DESIGN DATA SHEET

Department of the Navy, Bureau of Ships

1 January 1960

DDS4800-1
FRICTION PRESSURE DROP IN PIPING

Supersedes DDS48-1, Part 1 dated 1 September 1938
DDS48-1, Part 2 dated 1 February 1945

Acknowledgment
Figures 7 through 13, with minor modifications, are reprinted through the courtesy of the Hydraulic Institute and were taken from the Pipe Friction Manual, Copyright 1954 by the Hydraulic Institute, 122 East 42nd Street, New York 17, N. Y. Similarly other data in this design data sheet, particularly the data covered in Table 4, were developed from the results of tests conducted by the United States Naval Boiler and Turbine Laboratory, Philadelphia, Pennsylvania.

References

A. Pipe Friction Manual, Hydraulic Institute, 122 East 42nd Street, New York 17, New York

B. "National Standard Petroleum Oil Tables," NBS Circular C410, 1936

C. "Thermodynamic Properties of Steam," Keenan and Keyes, 1st Edition

D. "Determination of Hydraulic Characteristics of Ship's Piping System, Components and Design Criteria," NBTL Test Report I-25, 4 January 1955

E. "Friction Losses in Fuel Oil Pipes, Bends, Valves and Fittings," NBTL Test Report 3043 (III), 12 June 1941

F. "Review of Data on Dynamic Viscosity of Water and Superheated Steam," ASME Transactions, Vol. 70, No. 1, pages 19-23, Jan. 1948 by Hawkins, Sibitt and Solberg

G. "The Viscosity, Thermal Conductivity and Prandtl Number for Air, O_2, N_2, NO, H_2, CO, CO_2, H_2O, He and A" by Hilsevrath and Touloukian, ASME Transactions, Vol. 76, No. 6, pages 967 to 985, Aug. 1954

H. Flow of Water Through Wire Reinforced Rubber Hose, NAVSHIPS 250-344-11

I. Joseph Keenan: Thermodynamics, John Wiley and Sons, Inc., New York 1941

DDS4800-1-a. Scope

In the applications of the flow of fluids through piping systems, a knowledge of the frictional losses is essential. However, so extensive and complex are the laws of hydraulics and fluid mechanics and their application that very few people have more than a general knowledge of the subject. This design data sheet has been developed as an engineering aid for those engineers with this general knowledge. It is applicable for solution of any but the most unusual fluid flow problems encountered in Naval engineering design. To accomplish this, auxiliary data plus numerous charts and a step by step procedure has been incorporated.

DDS4800-1-b General Design

1. This design data sheet may be used for the computation of friction pressure drop through pipes and tubes, provided the specific volume and the viscosity of the fluid at flow conditions are known. Data for steam, water and some petroleum products are given for approximate calculations. Where more precise results are required, references (A) to (G) should be consulted for fluid properties.

2. Calculations are performed using a standard calculation form, reducing the computation to a step by step procedure. The term velocity pressure (P_v) is introduced to obtain the pressure loss directly in pounds per square inch rather than feet of fluid flowing.

3. When working with gases and vapors, precautions must be observed if accurate pressure loss calculations are to be made. The change in specific volume due to pressure loss must be kept within reasonable limits and the fluid velocity in the pipe or tube must be subsonic. To keep the change in specific volume within the accuracy limits of this design data sheet, the pressure loss through any portion of the system being calculated should not exceed one-tenth of the inlet pressure. If a loss greater than one-tenth is indicated, a smaller portion of the system should be calculated so that the one-tenth limit is not exceeded. At this terminal point the rest of the system should be calculated using the specific volume for the new pressure and so on until the pressure drop for the whole system is computed. To assure that subsonic flow is maintained, the pressure loss through the whole system must not exceed the critical pressure ratio. Reference (I) or any standard thermodynamic text should be consulted for the value of the critical pressure ratio when the overall pressure loss through the system is greater than four-tenths of the inlet pressure.

DDS4800-1-c Detail Design

1. Nomenclature - The following symbols are used in this design data sheet. The foot-pound-second system of English gravitational units is used.

d	internal diameter of pipe or tube	in.
d_b	internal diameter of fitting or valve	in.
D	internal diameter of pipe	ft.
f	friction factor	dimensionless
g	gravitational constant	$\frac{ft.}{sec^2}$ (that is ft/sec/sec)
G	specific gravity	dimensionless
h	head of fluid	ft.
h_v	velocity head	ft.
Δh	head loss	ft. of fluid flowing
K	resistance coefficient of fitting	dimensionless
K_b	resistance coefficient based on bore of fitting	dimensionless
K_p	equivalent K factor of pipe or tubing	dimensionless
ΣK	sum of "K's" of pipe and fittings	dimensionless
L	length of pipe or tubing	ft.
P	pressure	psi
P_a	absolute pressure	psia
P_v	velocity pressure	psi
ΔP	pressure loss	psi
R	radius of bend or elbow	in.
R_e	Reynold's number	dimensionless
SSF	viscosity - Saybolt Seconds Furol	sec.
SSU	viscosity - Saybolt Seconds Universal	sec.
T	temperature	°F
v	specific volume	$\frac{ft^3}{lb.}$
V	average velocity of flow	$\frac{ft.}{sec.}$
w	specific weight	$\frac{lb.}{ft.^3}$
ϵ/d	relative roughness coefficient of pipe or tubing	dimensionless
μ	absolute viscosity	$\frac{lb\text{-}sec}{ft^2}$
ν	Kinematic viscosity	$\frac{ft^2}{sec.}$

2. Specific Volume - The specific volume (v) may be obtained directly from Figures 2 and 5 for steam and water respectively and for petroleum products from Figure 3 when the A. P. I. gravity is known. When this property is given

in some other form such as specific gravity, specific weight, density, etc., use the factors for conversion to specific volume given in Table 1.

3. Kinematic Viscosity -

(a) The kinematic viscosity (ν) in square feet per second will be used for computations in this design data sheet. When the viscosity of a fluid is given in other units, conversion to kinematic viscosity (square feet per second) may be made from Table 2, noting that if the viscosity is given in absolute units, the specific volume obtained above is required for the conversion.

(b) The values of kinematic viscosity (ν) for steam and water may be obtained directly from Figures 1 and 4 respectively, and for common Naval oils from Figures 6a and 6b.

(c) Since viscosity is a measure of a fluid's resistance to flow, it has a significant effect on the friction pressure drop through a pipe. It is particularly important that the viscosity be known as accurately as possible for oils and other highly viscous fluids and also for fluids with viscosities which vary significantly with temperature.

4. Velocity - The velocity (V) in feet per second is used in these calculations. Conversion factors for converting other flow rates to feet per second are contained in Table 3.

5. Velocity Pressure Head -

(a) The pressure loss of a piping system is proportional to the velocity head. The velocity head (h_v), in feet, of a flowing fluid is:

$$h_v = \frac{V^2 \text{ feet}}{2g}$$

The pressure in pounds per square inch, corresponding to a given head (h), in feet, can be calculated from the equation:

$$P = \frac{wh}{144} \text{ p.s.i.}$$

Substituting ($V^2/2g$) for (h) and ($1/v$) for (w) gives the equation:

$$P_v = \frac{V^2}{144\ v\ 2g} \text{ p.s.i.}$$

which reduces to

$$P_v = 0.0001078 \frac{V^2}{v} \text{ p.s.i.} \qquad (1)$$

6. Reynolds' Number - The Reynolds' number (R_e) for fluid flow in pipes and tubes is found by using the formula:

♦ $$R_e = \frac{dV}{12\nu} \qquad (2)$$

Fluid flow in a pipe is either laminar or turbulent, according to the value of R_e for the condition of flow. Flow is usually considered laminar for R_e less than 2000 and turbulent for values of R_e greater than about 3500.

7. Friction Factor (f) -

(a) The friction factor (f) for a fluid flowing can be derived from the Darcy-Weisbach equation for the loss of head caused by a fluid flowing at a certain R_e through a pipe with a relative roughness (ϵ/d). This is shown as follows:

$$\text{Darcy formula,} \Delta h = f \frac{L}{D} \times \frac{V^2}{2g}$$

Solving for f gives

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

Friction factor f vs R_e is plotted in Figure 8 for various ϵ/d ratios obtained from experimental data. ϵ/d ratios for particular types of pipe and tubing can be found from Figure 7.

(b) Laminar Flow - As stated above when R_e is below 2000, flow is usually considered laminar. The value of (f) in this region of R_e is found from the equation:

$$f = \frac{64}{R_e} \qquad (3)$$

(c) Critical Zone - The critical zone lies between R_e 2000 to 3500. In this region, flow is either laminar or turbulent depending upon the direction of approach. If the R_e is gradually raised from below 2000 into the critical zone, the flow will be laminar and the value of f is that obtained from equation (3). Lowering the R_e from above 4000 into the critical zone, f will probably vary as shown by the cross hatching on Figure 8. To insure computation of maximum pressure loss in this region, calculation in this zone should be based on R_e = 3500. The friction factor should be obtained from the curve of relative roughness, applicable to the pipe for which the pressure loss is being calculated, at R_e = 3500. Design for operation in this region should be avoided wherever possible since the flow is unstable.

(d) Transition Zone - As shown in Figure 8, the transition zone is bounded by R_e = 3500 and the curve for complete turbulence. In this region, the flow in a pipe becomes more turbulent with increasing R_e until a maximum is reached at the curve of complete turbulence. The friction factor is obtained from the curve of ϵ/d, in Figure 8, for the particular pipe or tubing at the R_e for the condition of flow.

(e) Complete Turbulence - Fluid flow is completely turbulent for Reynolds' numbers above the curve for complete turbulence (see Figure 8). Increase in R_e above the value of the R_e at the intersection of the curve of complete turbulence and a given ϵ/d curve has no effect on the friction factor. In this zone
♦ of R_e's, f is obtained from Figure 8. ♦

8. Pressure Drop in Pipes and Tubes - This Design Data Sheet, wherever possible, considers the frictional resistance of the piping or tubing to fluid flow in terms of a dimensionless numerical titled "resistance coefficient" and designated by the letter "K". Thus the pressure drop due to frictional resistance in piping or tubing is computed from the equation:

$$\Delta P = K_p \, P_v \tag{4}$$

Where K_p is the resistance coefficient of the pipe and is found by the equation:

$$K_p = f \cdot 12 \cdot \frac{L}{d} \tag{5}$$

9. Pressure Drop through Valves and Fittings -

(a) The pressure drops through valves and fittings due to the frictional resistance is

$$\Delta P = K \cdot P_v \tag{6}$$

The values of K for valves and fittings are found in Figures 9 to 13 and Table 4.

(b) The validity of equation (6) for valves and fittings is based upon the assumption that the velocity of the fluid through the valve or fitting is the same as the velocity in the pipe to which the valve or fitting is connected. If the bore of the valve or fitting is different from (not equal to) the internal pipe diameter, a correction must be applied to the K found in Figures 9, 10 and Table 4. This is accomplished by using the equation:

$$K = K_b \left(\frac{d}{d_b}\right)^4 \tag{7}$$

Most commercial valves and fittings have bores identical to the corresponding pipe size, but Navy valves and fittings tend to be oversize thus requiring the use of equation (7).

Note: Symbol ♦ shows change to replaced page

(c) The values of K given in Figures 9 to 14 are not restricted to any particular flow region as in the case of friction factor for pipes and tubes. These resistance coefficients are generally for the completely turbulent region. Using these K's in other flow regions will not lead to a serious error. Further clarification of this subject may be found in reference (E).

10. Pressure Drop in Systems - The friction pressure drop in a piping system is found by summing up all K's and using the equation:

♦ $$\Delta P = \Sigma K \cdot P_v \qquad (8)$$ ♦

11. Procedure for Calculating Friction Pressure Loss in Systems - A form is used in this data sheet to facilitate ease of calculation. It is recommended that the user consider reproducing a similar form, and that a single form be used for each pipe size, pipe run or branch and flow. In using this form it should be understood that the format follows the step by step procedure given below:

(a) Obtain specific volume and kinematic viscosity, at the temperature and pressure conditions of the fluid - paragraphs 2 and 3.

(b) Obtain rate of flow in terms of velocity in feet per second - paragraph 4.

(c) Calculate velocity pressure - paragraph 5.

(d) Calculate Reynolds' number - paragraph 6.

(e) Determine friction factor for pipe - paragraph 7.

(f) Determine L/D ratio and calculate K_p - paragraph 8.

(g) Obtain and correct, if necessary, resistance factors of valves and fittings in system - paragraph 9.

(h) Calculate friction pressure drop in system - paragraph 10.

