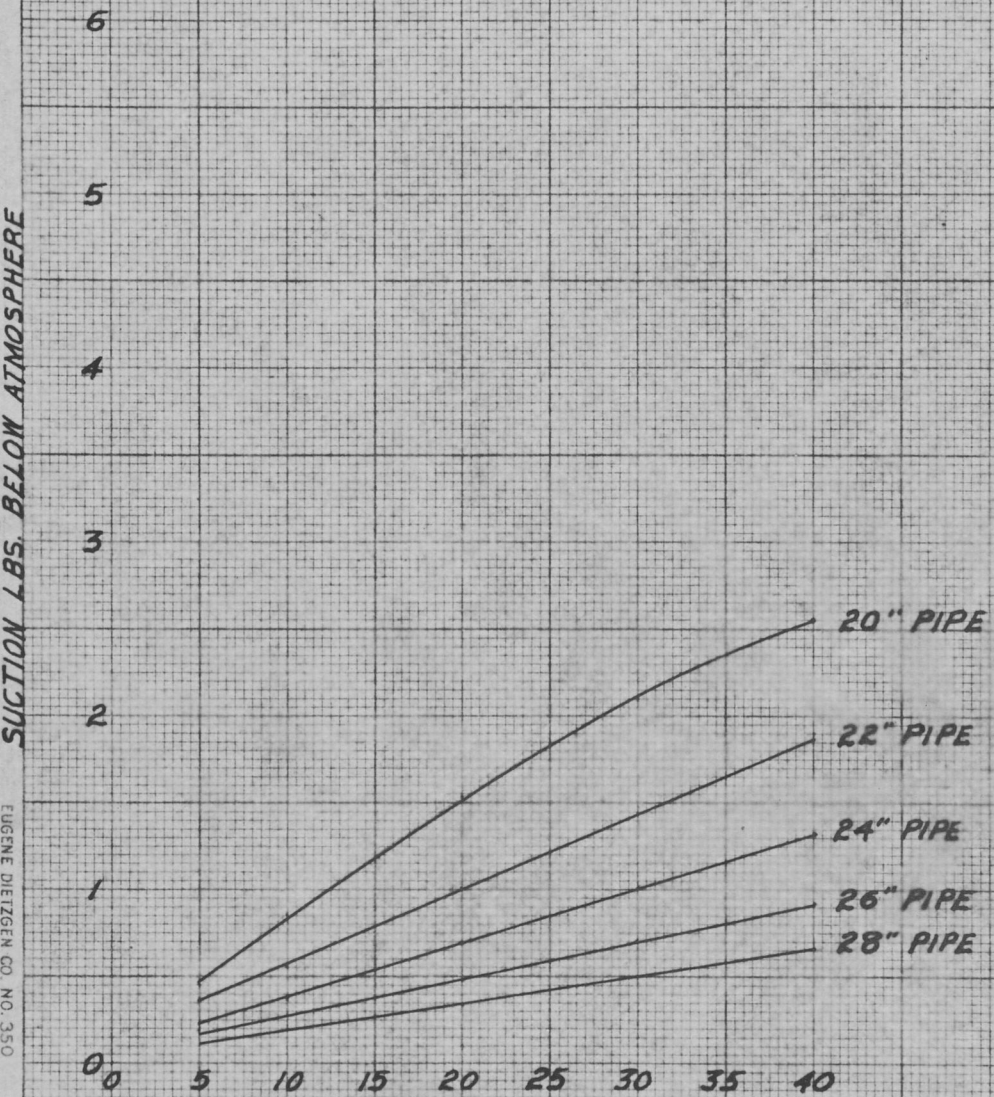


PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 350

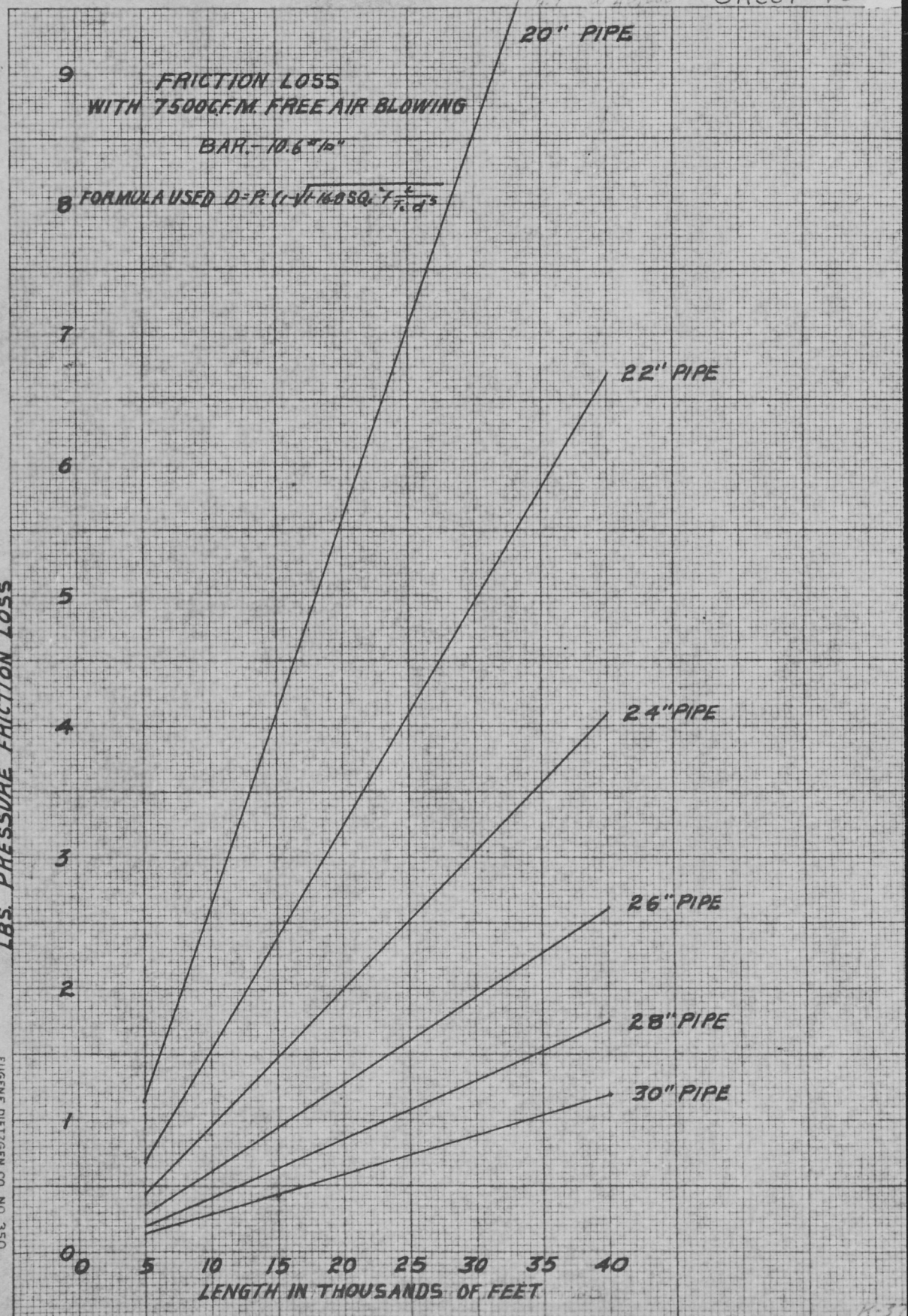
FRICTION LOSS
WITH 5000 C.F.M. BLOWER INLET AIR EXHAUSTING

BAR. - 10.6 "/a"

FORMULA USED $D = R\,(1 - \sqrt{1 - 1.68\,S\,Q^2\,f\,\frac{L}{R^2\,d^5}})$



EUGENE DIETZGEN CO. NO. 350
PRINTED IN U.S.A.

