Rule 58

INSTRUCTION MANUAL

FOR

TURBULENT FLOW SLIDE RULE

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FLOW SLIDE RULE MANUAL

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FIGURES

FLOW SLIDE RULE MANUAL

NOTE 1

Two types of Turbulent Flow Slide Rules are in use at the present time. The only difference between the two are the equivalent length scales on the liquid side of the rule. In this text, they will be referred to as Type 1 and Type 2.

TYPE 1 The K3 Scale lists the various fittings by name. Equivalent length is computed per individual fitting.

TYPE 2 K values are given on the K3 Scale. Equivalent length is computed per K value.

NOTE 2

The slide rules give results consistent with Data Book Method 67.1 when fittings are not considered and when the friction factor corrections shown in Figure 2 are used. The slide rules give results inconsistent with the Data Book method when fittings are involved. Usually, the slide rules will give conservative results for fittings in 2-inch and larger diameter pipe. A method of using the slide rules to obtain results consistent with the Data Book is presented in Research Progress Report 8, Assignment PJ-310, February 7, 1968. This method or the Data Book method should be followed when more accurate results are needed.

FLOW SLIDE RULE MANUAL

I GENERAL BASIS

The Braun Flow Slide Rule has been developed to assist in quick line-sizing and calculating pressure drops. The rule can be used for single-phase turbulent flow of fluids only. One side is for liquids. The other side is for gases and steam.

LIMITATIONS OF FANNINGS EQUATION For the general case of steady state fluid flow the total energy balance per pound of mass is given in differential form by

$$dU + \frac{VdV}{g_c} + \frac{g}{g_c}\,dZ + Pdv + vdP - dq + dw = 0 \qquad (1)$$

A force balance can be derived from the general equation above. If no work is done on or by the system the force balance gives

$$dP_T = \frac{\rho VdV}{g_c} + \rho\frac{g}{g_c}\,dZ + \frac{4\rho fV^2}{2g_c D}\,dL \qquad (2)$$

The third term of the right side of Equation 2 represents the pressure drop due to friction. It is the differential form of Fannings equation

$$dP = \frac{4\rho fV^2}{2g_c D}\,dL \qquad (3)$$

If the friction factor, density, and velocity are independent of dL, or can be represented with sufficient accuracy by some average value, Equation 3 can be integrated to yield the familiar form of Fannings equation.

$$\Delta P = \frac{1}{144}\int_o^L \frac{4\rho fV^2}{2g_c D}\,dL = \frac{1}{144}\,\frac{4\rho fV^2}{2g_c D}\int_o^L dL = \frac{4fL}{D}\,\frac{V^2}{2g_c}\,\frac{\rho}{144} \qquad (4)$$

The assumption of constant density and velocity is valid for liquids, which are nearly incompressible. For gases we apply a correction factor to account for the compressibility of the fluid. The correction factor is given in Figure 4.

I GENERAL BASIS Continued

PRESSURE DROP CALCULATIONS In order to represent Fannings equation on the rule the friction factor, f, must be a single-valued function of Reynolds number. For standard pipe the friction factor is

$$f = \frac{0.048}{(R_e)^{0.186}} \qquad (5)$$

The pressure drop for standard pipe then becomes

$$\Delta P/100' = 4.572 \times 10^{-5} \frac{W^{1.814}\mu^{0.186}}{\rho\ d^{4.814}}, \text{ psi/100 ft} \qquad (6)$$

For smooth tubes the friction factor is given by

$$f = \frac{0.041}{(R_e)^{0.186}} \qquad (7)$$

The pressure drop for smooth tubes is then

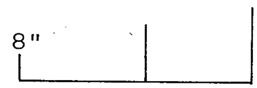
$$\Delta P/100' = 3.905 \times 10^{-5} \frac{W^{1.814}\mu^{0.186}}{\rho\ d^{4.814}}, \text{ psi/100 ft} \qquad (8)$$

Figure 1 is a plot of the friction factors given by Equations 5 and 7 along with the Moody friction-factor curves recommended by the Hydraulics Institute.

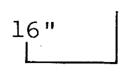
CAST-IRON PIPE The liquid side of the rule includes an index for cast-iron pipe. Friction factors for cast-iron pipe vary over a wide range depending on manufacture. Use pressure drop calculations for cast-iron pipe only as a rough guide.

I GENERAL BASIS Continued

PIPE SIZES Pipe sizes from 1 1/2-inch through 24-inch are given on the rule. Schedules 40, 80, and 160 are given for 1 1/2-inch through 10-inch pipe. On the rule they look like this.