12. Total Pressure Drop - The total pressure drop between the terminal points of any piping system is the sum of the friction pressure drops between the two terminal points, including entrance and exit losses, plus "static lift." "Static lift" is the difference in elevation of the inlet and outlet (terminal points) of a system, and is usually expressed in feet of fluid. The equation

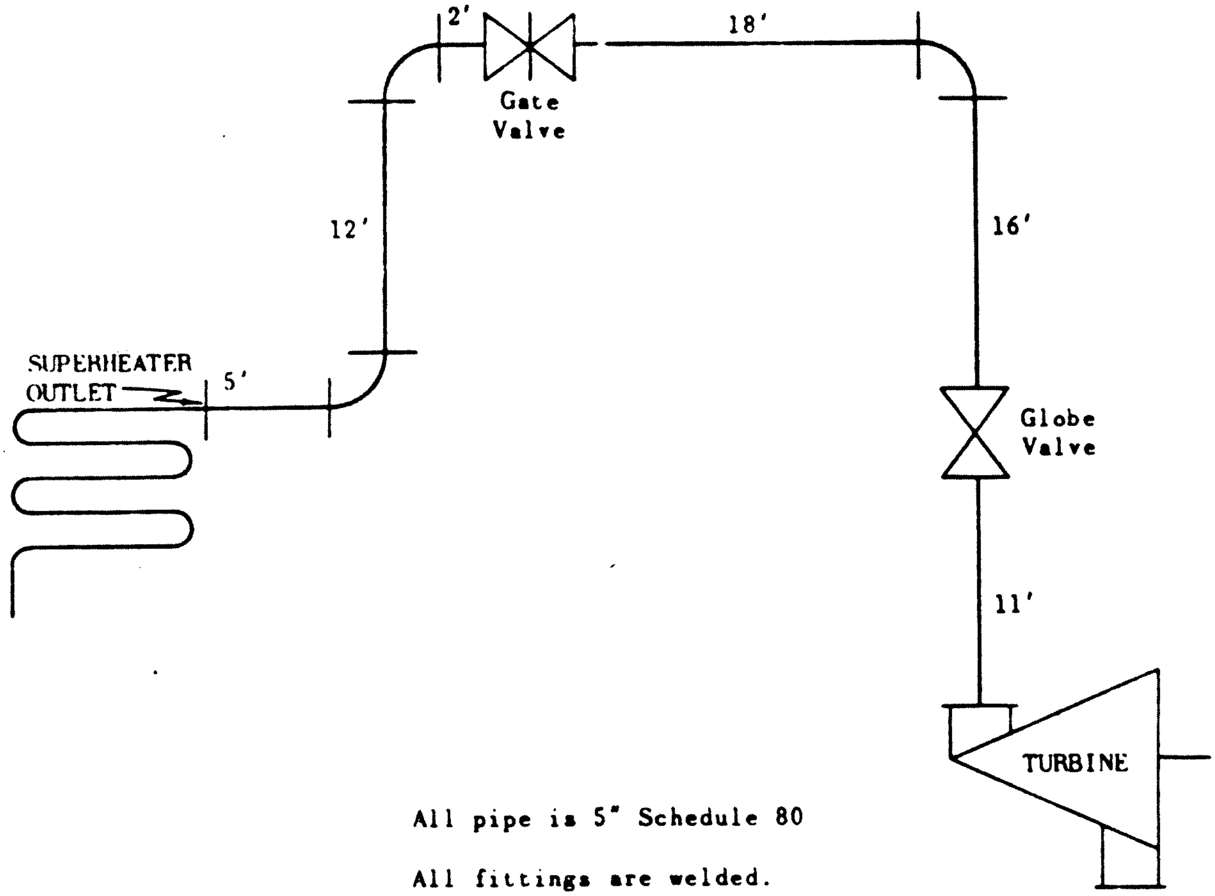
$$P = \frac{Wh}{144} \text{ p.s.i.}$$

will convert feet of fluid into p.s.i. which when added to the friction pressure drop should give the pressure drop of the system. "Static lift" should be considered positive if the outlet is above the inlet and negative if vice versa. For example, a 65F fresh water system with a friction pressure drop of 10 p.s.i. and a "static lift" of 6.5 p.s.i. (system outlet 15 feet above the inlet) has a total system pressure drop of 16.5 p.s.i. Should the outlet be 15 feet below the inlet the "Static lift" would be subtractive and the total system pressure drop would be 3.5 p.s.i.

13. The following sample friction pressure drop calculations illustrate the use of this Design Data Sheet. These calculations are shown on the previously mentioned form. It is considered that use of this form would minimize the possibility of error and further provides for ease of checking. However, this "standard calculation form" may be altered to suit the user or the problem.

In all three examples the calculations are for friction pressure drop. Where elevation is involved in the problem it should be taken into account as explained in paragraph 12.

Example 1 - Sheet 1



All pipe is 5" Schedule 80

All fittings are welded.

Steam at 975°F and 1200 psia flows from the super-heater outlet at the rate of 140,000 pounds per hour.

Determine the friction pressure drop in the pipe between the super-heater outlet and the turbine inlet flange.

Example 1 - Sheet 2

STANDARD CALCULATION FORM

Fluid STEAM   Temperature 975 °F   Pressure 1200 PSIA

Step	Item	Given Amount	Given Units	Conversion	Results
1st Step Fluid Properties	Specific Volume (v)	—	—	STEAM TABLES	0.6695 ft^3/lb
	Kinematic Viscosity (ν)	—	—	FIG. (1)	1.30×10^{-5} ft^2/sec
2nd Step Standard Flow Units	Inside Pipe Diameter				4.813 in
	Velocity (V)	140,000	LB/HR	TABLE (3), $V = 0.0509 \frac{v}{d^2} \times \frac{LB}{HR}$	206.0 ft/sec
	Velocity Pressure (P_v)	$0.0001078V^2/v$		$0.0001078 \times \frac{(206.0)^2}{0.6695}$	6.833 psi
	Reynolds Number (R_e)	$dV/12\nu$		$\frac{4.813 \times 206.0}{12 \times 1.30 \times 10^{-5}}$	6.356×10^6

Tubing

3rd Step Determine K Values	Material	CH-MO STEEL	
	Length	5 + 12 + 2 + 18 + 16 + 11	64 ft
	Friction Factor (f)	$\epsilon/d = 0.00034$ FROM FIG. (7), FROM FIG. (8) f =	0.0155

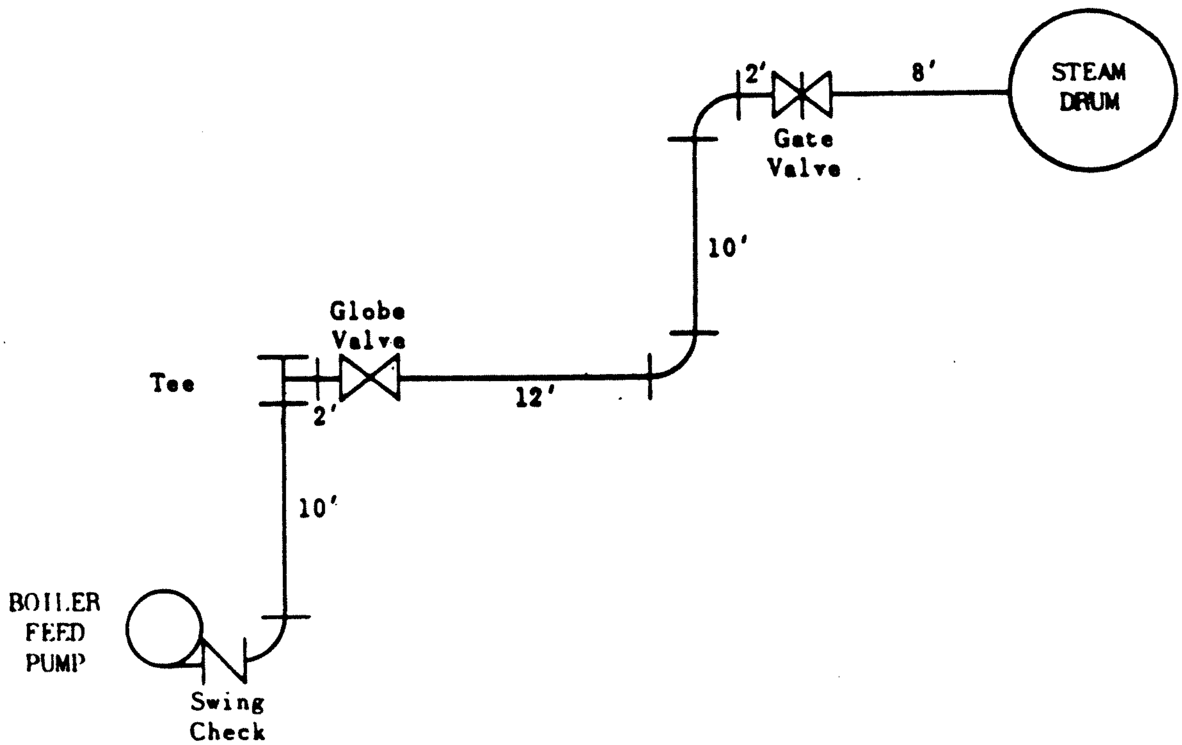
Valves and Fittings

Fitting	Number (N)	Type	d_b	K_b Value Figure	K_b	$(d/d_b)^4$	Actual $K = NK_b(d/d_b)^4$
90° STD. EL.	3	FLANGE	4.813	10	0.29	1	0.87
GATE VLV.	1	"	"	9	0.13	1	0.13
GLOBE VLV.	1	"	"	9	5.90	1	5.90
Equivalent K of Tubing	$12\ fl/d$	$\frac{12 \times 0.0155 \times 64}{4.813}$					2.47
Total ΣK							9.37

Losses

Step	Part of System	ΣKP_v	ΔP
4th Step Compute Losses	SUPERHEATER OUTLET TO TURBINE INLET FLANGE	9.37×6.833	64.0 psi
			psi
			psi
			psi
			psi
			psi
			psi
			psi
	Total		64.0 psi

Example 2 - Sheet 1



All pipe is 4" nominal

All fittings are welded

297 gallons of water per minute are delivered from the feed pump at 1500 psia and 246°F.

Determine the friction pressure drop through the pipe leading to the steam drum.

NOTE: (1) To obtain total pressure drop from pump to drum, static lift must be computed and added to the friction loss.

(2) A feed water regulating valve was not included in this calculation. However, in actual practice a feed water regulating valve should be included when making the calculation.

Example 2 - Sheet 2

STANDARD CALCULATION FORM

Fluid WATER Temperature 246 °F Pressure 1500 PSIA

Step	Item	Given Amount	Given Units	Conversion	Results
1st Step Fluid Properties	Specific Volume (v)	—	—	FIG. (5)	0.01695 ft^3/lb
	Kinematic Viscosity (ν)	—	—	FIG. (4)	2.76×10^{-6} ft^2/sec
2nd Step Standard Flow Units	Inside Pipe Diameter				4.026 in
	Velocity (V)	297	GPM	TABLE (3) $V = \frac{0.4087}{d^2} \times GPM$	7.489 ft/sec
	Velocity Pressure (P_v)	$0.0001078 V^2/v$		$0.0001078 \times \frac{(7.489)^2}{0.01695}$	0.357 psi
	Reynolds Number (R_e)	$dV/12\nu$		$\frac{7.489 \times 4.026}{12 \times 2.76 \times 10^{-6}}$	910,348

Tubing

Item	Conversion	Results
Material	STEEL	
Length	10 + 2 + 12 + 10 + 2 + 8	44 ft
Friction Factor (f)	ϵ/d = 0.00043 FROM FIG (7), FROM FIG (8) f =	0.0168