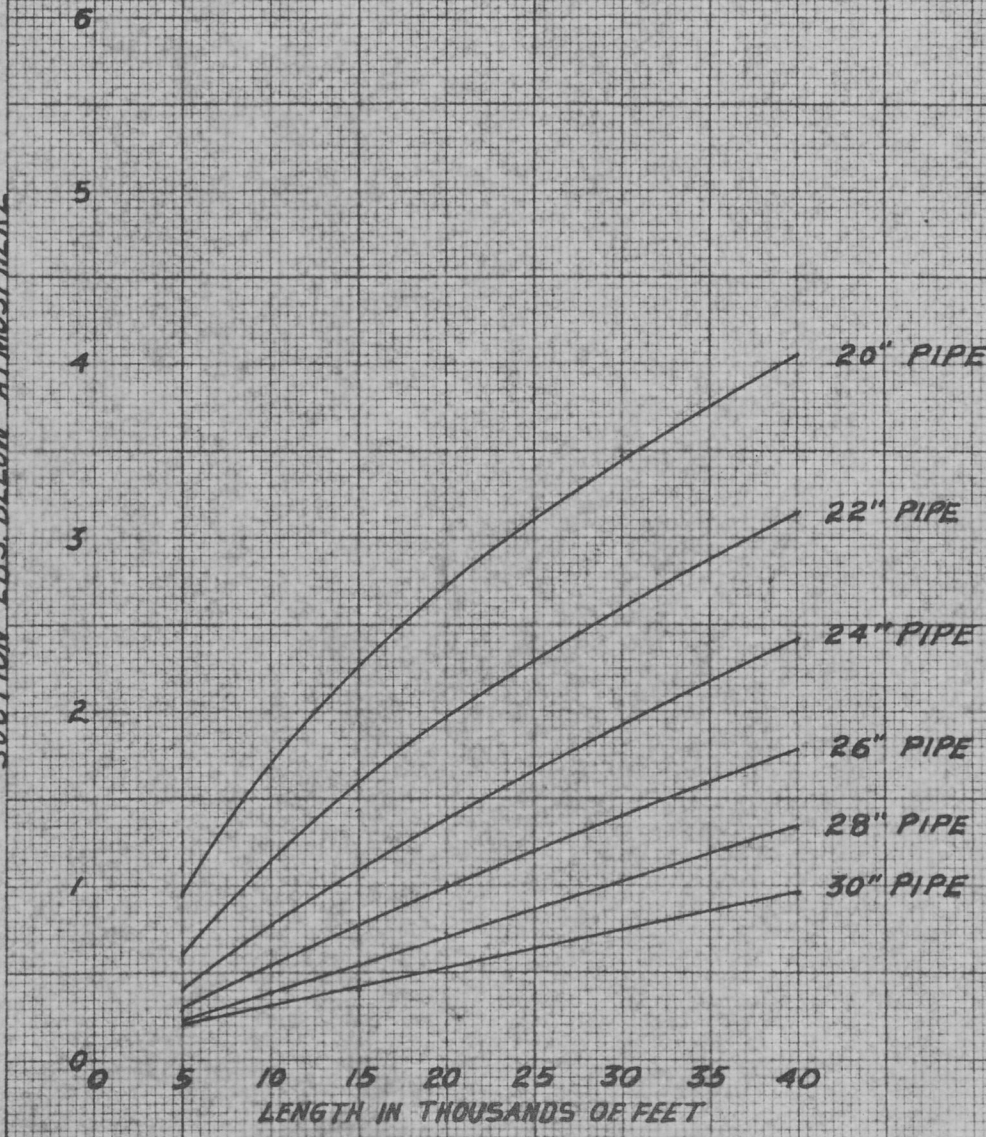


PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 350

FRICTION LOSS WITH 7500 CFM BLOWER INLET AIR EXHAUSTING

BAR- 10.6 "/12"

FORMULA USED $D = P_1 (1 - \sqrt{1 - 16.8 SQ \frac{L}{P_2 d^5}})$



PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 350

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name Royce W. Morton

Title Professor of Mechanical Engineering