The marks indicate different schedules for the same nominal pipe size. The number indicating the nominal pipe size is always placed at the mark corresponding to the thinnest wall. Thus, for the example above the mark at the left end, under the 8", indicates 8" (nominal size) Schedule-40 pipe. The middle mark indicates 8" (nominal size) Schedule-80 pipe. And the mark at the right end indicates 8" (nominal size) Schedule-160 pipe. Wall thicknesses of 1/2-inch and 3/8-inch are given for pipe sizes 12-inch through 24-inch. On the rule they look like this.



Again the numeral indicating the nominal pipe size is always placed at the mark corresponding to the thinnest wall. Thus, for the example above, the mark at the left end, under the 16", indicates 16" pipe (nominal size) with a 3/8-inch wall thickness. The mark at the right end indicates 16" pipe (nominal size) with a 1/2-inch wall thickness. Table I lists the inside diameters of the pipe sizes covered on the rule.

CORRECTION FACTOR The friction factors used on the rule for the pressure drop calculations are a single valued function of Reynolds number. They deviate from values recommended by the Hydraulic Institute for low pipe diameters and high Reynolds numbers.

To improve the accuracy of computations in this region, it is necessary to apply a friction factor correction from Figure 2. Reynolds numbers may be computed from pipe diameter, weight rate of flow and viscosity using Figure 3.

The friction factors used on the rule for the equivalent length computation are a single valued function of the pipe diameter. The correction factor, obtained from Figure 2, can not be used here. Thus, a considerable error will still be incorporated in the result when, in addition to low pipe diameter and high Reynolds numbers, the system has a large equivalent length.

I GENERAL BASIS Continued

STEAM CHART On the gas side of the rule there is a graph for steam densities. Densities are given covering the range of 100 F to 900 F and 5 psia to 1000 psia. The diagonal line on the graph is the saturated steam locus. Below this line the steam is superheated.

II OPERATION, LIQUID SIDE

PRESSURE DROP To calculate pressure drop five things must be known. Pipe type (i e, smooth tube, standard pipe, or cast iron). Specific gravity at flow conditions. Viscosity in centipoise at flow conditions. Stream flow in pounds per hour. And pipe size and schedule. The scales used for pressure drop calculations are numbered in the sequence of their use, with a Δ for pressure drop preceding the numberal.

1 Set the specific gravity of Δ1 Scale under the pipe type on the Δ2 Scale.

2 Move the hairline over the viscosity in centipoise on Δ3 Scale.

3 Move the center slide so that the flow rate in pounds per hour on Δ4 Scale is under the hairline.

4 Move the hairline over the specified pipe and schedule size on Δ5 Scale.

5 Read the pressure drop, psi per 100 feet on Δ6 Scale.

6 The total pressure drop can be calculated if the number of hundreds of feet of pipe is known. Place the 1.0 on the Δ7 Scale over the pressure drop per 100 feet on the Δ6 Scale. Move the hairline over the number of hundreds of feet of pipe on the Δ7 Scale. Read total pressure drop at hairline on Δ6 Scale.

II OPERATION, LIQUID SIDE Continued

LINE SIZING Pipe size can be calculated if six things are known. Pipe Type. Specific gravity at flow conditions. Viscosity in centipoise at flow conditions. Stream flow in pounds per hour. Allowable pressure drop in psi per 100 feet. And pipe schedule or wall thickness.

1 Set the specific gravity on Δ1 Scale under the pipe type on Δ2 Scale.

2 Move the hairline over the viscosity in centipoise on Δ3 Scale.

3 Move the center slide so that the flow rate in pounds per hour on Δ4 Scale is under the hairline.

4 Move the hairline over the allowable pressure drop per 100 feet on Δ6 Scale.

5 Line size is read on Δ5 Scale as the smallest size pipe of given schedule which is to the left of the hairline.

GPM TO LB/HR To convert gallons per minute to pounds per hour the specific gravity must be known.

1 Place the hairline over specific gravity of 1.0 on the V1 Scale.

2 Move the center slide so that the gallons per minute on V2 Scale is under the hairline.

3 Move the hairline along V1 Scale to the specific gravity of the stream.

4 Read pounds per hour on Δ4 Scale.

II OPERATION, LIQUID SIDE Continued

VELOCITY To calculate velocity the gallons per minute and the pipe size and schedule must be known.

1 Move the hairline over the VELOCITY ARROW.

2 Move the center slide until the flow in gallons per minute on V2 Scale is under the hairline.

3 Move the hairline along V3 Scale to the specified pipe and scheduled size.

4 Read velocity in feet per second on V4 Scale.

EQUIVALENT LENGTHS The equivalent length of a fitting can be calculated if the pipe size is known.