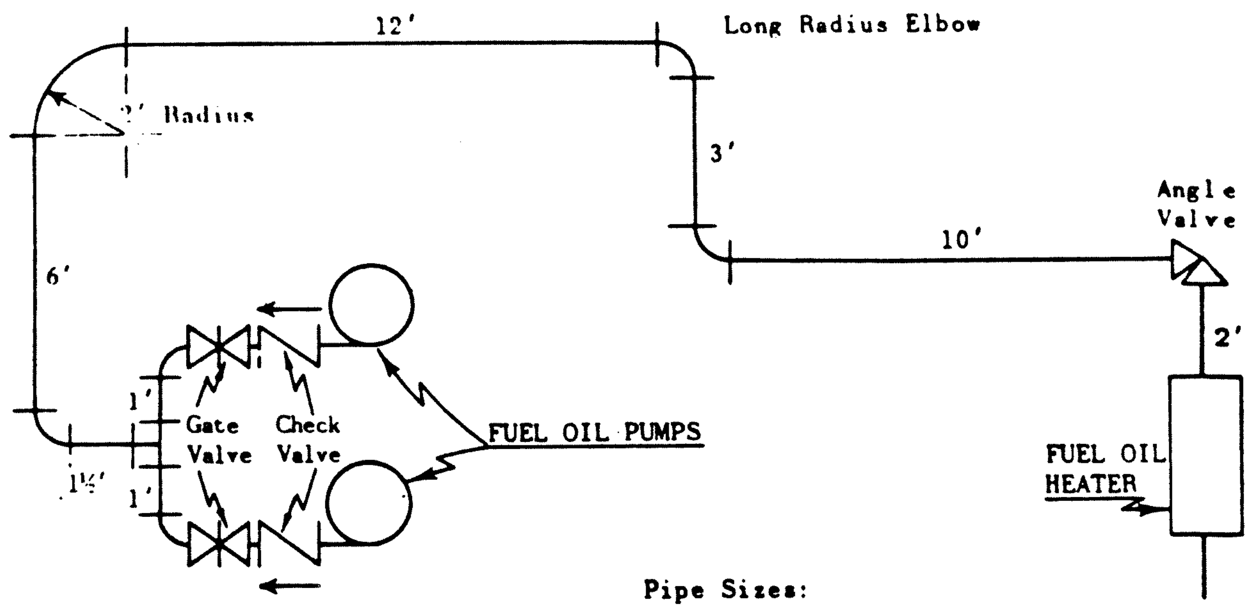
Valves and Fittings (3rd Step: Determine K Values)

Fitting	Number (N)	Type	d_b	K_b Value: Figure	K_b Value: K_b	$(d/d_b)^4$	Actual K = $NK_b(d/d_b)^4$
90° STD. EL.	3	WELDED	4.026	10	0.30	1	0.90
SWING CHECK	1	"	"	9	2.00	1	2.00
TEE	1	"	"	10	0.68	1	0.68
GLOBE VLV.	1	"	"	9	6.20	1	6.20
GATE VLV.	1	"	"	9	0.17	1	0.17
Equivalent K of Tubing	$12\ fl/d$	$\frac{12 \times 0.0168 \times 44}{4.026}$					2.20
Total ΣK							12.15

Losses (4th Step: Compute Losses)

Part of System	$\Sigma K P_v$	Δp
PUMP TO STEAM DRUM	12.15 × 0.357	4.33 psi
		psi
		psi
		psi
		psi
		psi
		psi
Total		4.33 psi

Example 3 - Sheet 1



Pipe Sizes:

Pumps to Tee........2" nominal

Tee to Heater.......3" nominal

All Fittings Flanged

50 GPM of fuel oil is discharged from each pump at 650 psia and 100°F. The viscosity of the oil is 4000 SSU and the specific gravity of the oil is 11.9° A.P.I. at 60°/60°.

Determine the friction pressure drop in the pipe between the Fuel Oil Pumps and the Fuel Oil Heater.

Example 3 - Sheet 2

STANDARD CALCULATION FORM

Fluid: FUEL OIL | Temperature: 100° F | Pressure: 650 PSIA

Step	Item	Given: Amount	Given: Units	Conversion	Results
1st Step Fluid Properties	Specific Volume (v)	11.9°	A.P.I. @60/60	FIG. (3)	0.0164 ft^3/lb
	Kinematic Viscosity (ν)	4000	SSU	TABLE (2), $0.001075(0.0022t - \frac{135}{t})$	0.00946 ft^2/sec
2nd Step Standard Flow Units	Inside Pipe Diameter				2.067 in
	Velocity (V)	50	GPM	TABLE (3), $V = \frac{0.4087}{d^2} \times GPM$	4.783 ft/sec
	Velocity Pressure (P_v)	$0.0001078V^2/v$		$0.0001078 \times \frac{(4.783)^2}{0.0164}$	0.150 psi
	Reynolds Number (R_e)	$dV/12\nu$		$\frac{4.783 \times 2.067}{12 \times 0.00946}$	87.1

Tubing

Item		Results
Material	STEEL	
Length	1	1 ft
Friction Factor (f)	$f = \frac{64}{Re} = \frac{64}{87.1}$	0.735

Valves and Fittings

3rd Step: Determine K Values

Fitting	Number (N)	Type	d_b	K_b Value: Figure	K_b Value: K_b	$(d/d_b)^4$	Actual $K = NK_b(d/d_b)^4$
CHECK VLV.	1	FLANGE	2.067	9	2.00	1	2.00
GATE VLV.	1	"	"	*	0.30	1	0.30
90° STD. EL.	1	"	"	10	0.37	1	0.37
Equivalent K of Tubing	$12\,fl/d$	$\frac{12 \times 0.735 \times 1}{2.067}$					4.27
Total ΣK							6.94

Losses

4th Step: Compute Losses

Part of System	ΣKP_v	ΔP
PUMP TO TEE	6.94 × 0.150	1.04 psi
		psi
		psi
		psi
		psi
		psi
* EXTRAPOLATION FROM TABLE (4) AND PAGE (32)		psi
Total		1.04 psi

Example 3 - Sheet 3

STANDARD CALCULATION FORM

Fluid: FUEL OIL   Temperature: 100° F   Pressure: 650 PSIA

Step	Item	Given: Amount	Given: Units	Conversion	Results
1st Step Fluid Properties	Specific Volume (v)	11.9°	A.P.I. 60/60	FIG. (3)	0.0164 ft³/lb
	Kinematic Viscosity (ν)	4000	SSU	TABLE (2), $0.001075(0.0022t - \frac{1.35}{t})$	0.00946 ft²/sec
2nd Step Standard Flow Units	Inside Pipe Diameter				3.068 in
	Velocity (V)	100	GPM	TABLE (3), $V = \frac{0.4087}{d^2} \times GPM$	4.342 ft/sec
	Velocity Pressure (P_v)	$0.0001078V^2/v$		$0.0001078 \times \frac{(4.342)^2}{0.0164}$	0.124 psi
	Reynolds Number (R_e)	dV/12ν		$\frac{3.068 \times 4.342}{12 \times 0.00946}$	117.3

Tubing

Material	STEEL	
Length	1.5 + 6 + 12 + 3 + 10 + 2	34.5 ft
Friction Factor (f)	$f = \frac{64}{Re} = \frac{64}{117.3}$	0.546

Valves and Fittings (3rd Step: Determine K Values)

Fitting	Number (N)	Type	d_b	K_b Value: Figure	K_b Value: K_b	$(d/d_b)^4$	Actual K = $NK_b(d/d_b)^4$
90° STD. EL.	2	FLANGE	3.068	10	0.32	1	0.64
90° LONG RADIUS EL.	1	"	"	10	0.25	1	0.25
90° BEND	1	"	"	13	0.16	1	0.16
ANGLE VLV.	1	"	"	9	2.10	1	2.10
2"x2"x3" TEE	1	"	—	10	0.82	1	0.82
Equivalent K of Tubing	12 fl/d	$\frac{12 \times 0.546 \times 34.5}{3.068}$					73.69
Total ΣK							77.66

Losses (4th Step: Compute Losses)

Part of System	ΣKP_v	ΔP
TEE TO HEATER	77.66 × 0.124	9.63 psi
PUMP TO TEE		1.04 psi
		psi
		psi
		psi
		psi
		psi
Total		10.67 psi

Table 1

Conversion Equations to be used to obtain Specific Volume (v) in $\frac{ft^3}{lb}$

Given		Units	Equation
Specific Vol.,	v	$= \frac{ft^3}{lb}$	
	v_1	$= \frac{in^3}{lb}$	$0.0005787 \times v_1 = v$
	v_2	$= \frac{gal}{lb}$	$0.1337 \times v_2 = v$
	v_3	$= \frac{cm^2}{gm}$	$0.01602 \times v_3 = v$
Specific Weight,	w	$= \frac{lb}{ft^3}$	$\frac{1}{w} = v$
	w_1	$= \frac{lb}{in^3}$	$\frac{0.0005787}{w_1} = v$
	w_2	$= \frac{lb}{gal}$	$\frac{0.1337}{w_2} = v$
	w_3	$= \frac{gm}{cm^3}$	$\frac{0.01602}{w_3} = v$
Specific Gravity relative to water at 60°F	G	--	$\frac{0.01603}{G} = v$
Density	ρ_1	$= \frac{slug}{ft^3}$	$\frac{0.03108}{\rho_1} = v$
	ρ_2	$= \frac{gm}{cm^3}$	$\frac{0.00001633}{\rho_2} = v$
A. P. I. gravity at 60/60		°A.P.I.	Use figure 3

Table 2

Conversion Equations to be used to obtain

Kinematic Viscosity in $\frac{ft^2}{sec}$

Given Viscosity	Units	Equation
Kinematic		
English, ν	= $\frac{ft^2}{sec}$	$\nu = \nu$
Metric-Stoke, ν_1	= $\frac{cm^2}{sec}$	$0.001076\ \nu_1 = \nu$
centi-stoke, ν_2	= 0.01 Stoke	$0.00001076\ \nu_2 = \nu$
Absolute		
English, μ	= $\frac{lb\text{-}sec}{ft^2}$	$32.17\ v\mu = \nu$
μ_1	= $\frac{lb}{ft\text{-}sec}$	$v\mu_1 = \nu$
Metric-poise, μ_2	= $\frac{dyne\text{-}sec}{cm^2}$	$0.0672\ v\mu_2 = \nu$
centi-poise, μ_3	= .01 Poise	$0.000672\ v\mu_3 = \nu$
Saybolt Seconds Universal,		
SSU t = 32 to 100 seconds	sec	$0.001075\ (0.00226t - 1.95/t) = \nu$
t = over 100 seconds	sec	$0.001075\ (0.00220t - 1.35/t) = \nu$
Saybolt Seconds Furol, SSF		
t = 25 to 40 seconds	sec	$0.001075\ (0.0224t - 1.84/t) = \nu$
t = over 40 seconds	sec	$0.001075\ (0.0216t - 0.60/t) = \nu$
Redwood No. 1 - English		
t = 34 to 100 seconds	sec	$0.001075\ (0.00260t - 1.79/t) = \nu$
t = over 100 seconds	sec	$0.001075\ (0.00247t - 0.50/t) = \nu$
Redwood Admiralty-English	sec	$0.001075\ (0.027t - 20/t) = \nu$
Engler-German	sec	$0.001075\ (0.00147t - 3.74/t) = \nu$

Table 3

Conversion Factors to Velocity in Feet Per Second

Given Flow Units	Equation
Feet per	
second, V	$V = V$
minute, V_1	$V_1/60 = V$
hour, V_2	$V_2/3600 = V$
Cubic Feet per	
second, CFS	$CFS \times 183.4/d^2 = V$
minute, CFM	$CFM \times 3.057/d^2 = V$
hour, CFH	$CFH \times 0.05095/d^2 = V$
Pounds per	
second, PPS	$PPS \times 183.4\ v/d^2 = V$
minute, PPM	$PPM \times 3.057\ v/d^2 = V$
hour, PPH	$PPH \times 0.05095\ v/d^2 = V$
Gallons per	
second, GPS	$GPS \times 24.52/d^2 = V$
minute, GPM	$GPM \times 0.4087/d^2 = V$
hour, GPH	$GPH \times 0.006812/d^2 = V$

d = inches
v = specific volume ($ft^3/lb.$)

Table 4

Resistance Coefficients for Navy and other Fittings

Fitting	Nominal Size	K
Elbow, 90°, welded or brazed		
Bureau of Ships Plan 5000-S4823-841166	1-1/2	0.33
	2-1/2	0.29
	4	0.20
	6	0.23
Bureau of Ships Standard, B-105, Long Radius	1-1/2	0.70
	2-1/2	0.42
	4	0.25
	6	0.42
Bureau of Ships Standard, B-105, Standard Radius	1-1/2	0.76
	2-1/2	0.48
	4	0.33
	6	0.52
Military Specification, MIL-F-1183, Type A and B	1-1/2	0.59
	2-1/2	0.57
	4	0.53
	6	0.67
Manifold for Drainage Systems		
Valve nearest outlet (stop check, full open)	2-1/2	1.02
		6.41_2
Center valve (stop check, full open)	2-1/2	0.99_1
		6.26_2
Valve farthest from outlet (stop check position)	2-1/2	1.11_1
		6.97_2
Valve farthest from outlet (high lift position)	2-1/2	0.72_1
		4.55_2
Strainer		
Fire Main, Bureau of Ships Dwg. S-9300-461049	1-1/2	1.31
Fire Main, Bureau of Ships Dwg. S-9300-461052	2-1/2	1.71
Macomb, Bethlehem Shipbuilding Corp. Dwg. BS-34A	2-1/2	3.14

1 Based on 2-1/2 inch inlet

2 Based on 4 inch outlet

Table 4—Continued

Fitting	Nominal Size	K
Valve		
Angle		
Bureau of Ships Plan 5000-S4824-1385541	1-1/2	2.10
Bureau of Ships Plan 5000-S4824-1385512	2-1/2	3.56
	4	3.29
	6	4.53
Gate, Mil-V-1189	1-1/2	0.38
	2-1/2	0.22
	4	0.11
	6	0.11
Globe		
Bureau of Ships Plan 5000-S4824-1385512	1-1/2	7.03
	2-1/2	6.68
	4	5.15
	6	5.62
Mil-V-17513, 600 psi. steel	1-1/2	6.41
Straightway, Bureau of Ships Mechanical Standard Plan No. B-200	2-1/2	4.46
Swing Check, Mil-V-17547	4	0.42
	2-1/2	0.50
Tee		
Regular, Bureau of Ships Plan 5000-S4823-841166		
Through Flow	1-1/2	0.05
	2-1/2	0.10
	4	0.10
	6	0.10
Branch to Run	6	1.10
Run to Branch	1-1/2	0.86
	2-1/2	0.70
	4	0.76
	6	1.05

Table 4--Continued

Fitting	Nominal Size	K
Tee--Continued		
Reducing, Bureau of Ships Plan 5000-S4823-841166		
Branch to Run	2-1/2 x 4	0.88[1]
		5.56[2]
	4 x 6	1.10[1]
		5.29[2]
Run to Branch	2-1/2 x 4	1.15[1]
		7.29[2]
	4 x 6	1.19[1]
		5.70[2]

1 Based on diameter of branch
2 Based on diameter of run

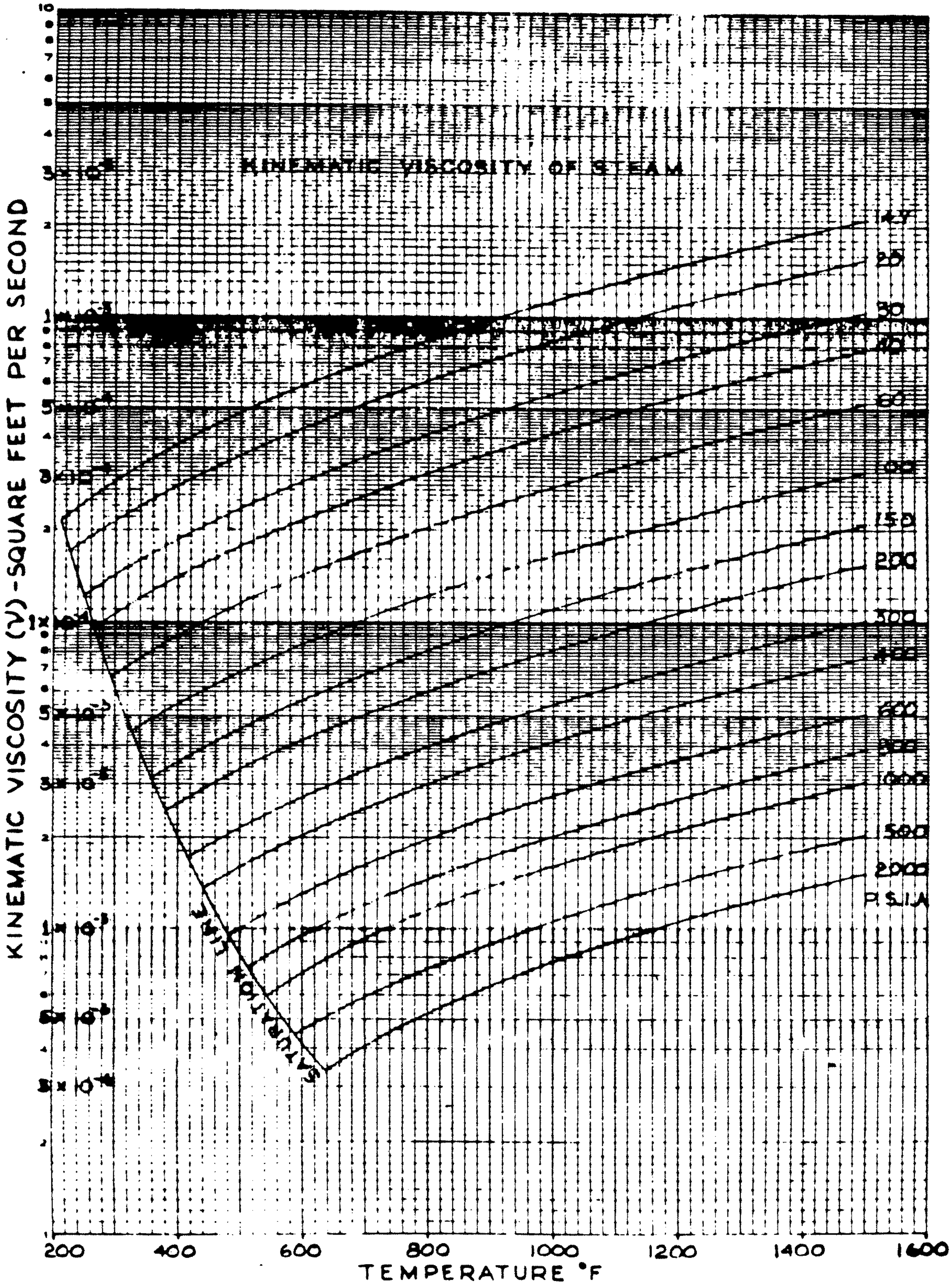

KINEMATIC VISCOSITY OF STEAM
KINEMATIC VISCOSITY (V) - SQUARE FEET PER SECOND
TEMPERATURE °F
SATURATION LINE
P.S.I.A.
200
400
600
800
1000
1200
1400
1600

Figure 1

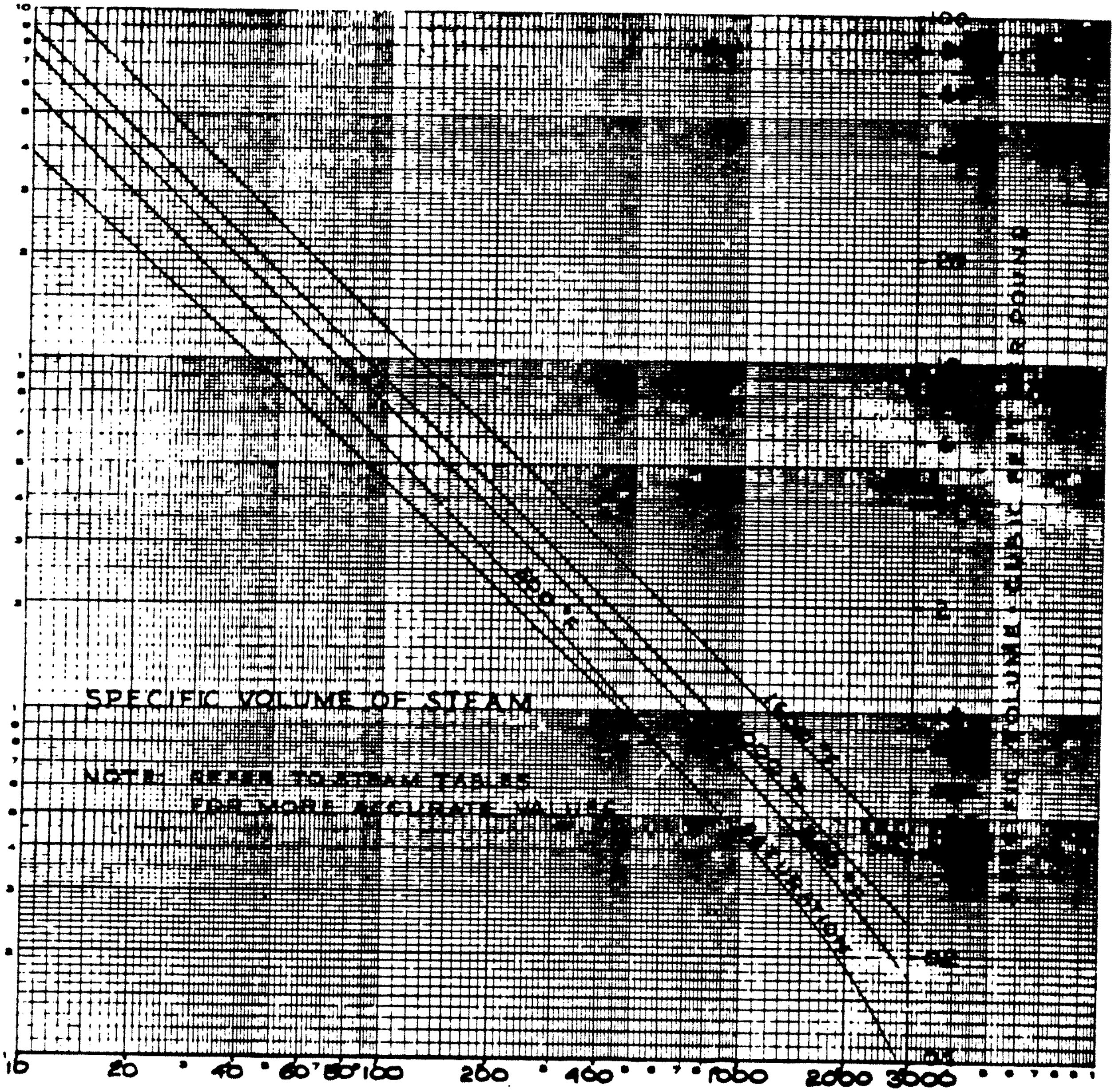

SPECIFIC VOLUME OF STEAM
NOTE: REFER TO STEAM TABLES
FOR MORE ACCURATE VALUES
10 20 40 60 80 100 200 400 1000 2000 3000
PRESSURE — PSIA

Figure 2

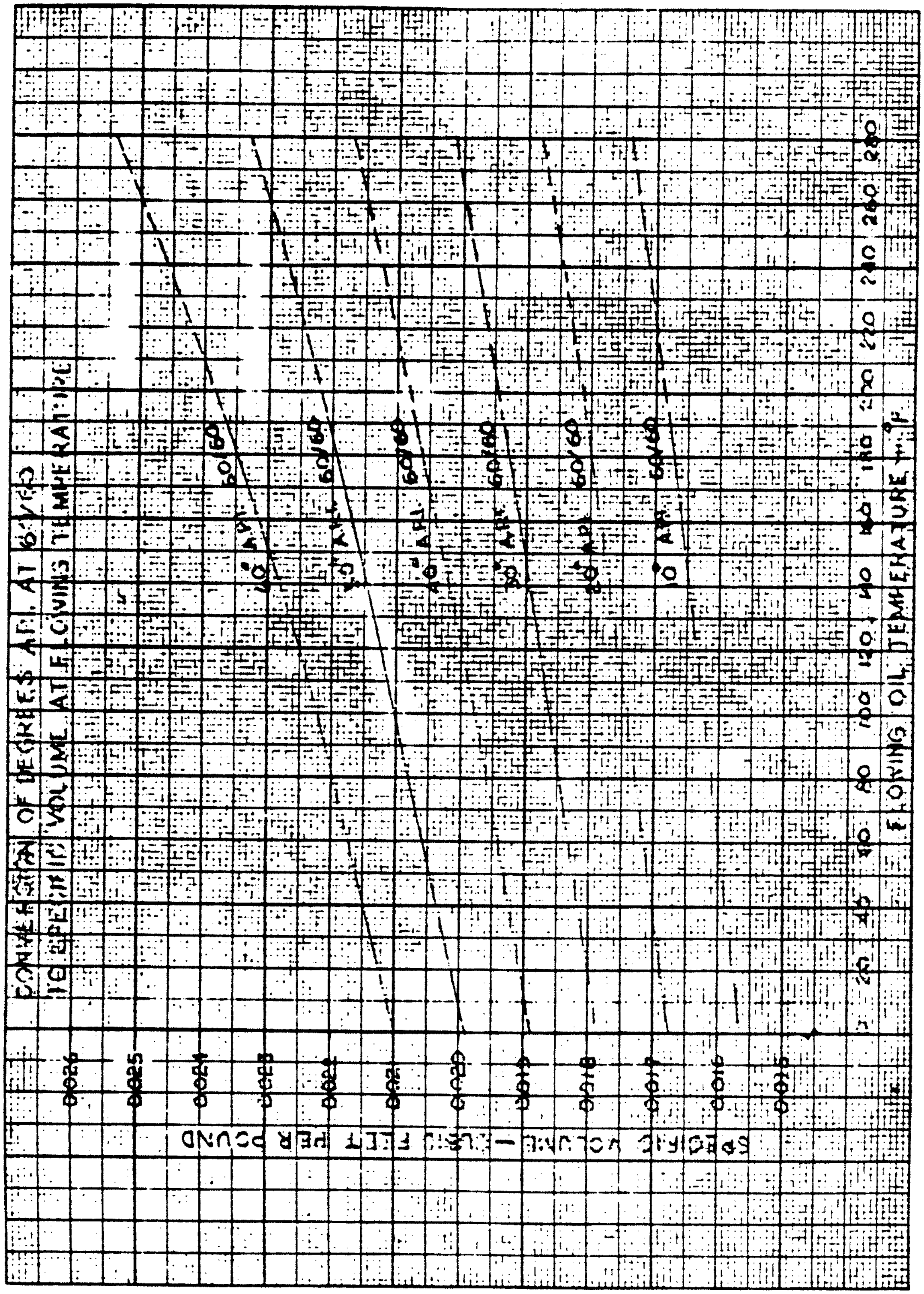

CONVERSION OF DEGREES API AT 60/60 TO SPECIFIC VOLUME AT FLOWING TEMPERATURE
10° API 60/60
20° API 60/60
30° API 60/60
40° API 60/60
50° API 60/60
60° API 60/60
70° API 60/60
0.026
0.025
0.024
0.023
0.022
0.021
0.020
0.019
0.018
0.017
0.016
0.015
SPECIFIC VOLUME — CUBIC FEET PER POUND
20
40
60
80
100
120
140
160
180
200
220
240
260
280
FLOWING OIL TEMPERATURE — °F