1 Place the hairline over the specified pipe and schedule size on K1 Scale.

2 Move the center slide until the EQUIV LENGTH arrow is under the hairline.

3a Move the hairline over the fitting on the K3 Scale. (For Type 1 only)

3b Move the hairline over the K value on the K3 Scale. (For Type 2 only)

4 Read equivalent length in feet on K2 Scale.

III OPERATION, GAS SIDE

PRESSURE DROP To calculate pressure drop five things must be known. The pipe type (i e, smooth tubes or standard pipe). The viscosity in centipoise at flow conditions. The density in pounds per cubic foot at flow conditions. The stream flow in pounds per hour. And pipe and schedule size. The pressure drop scales are numbered in order of use, and are preceded by a Δ to indicate pressure drop.

1 Move the center slide until the viscosity in centipoise on Δ1 Scale is under the pipe type on Δ2 Scale.

2 Move the hairline over the density in pounds per cubic foot on Δ3 Scale.

3 Move the center slide so that the pounds per hour on Δ4 Scale is under the hairline.

4 Move the hairline over the specified pipe and schedule size.

5 Read pressure drop, psi per hundred feet on Δ6 Scale.

6 The total pressure drop can be calculated if the number of hundreds of feet of pipe is known. Place the 1.0 on the Δ7 Scale over the pressure drop per 100 feet on the Δ6 Scale. Move the hairline over the number of hundreds of feet of pipe on the Δ7 Scale. Read total pressure drop at hairline on Δ6 Scale.

ACFM TO LB/HR To convert actual cubic feet per minute to pounds per hour the density in pounds per cubic foot at flow conditions must be known.

1 Move the hairline over the flow in actual cubic feet per minute on V2 Scale.

2 Move the center slide until the density in pounds per cubic foot on Δ3 Scale is under the hairline.

3 Move the hairline along Δ3 Scale to a density of 1.0 pound per cubic foot.

4 Read flow in pounds per hour on V1 Scale.

III OPERATION, GAS SIDE Continued

VELOCITY Gas velocities are calculated from flow in actual cubic feet per minute and pipe and schedule size.

1 Move the hairline along V2 Scale to the flow rate in actual cubic feet per minute.

2 Move the center slide until the VELOCITY ARROW is under the hairline.

3 Move the hairline along V3 Scale to the specified pipe and schedule size.

4 Read velocity in feet per second on V4 Scale.

IV SAMPLE CALCULATIONS, LIQUID SIDE

EXAMPLE 1 Calculate the pressure drop for the following conditions.

76,800 pounds per hour of pentane

0.580 specific gravity

0.15 centipoise viscosity

4-inch Schedule-40 standard pipe

2500-foot pipe run

1 Move center slide until specific gravity 0.580 on Δ1 Scale is below standard pipe mark on Δ2 Scale.

2 Move hairline along Δ3 Scale to viscosity of 0.15 centipoise.

3 Move center slide until flow rate of 7.68×10^4 pounds per hour on Δ4 Scale is under hairline.

4 Move hairline along Δ5 Scale to 4-inch Schedule-40 pipe.

5 Read ΔP/100' of 0.79 psi on Δ6 Scale.

6 Move the center slide until the 1.0 on the Δ7 Scale is over 0.79 on the Δ6 Scale.

7 Move the hairline along Δ7 Scale to 25.

8 Read total pressure drop of 19.8 psi on Δ6 Scale under the hairline.

IV SAMPLE CALCULATIONS, LIQUID SIDE Continued

EXAMPLE 2 Correct the pressure drop of Example 1 for friction factor deviation.

1 Enter Figure 3 with a diameter of 4.026 inches, go vertically to 7.68×10^4 lb/hr, horizontally to 0.15 centipoise viscosity, and down to find Reynolds number. Read Reynolds number of 8.08×10^5.

2 Enter Figure 2 with Reynolds number of 8.08×10^5 and read $\phi = 1.1$.

3 Compute correct pressure drop of (19.8)(1.1) = 21.8 psi per 2500 feet.

EXAMPLE 3 Size a line for the following service.

760,000 pounds per hour of cooling water

1.0 centipoise viscosity

1.0 specific gravity

2 psi per 100 feet allowable pressure drop

Schedule-40 standard pipe

1 Place specific gravity of 1.0 on Δ1 Scale under standard pipe on Δ2 Scale.

2 Move the hairline over 1.0 centipoise viscosity on Δ3 Scale.

3 Move the center slide until 760,000 pounds per hour on Δ4 Scale is under hairline.

4 Move the hairline along Δ5 Scale to the smallest Schedule-40 pipe that gives a pressure drop equal to or less than 2 psi per 100 feet on Δ6 Scale. It is an 8-inch pipe. The pressure drop is 1.55 psi per 100 feet.

IV SAMPLE CALCULATIONS, LIQUID SIDE Continued

EXAMPLE 4 Convert gallons per minute to pounds per hour for the following conditions.