Figure 3

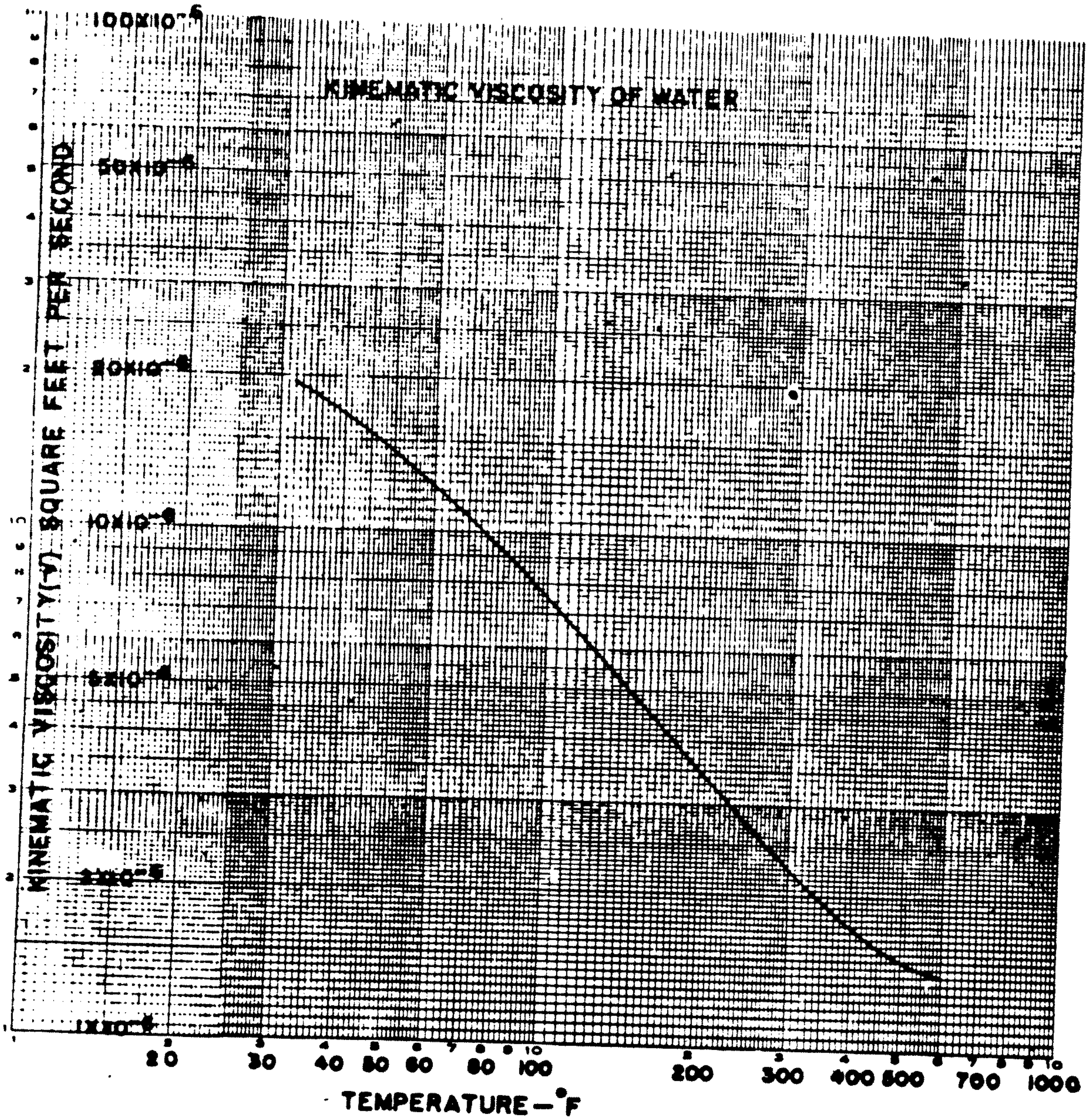

KINEMATIC VISCOSITY OF WATER
KINEMATIC VISCOSITY(ν) SQUARE FEET PER SECOND
100x10^-6
50x10^-6
20x10^-6
10x10^-6
5x10^-6
2x10^-6
1x10^-6
20
30
40
50
60
80
100
200
300
400
500
700
1000
TEMPERATURE—°F

Figure 4

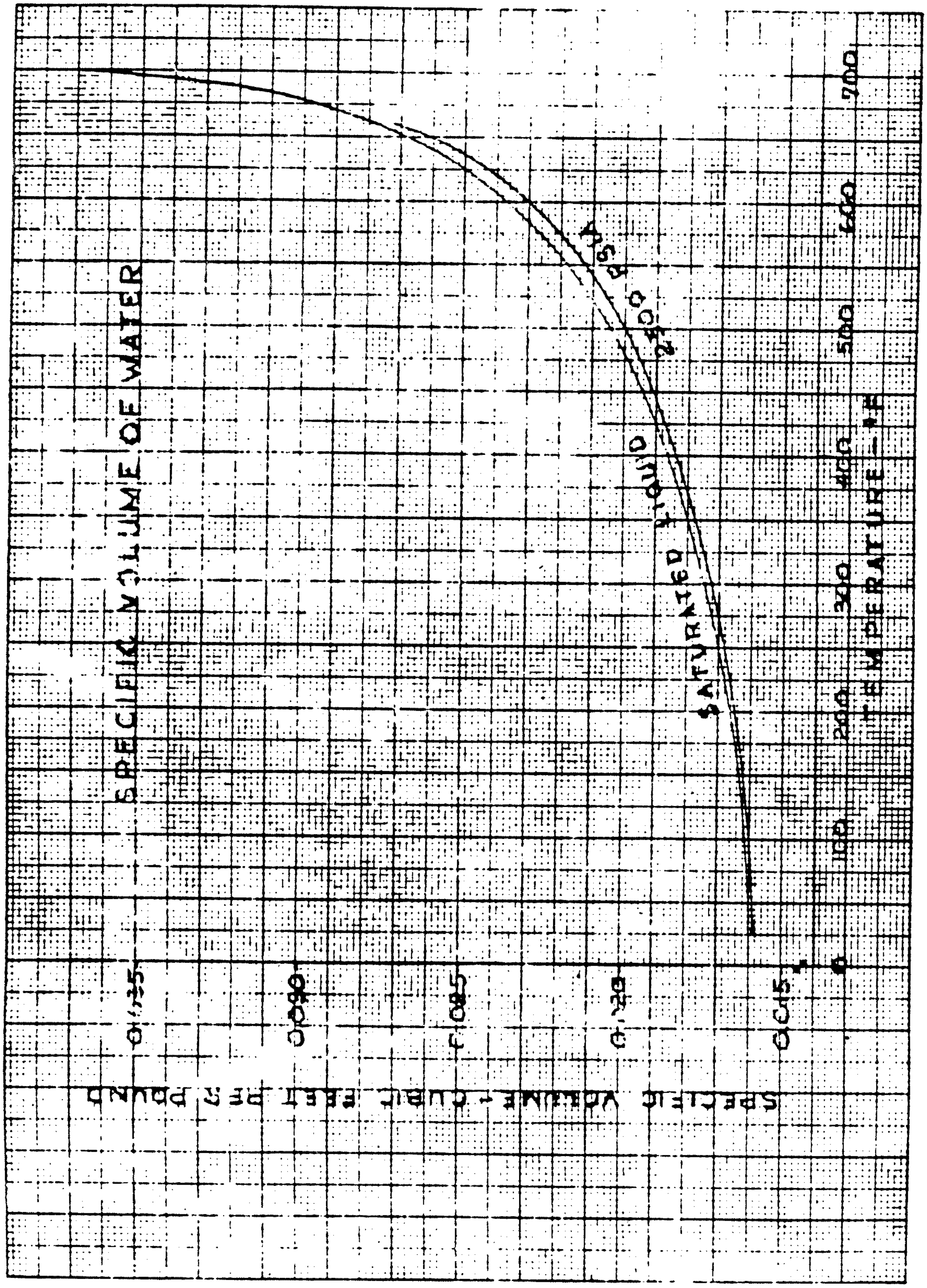

SPECIFIC VOLUME OF WATER
SATURATED LIQUID
2500 PSIA
TEMPERATURE — °F
0
100
200
300
400
500
600
700
0.015
0.020
0.025
0.030
0.035
SPECIFIC VOLUME - CUBIC FEET PER POUND

Figure 5

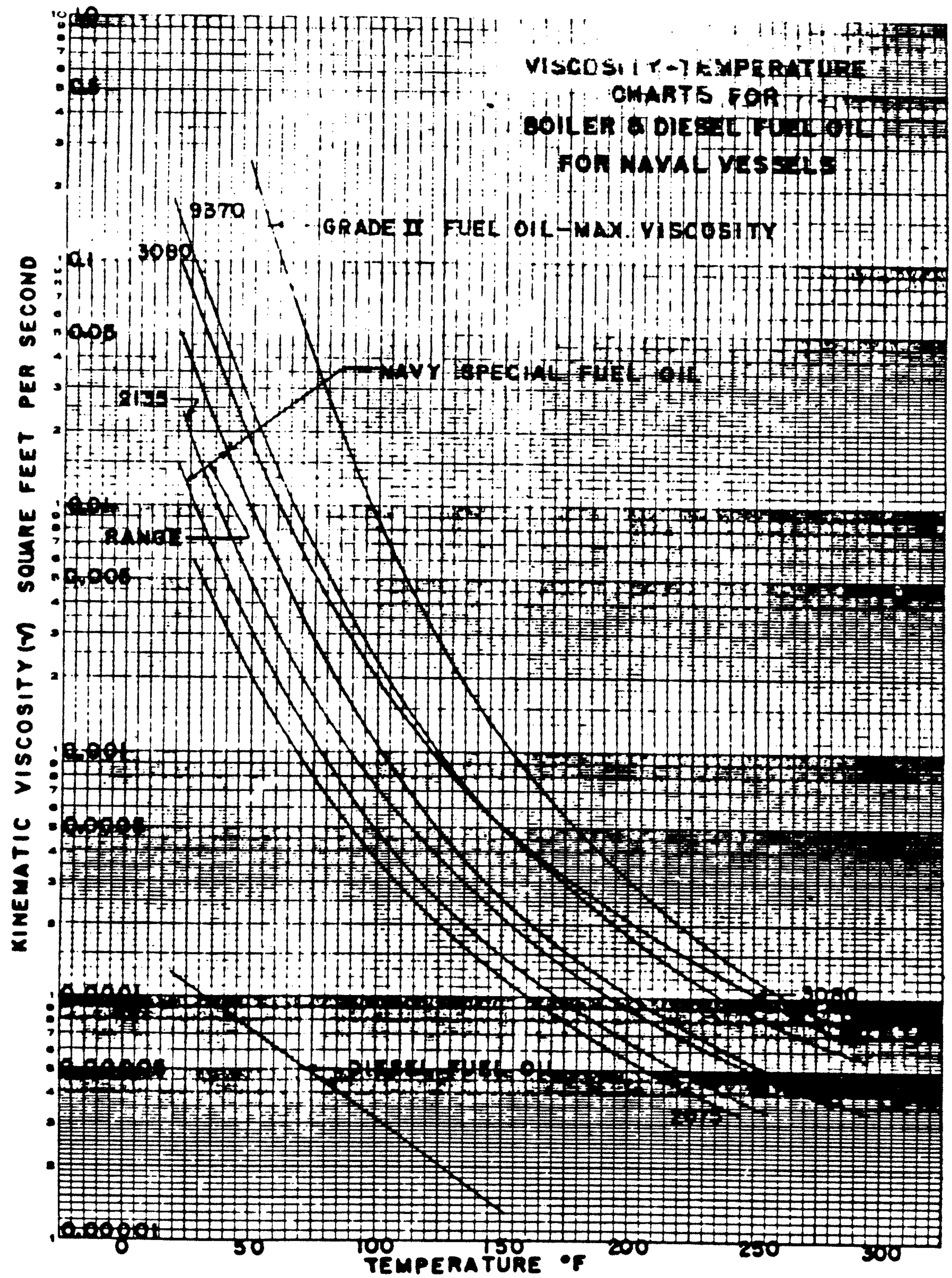

VISCOSITY-TEMPERATURE CHARTS FOR BOILER & DIESEL FUEL OIL FOR NAVAL VESSELS
9370
GRADE II FUEL OIL-MAX. VISCOSITY
3080
NAVY SPECIAL FUEL OIL
2135
RANGE
DIESEL FUEL OIL
3080
2075
1.0
0.5
0.1
0.05
0.01
0.005
0.001
0.0005
0.0001
0.00005
0.00001
0
50
100
150
200
250
300
TEMPERATURE °F
KINEMATIC VISCOSITY (V) SQUARE FEET PER SECOND

Figure 6(A)

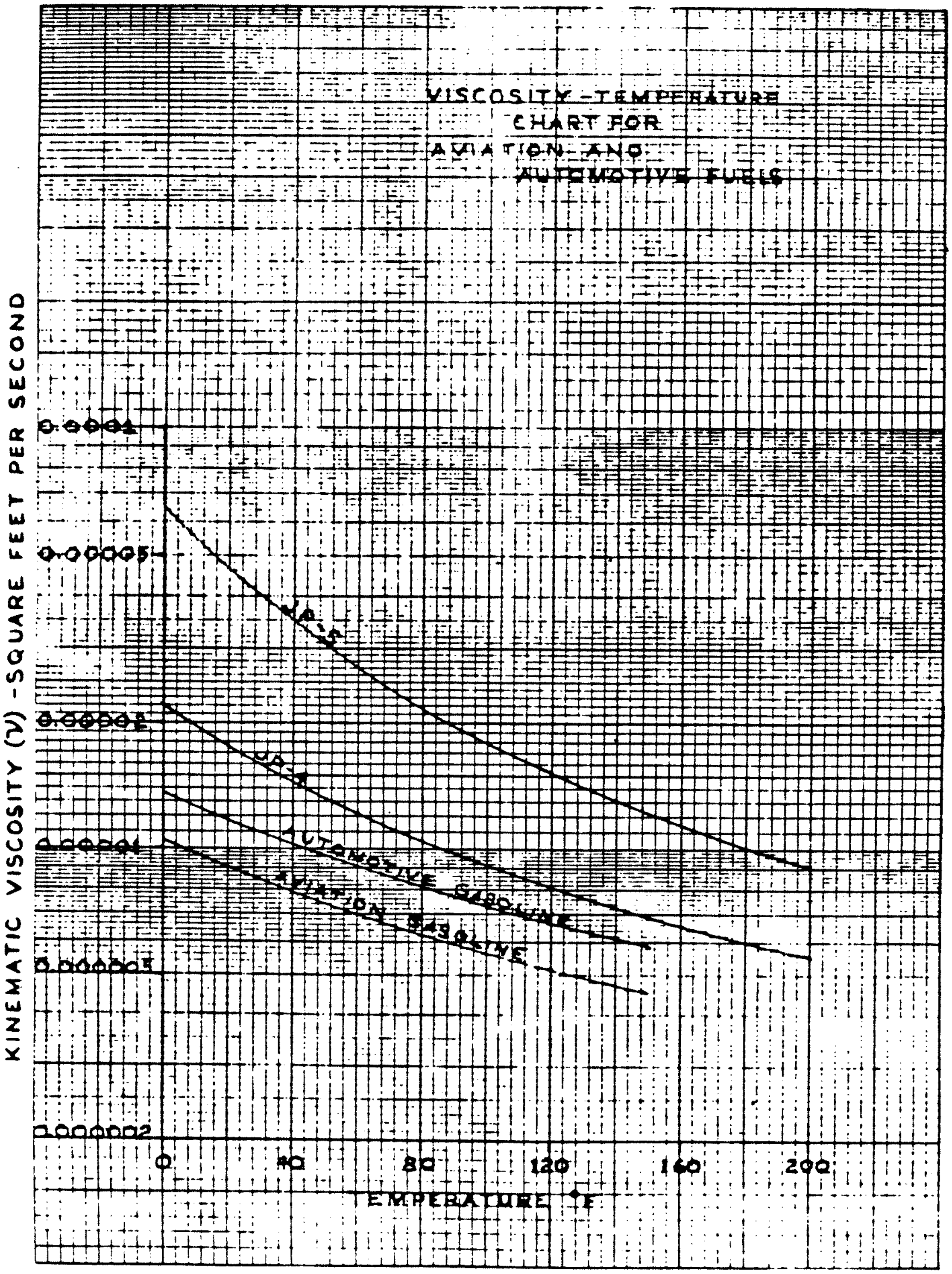

VISCOSITY-TEMPERATURE
CHART FOR
AVIATION AND
AUTOMOTIVE FUELS
KINEMATIC VISCOSITY (ν) -SQUARE FEET PER SECOND
0.0001
0.00005
0.00002
0.00001
0.000005
0.000002
JP-5
JP-4
AUTOMOTIVE GASOLINE
AVIATION GASOLINE
0
40
80
120
160
200
TEMPERATURE °F

Figure 6(B)

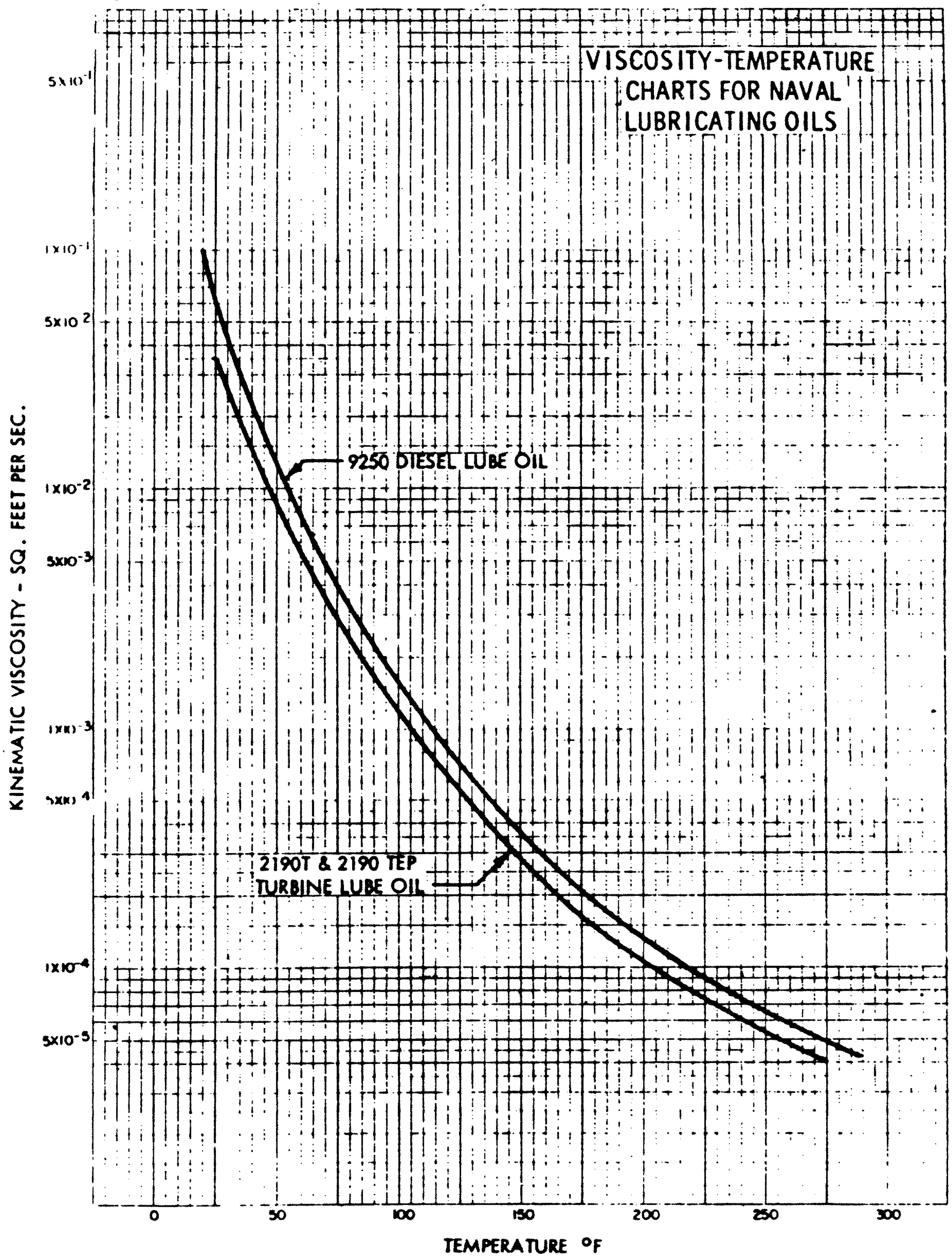
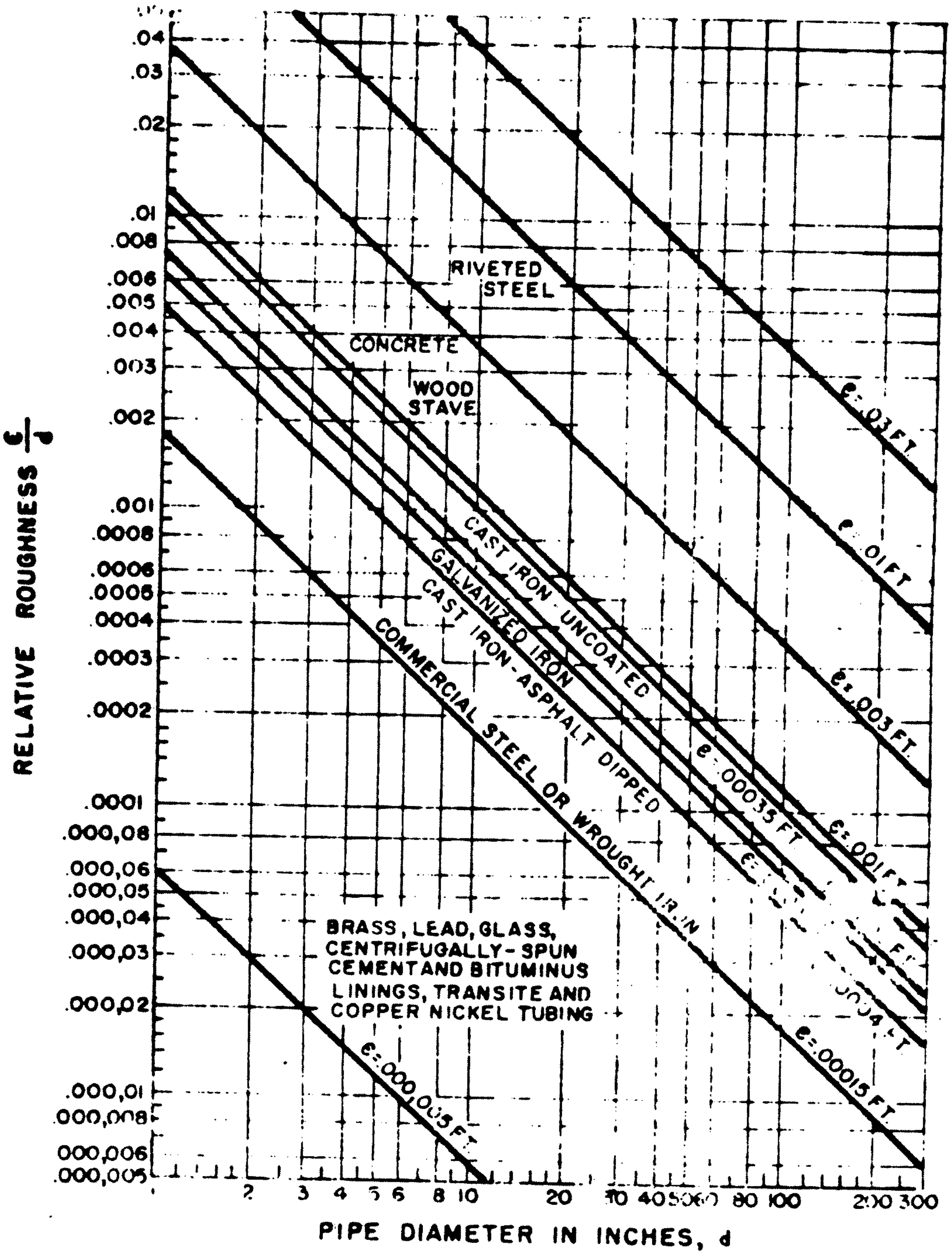