730 gpm of Freon-12

1.30 specific gravity

1 Place the hairline over specific gravity of 1.0 on V1 Scale.

2 Move the center slide until 730 gpm on V2 Scale is under the hairline.

3 Move the hairline along V1 Scale to specific gravity of 1.30.

4 Read 475,000 lb/hr on Δ4 Scale. ✓

EXAMPLE 5 Compute the velocity for the conditions given below.

2250 gpm of water

14-inch pipe with 1/2-inch wall

1 Move hairline over VELOCITY ARROW.

2 Move center slide until 2250 gpm on V2 Scale is under the hairline.

3 Move the hairline along V3 Scale to 14-inch pipe with 1/2-inch wall.

4 Read velocity of 5.42 feet per second on V4 Scale.

EXAMPLE 6a (Type 1 only) Compute the equivalent length of a TEE FLOW OUT, in a 10-inch Schedule-40 line.

1 Move hairline along K1 Scale to 10-inch Schedule-40.

2 Move center slide until the EQUIV LENGTH arrow is under the hairline.

3 Move the hairline along K3 Scale to TEE FLOW OUT.

4 Read equivalent length of 70 feet on K2 Scale.

IV SAMPLE CALCULATIONS, LIQUID SIDE Continued

EXAMPLE 6b (Type 2 only) Compute the equivalent length of a TEE FLOW OUT, K = 1.1, in a 10-inch Schedule-40 line.

1 Move hairline along K1 Scale to 10-inch Schedule-40.

2 Move center slide until the EQUIV LENGTH arrow is under the hairline.

3 Move the hairline along K3 Scale to 1.1.

4 Read equivalent length of 66 feet on K2 Scale.

V SAMPLE CALCULATIONS, GAS SIDE

EXAMPLE 1 Compute the pressure drop for the conditions given below.

82,000 pounds per hour of ammonia vapor

0.581 pounds per cubic foot

0.013 centipoise viscosity

6-inch Schedule-80 standard pipe

700-foot pipe run

1 Move the center slide until the viscosity of 0.013 centipoise on $\Delta 1$ Scale is under the standard pipe mark on $\Delta 2$ Scale.

2 Move the hairline along $\Delta 3$ Scale to a density of 0.581 pounds per cubic foot.

3 Move the center slide until 82,000 pounds per hour on $\Delta 4$ Scale is under the hairline.

4 Move the hairline along $\Delta 5$ Scale to 6-inch Schedule-80 pipe.

5 Read $\Delta P/100'$ of 6.2 psi per hundred feet on $\Delta 6$ Scale.

6 Move center slide so that 1.0 on $\Delta 7$ Scale is over 6.2 on $\Delta 6$ Scale.

7 Move hairline along $\Delta 7$ Scale to 7.

8 Read total pressure drop 43.4 psi on $\Delta 6$ Scale under hairline.

V SAMPLE CALCULATIONS, GAS SIDE Continued

EXAMPLE 2 Correct the pressure drop of Example 1 for friction factor deviation and compressible flow. The initial pressure is, say, 200 psia.

1 From Figure 3 compute Reynolds number of 6.9×10^6.

2 Read friction factor correction, Ø, of 1.47 from Figure 2.

3 Compute pressure drop adjusted for friction factor deviation of (43.4)(1.47) = 63.8 psi per 700 feet.

4 Compute the ratio of this adjusted pressure drop to the initial upstream pressure, 63.8/200 = .319.

5 From Figure 4 read θ, correction for compressible flow, = 1.25.

6 Compute correct pressure drop as (1.25)(63.8) = 79.8 psi per 700 feet.

EXAMPLE 3 Size a line for the conditions given below.

8600 pounds per hour of steam

0.015 centipoise viscosity

0.22 pounds per cubic foot

3 psi per 100 feet allowable pressure drop

Schedule-80 standard pipe

1 Move the center slide until a viscosity of 0.015 centipoise on Δ1 Scale is under the standard pipe mark on Δ2 Scale.

2 Move the hairline along the Δ3 Scale to a density of 0.22 pounds per cubic foot.

3 Shift the center slide so that 8600 pounds per hour on Δ4 Scale is under the hairline.

4 Move the hairline along Δ5 Scale to the smallest Schedule-80 pipe that gives a pressure drop equal to or less than 3 psi per 100 feet on Δ6 Scale. It is a 4-inch pipe and the pressure drop is 2.03 psi per 100 feet.

V SAMPLE CALCULATIONS, GAS SIDE Continued

EXAMPLE 4 Convert 1640 actual cubic feet per minute of fuel gas to pounds per hour. The density is 0.35 pounds per cubic foot.

1. Move the hairline along V2 Scale to 1640 ACFM.
2. Move the center slide until a density of 0.35 on Δ3 Scale is under the hairline.
3. Move the hairline along Δ3 Scale to the CONVERSION ARROW.
4. Read 34,600 pounds per hour under hairline on V1 Scale.

EXAMPLE 5 Calculate the velocity for the conditions given below.

170 ACFM of an inert gas

3-inch Schedule-40 pipe

1. Move hairline along V2 Scale to 170 ACFM.
2. Move center slide until VELOCITY ARROW is under the hairline.
3. Move the hairline along V3 Scale to 3-inch Schedule-40 pipe.
4. Read velocity of 55 feet per second at the hairline on V4 Scale.

EXAMPLE 6 Find the density of steam at 500 F and 100 psia.

1. Place hairline over the intersection of 500 F and 100 psia on the steam chart grid.
2. Read density of 0.179 pounds per cubic foot at hairline on Δ3 Scale.

NOMENCLATURE

d	Inside diameter of pipe, inches
D	Inside diameter of pipe, feet
f	Friction factor, defined by Fannings equation, dimensionless
g	Acceleration due to gravity, 32.2 ft/sec^2
g_c	Proportionality constant, 32.2 pound-mass feet per pound-force second squared
K	Friction coefficient for valves and fittings
L	Length of pipe, feet
M	Molecular weight
P	Absolute pressure, pounds-force per square foot
P_T	Total pressure, pounds-force per square foot
ΔP	Pressure drop due to friction losses, pounds per square inch
$\Delta P/100'$	Pressure drop, pounds per square inch per 100 feet of pipe
q	Heat input, foot pounds-force per pound-mass of fluid
R_e	Reynolds number, dimensionless
U	Internal energy, foot pounds-force per pound-mass
v	Specific volume of fluid, cubic feet per pound-mass of fluid
V	Velocity of stream in pipe, feet per second
w	Work input, foot pounds-force per pound-mass of fluid
W	Rate of stream flow, pounds per hour
Z	Potential energy, feet
ρ	Density, pounds per cubic foot
μ	Viscosity, centipoise
θ	Correction factor for compressible flow
$\emptyset$	Correction factor for friction factor deviation

TABLE I

INSIDE DIAMETERS OF PIPE SIZES COVERED ON RULE

NOMINAL PIPE SIZE	SCHEDULE	INSIDE DIAMETER INCHES	NOMINAL PIPE SIZE	WALL	INSIDE DIAMETER INCHES
1 1/2	160	1.338	12	1/2	11.750
	80	1.500		3/8	12.000
	40	1.610			
			14	1/2	13.000
2	160	1.689		3/8	13.250
	80	1.939			
	40	2.067	16	1/2	15.000
				3/8	15.250
3	160	2.626			
	80	2.900	18	1/2	17.000
	40	3.068		3/8	17.250
4	160	3.438	20	1/2	19.000
	80	3.826		3/8	19.250
	40	4.026			
			22	1/2	21.000
6	160	5.189		3/8	21.250
	80	5.761			
	40	6.065	24	1/2	23.000
				3/8	23.250
8	160	6.813			
	80	7.625			
	40	7.981			
10	160	8.500			
	80	9.564			
	40	10.02			