VISCOSITY-TEMPERATURE CHARTS FOR NAVAL LUBRICATING OILS
KINEMATIC VISCOSITY - SQ. FEET PER SEC.
5x10⁻¹
1x10⁻¹
5x10⁻²
1x10⁻²
5x10⁻³
1x10⁻³
5x10⁻⁴
1x10⁻⁴
5x10⁻⁵
9250 DIESEL LUBE OIL
2190T & 2190 TEP TURBINE LUBE OIL
0
50
100
150
200
250
300
TEMPERATURE °F

Figure 6(C)



RELATIVE ROUGHNESS FACTORS FOR NEW CLEAN PIPES

Figure 7

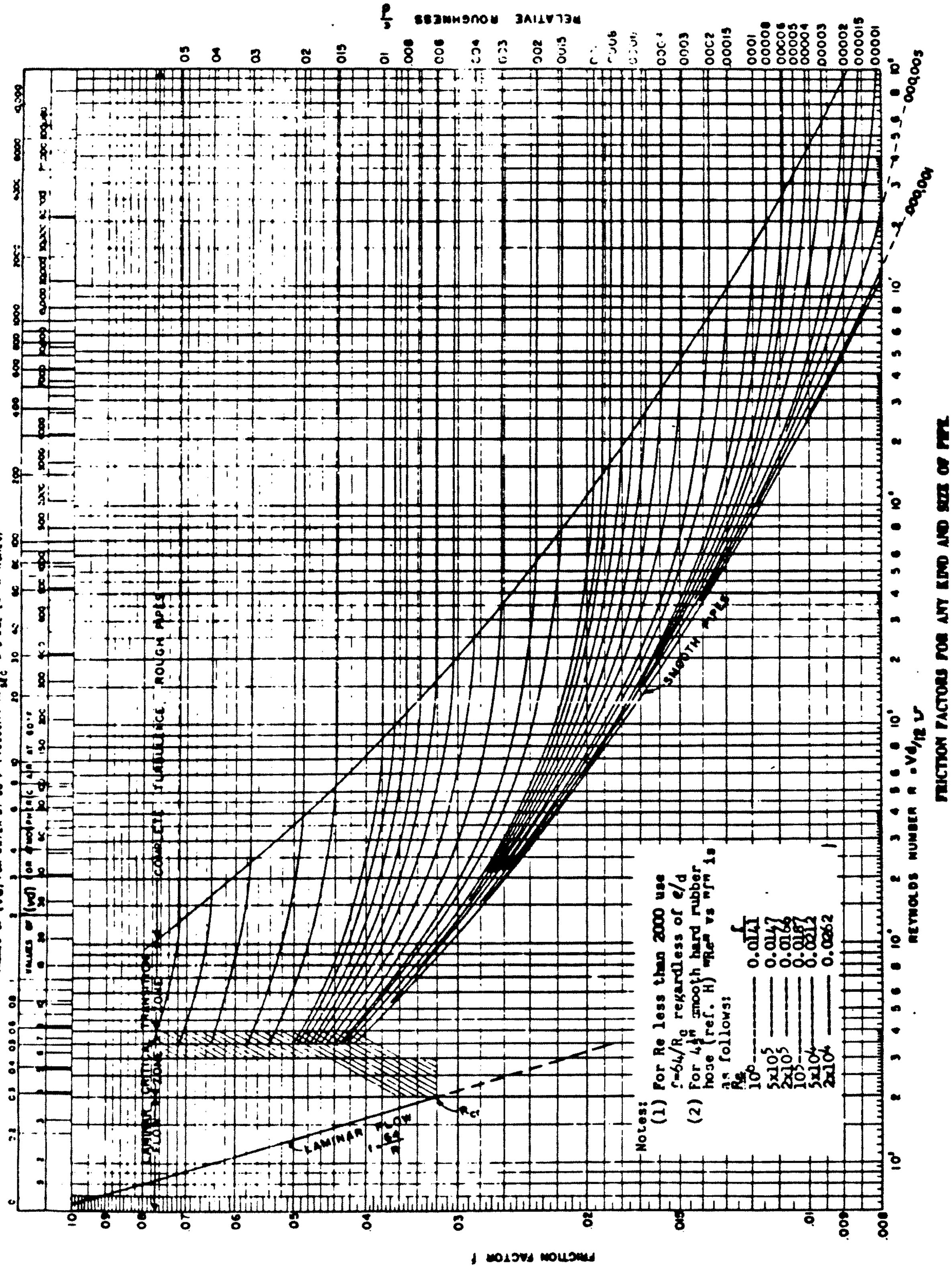
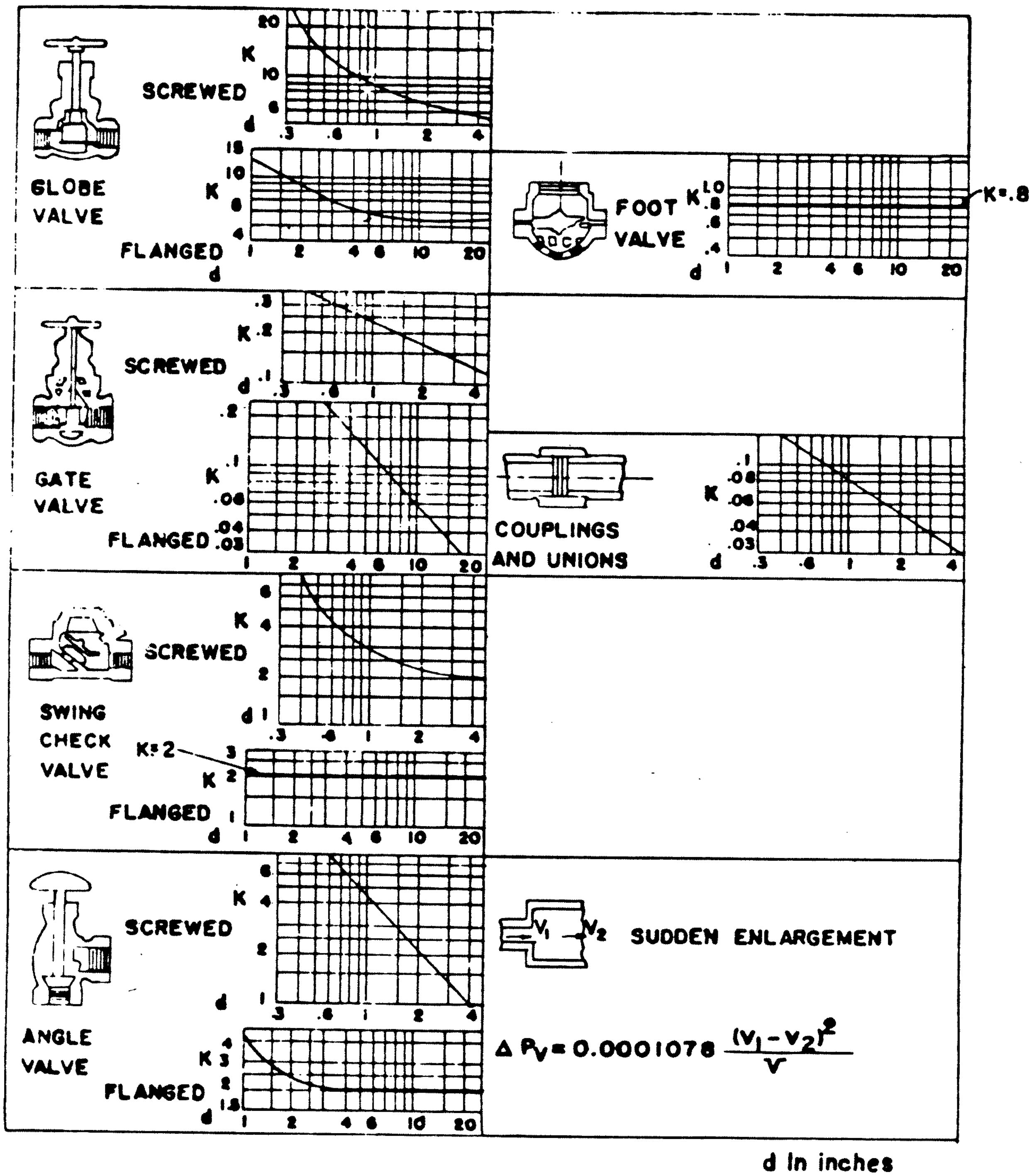

FRICTION FACTORS FOR ANY KIND AND SIZE OF PIPE
REYNOLDS NUMBER R = Vd/12ν
FRICTION FACTOR f
RELATIVE ROUGHNESS e/d
COMPLETE TURBULENCE, ROUGH PIPES
SMOOTH PIPES
LAMINAR FLOW f = 64/R
Notes:
(1) For Re less than 2000 use f=64/Rc regardless of e/d
(2) For 4" smooth hard rubber hose (ref. H) "Re" vs "f" is as follows:
Re f
10^6 0.0111
5x10^5 0.0147
2x10^5 0.0166
10^5 0.0187
5x10^4 0.0212
2x10^4 0.0262