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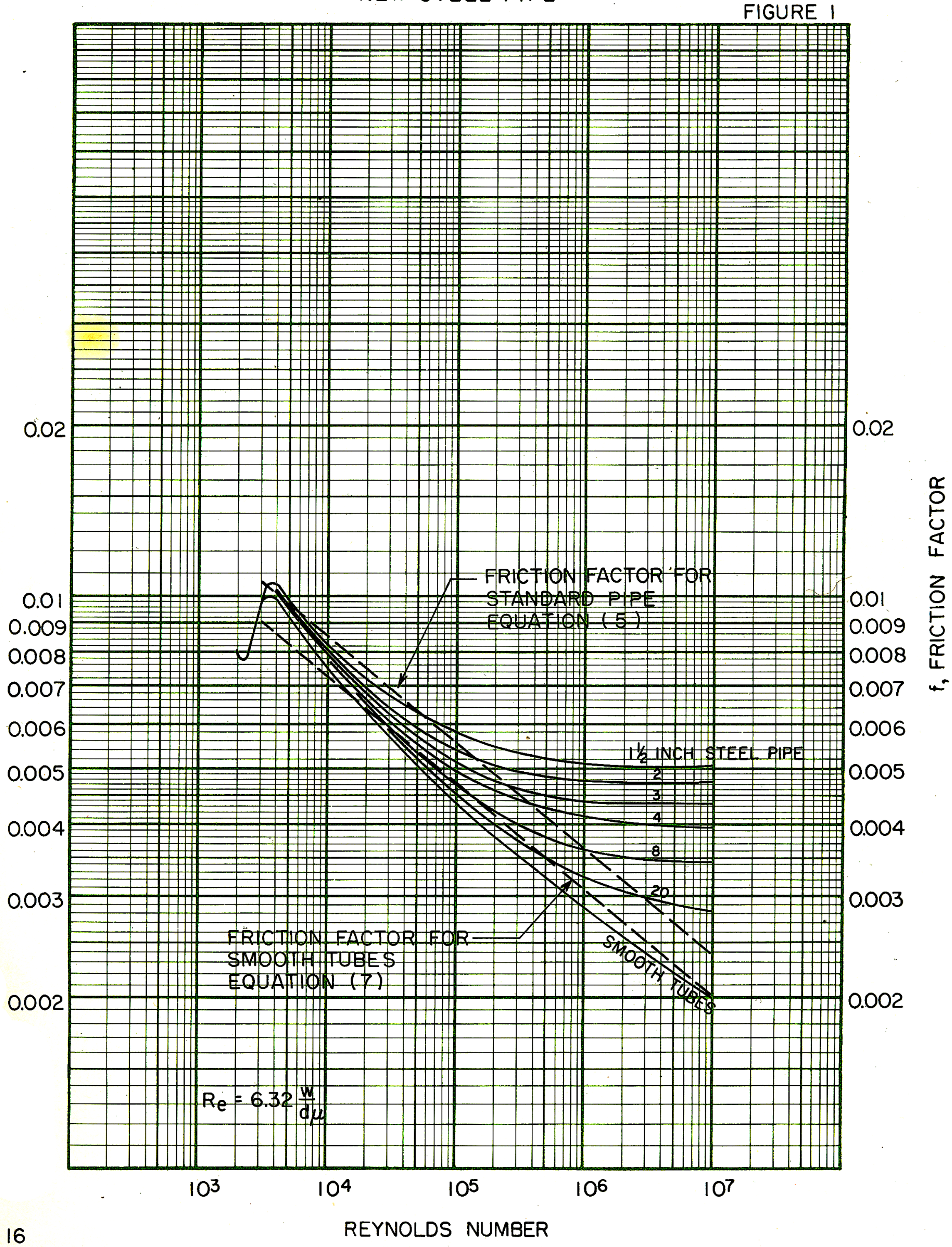
FRICTION FACTORS
NEW STEEL PIPE

FIGURE 1



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FRICTION FACTOR CORRECTION
FOR STANDARD PIPE

FIGURE 2

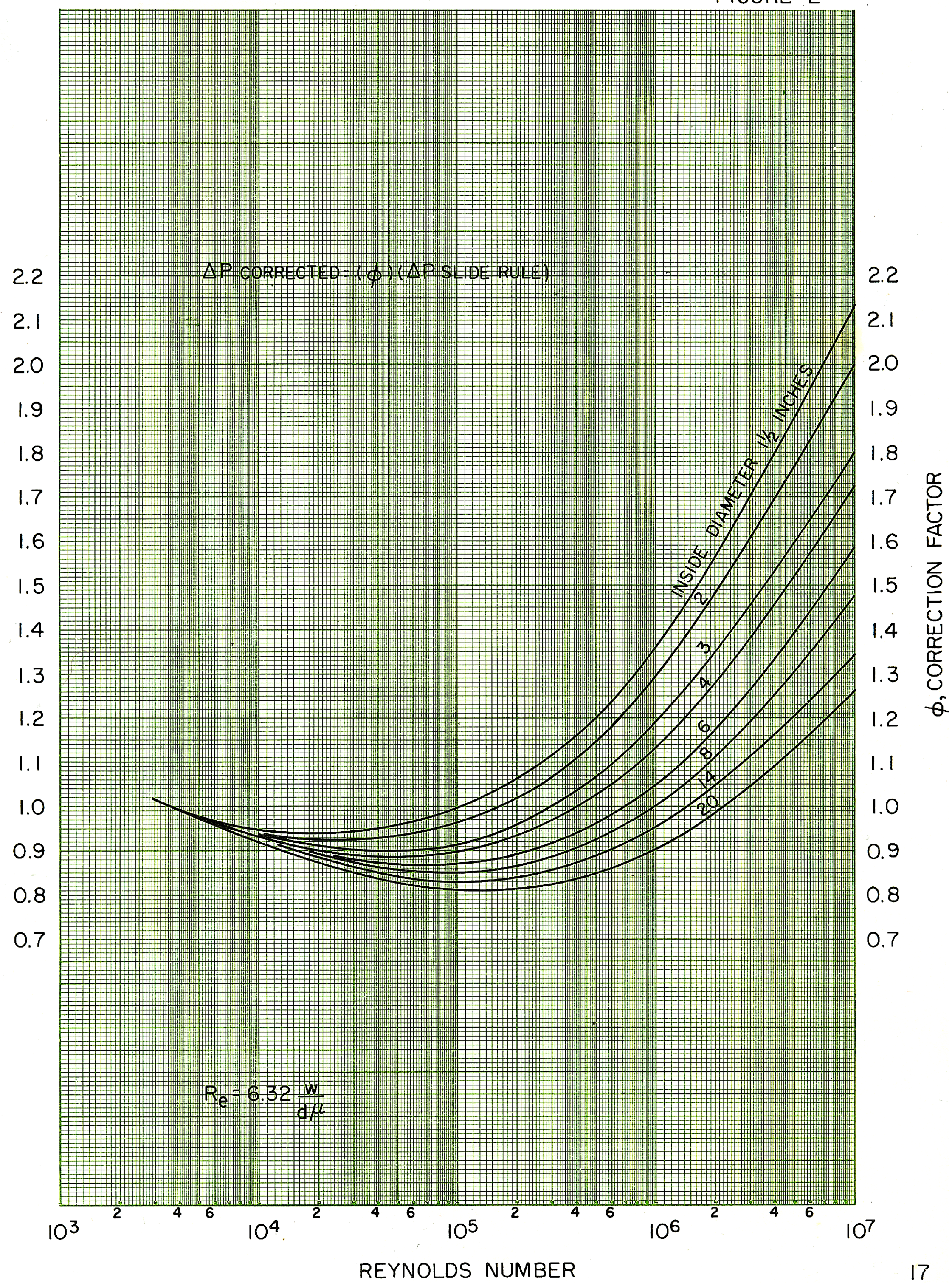
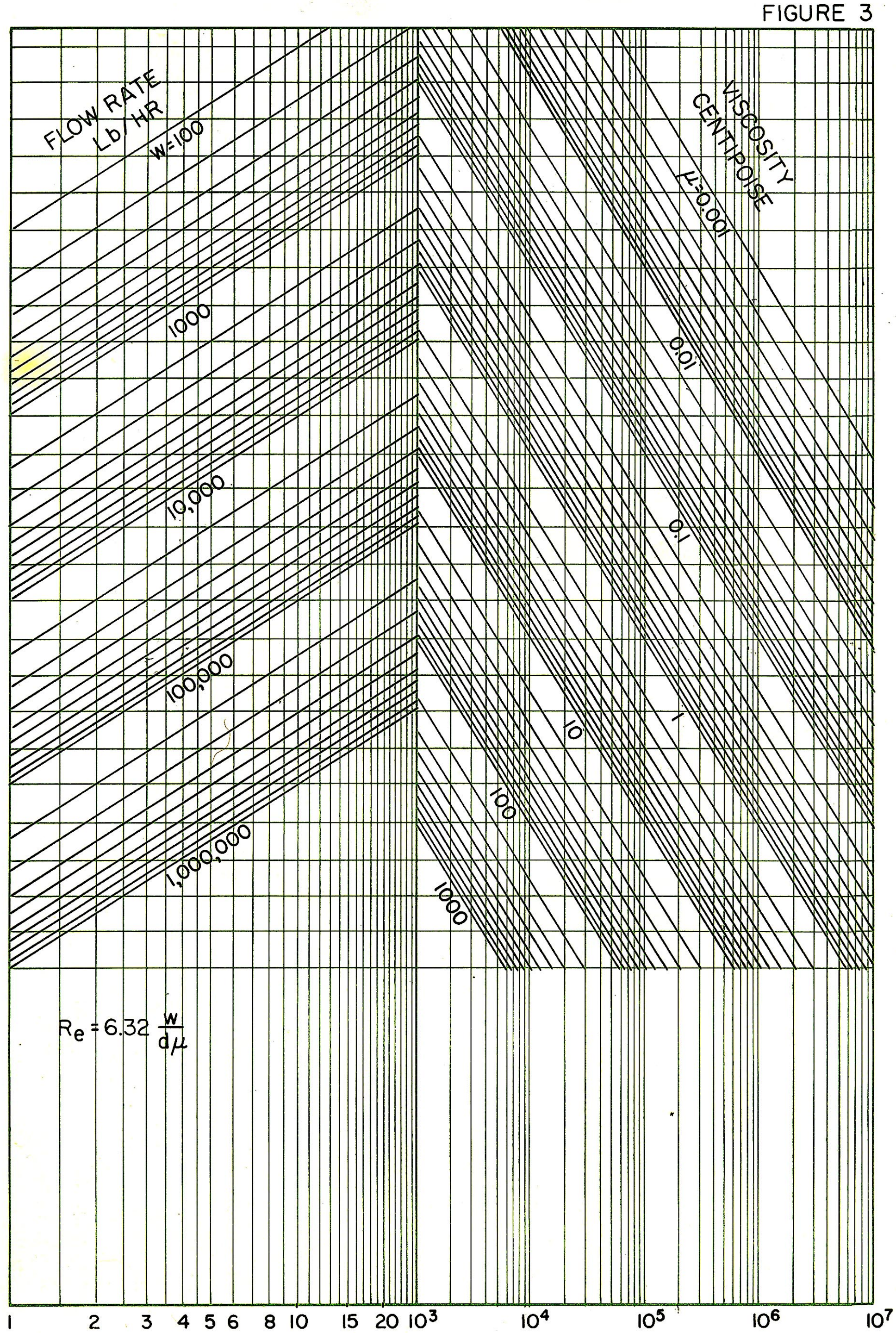