Figure 8

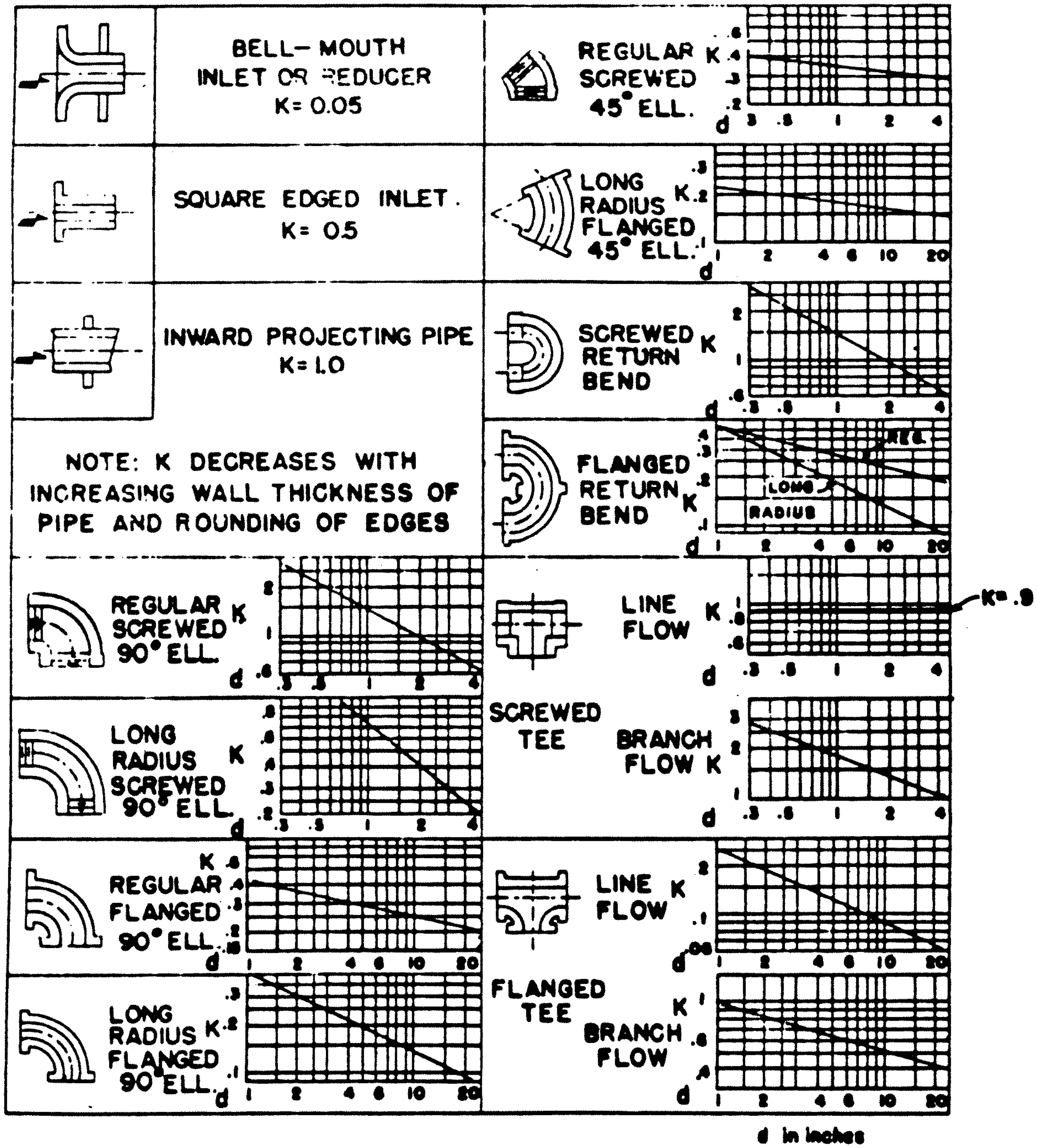
RESISTANCE COEFFICIENTS FOR COMMERICIAL VALVES AND FITTING



NOTE: WELDED SAME AS FLANGED

Figure 9

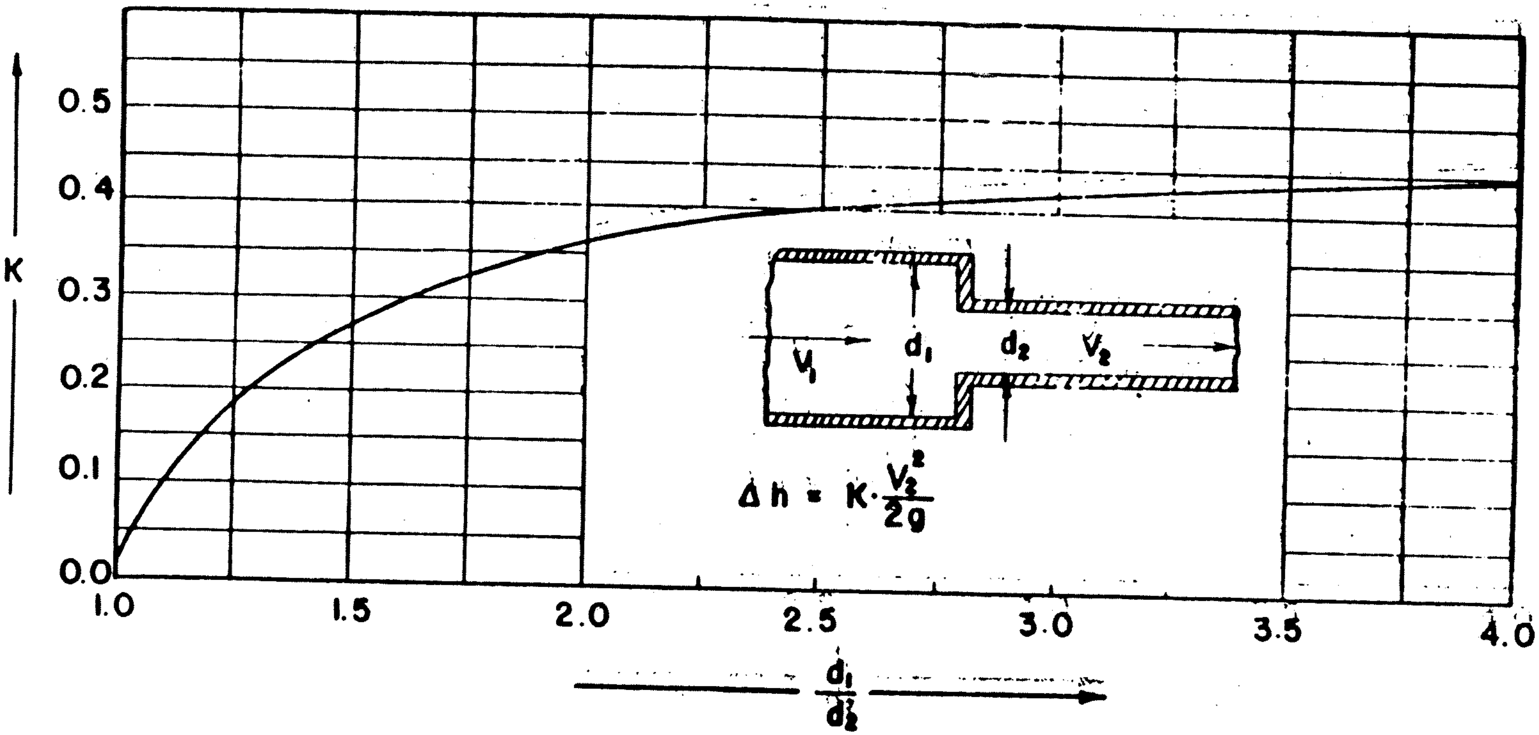
RESISTANCE COEFFICIENTS FOR COMMERICIAL VA·ʏᴇ.: AND FITTINGS



NOTE: WELDED SAME AS FLANGED

IT IS PREFERABLE TO USE FIG. 13 FOR FLANGED ELBOWS WHEN THE $\frac{R}{d}$ RATIO IS GREATER THAN UNITY

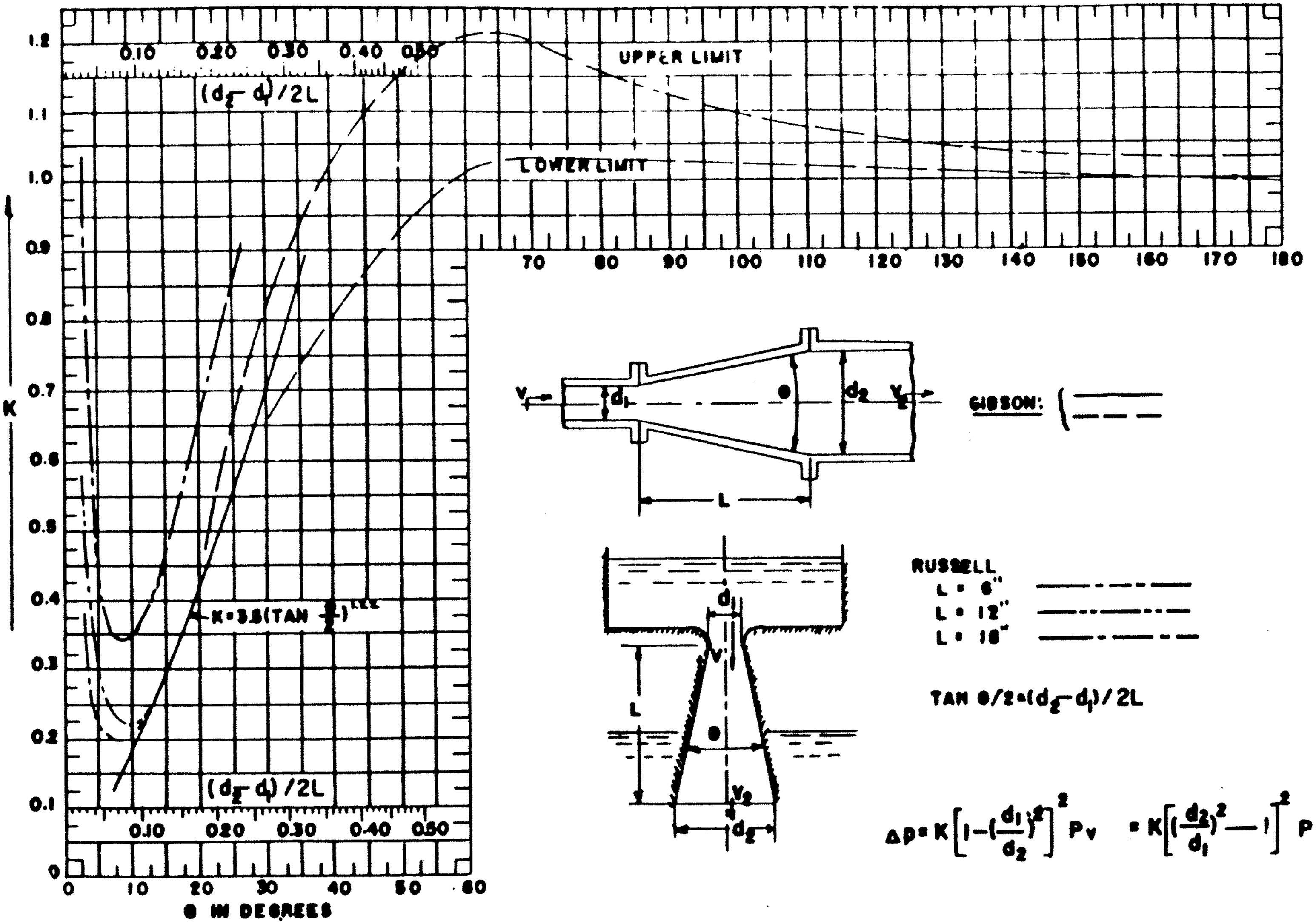
Figure 10



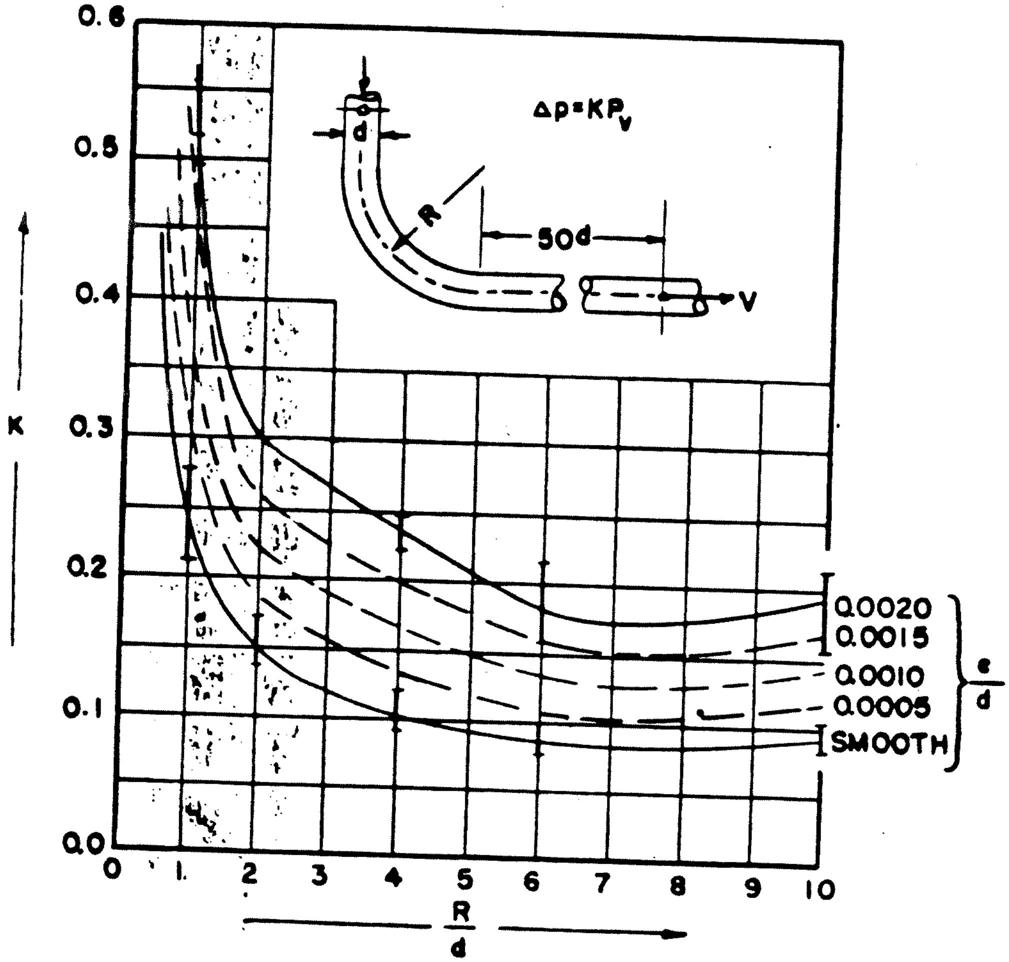
RESISTANCE COEFFICIENTS FOR REDUCERS

Figure 11

Figure 12



RESISTANCE COEFFICIENTS FOR INCREASERS AND DIFFUSERS



RESISTANCE COEFFICIENTS FOR 90 DEGREE BENDS OF UNIFORM DIAMETER

Figure 13