CHART FOR REYNOLDS NUMBER

FIGURE 3



PROCESS OPERATIONS

Absorption
Adsorption
Agglomeration
Agitation
Alkylation
Ammonolysis
Aromatization
Azeotropic distillation
Bromination
Calcination
Catalytic cracking
Catalytic reforming
Centrifugation
Chlorination
Coking
Countercurrent decantation
Crushing and grinding
Crystallization
Dehydration
Dehydrogenation
Distillation
Dust collection
Electrolysis
Electrostatic separation
Evaporation
Extrusion
Filtration
Flotation
Fluid-bed reduction
Fluidized solids handling
Fractionation
Friedl-Crafts reaction
Gangue disposal
Granulation
Halogenation
Heat transfer
High-pressure metallurgy
High-level heat recovery
Hydrocracking
Hydroforming
Hydrogenation
Hydrolysis
Hydrotreating
Isomerization
Joule-Thompson refrigeration
Leaching
Low-temperature fractionation
Low and high-pressure synthesis
Magnetic separation
Mechanical separation
Methanation
Methane chlorination
Neutralization
Oxidation
Oxychlorination
Oxythermal process
Packaging
Phosphoric hydration
Polymerization
Precipitation
Prilling
Pyrolysis
Retorting
Screening
Sedimentation
Shift conversion
Smelting
Solvent extraction
Solvent purification
Steam cracking
Sublimation
Sulfation
Sulfuric acid hydrolysis
Superfractionation
Thermal cracking
Thermal dehydrochlorination
Thermal partial oxidation
Thickening
Treating

CHEMICALS AND MINERALS

Acetone
Acetylene
Acrylonitrile
Adipic acid
Allyl alcohol
Allyl chloride
Alumina
Ammonia
Ammonium nitrate
Ammonium sulfate
Asbestos
Benzene
Borax
Butadiene
Butylene
Butyl alcohol
Butyl rubber
Calcium carbide
Carbon black
Carbon dioxide
Carbon tetrachloride
Chlorine
Chloroform
Chloromethanes
Cobalt
Copper
Cresylic acids
Cyclohexane
Cumene
Diacetone alcohol
Diallyl phthalate
Dimethoxyethyl phthalate
Dimethylterephthalate
Dodecylbenzene
Ethanolamines
Ethyl alcohol
Ethyl chloride
Ethylene
Ethylene diamine
Ethylene dichloride
Ethylene glycol
Ethylene oxide
Fertilizers
Glycerine
Gold
Helium
Hexamethylene diamine
Hydrogen
Hydrogen peroxide
Iron
Isobutylene
Isooctyl alcohol
Isoprene
Isopropyl alcohol
Isopropyl ether
Levulinic acid
Lignite
Lithium
Magnesia
Manganese
Mercury
Mesityl oxide
Methane
Methanol
Methyl chloride
Methyl ethyl ketone
Methyl isobutyl carbinol
Methyl isobutyl ketone
Methylene chloride
Morpholine
Naphthalene
Nickel
Nitric acid
Nitrogen
Octyl alcohol
Ortho-xylene
Para-xylene
Perchlorethylene
Phenol
Phosphates
Phosphoric acid
Phosphorus
Phthalic anhydride
Piperazine
Polyolefins
Polyester
Polystyrene
Polyvinyl chloride
Potash
Potassium carbonate
Propylene
Propylene tetramer
Sodium carbonate
Sodium chlorate
Sodium cyanide
Sodium sulfate
Styrene
Sulfur
Sulfuric acid
Synthetic rubber
Tantalum
Terephthalic acid
Tetraethyl lead
Thorium
Titanium
Toluene
Toluene diisocyanate
Trichlorethylene
Uranium
Urea
Vinyl chloride
Zinc