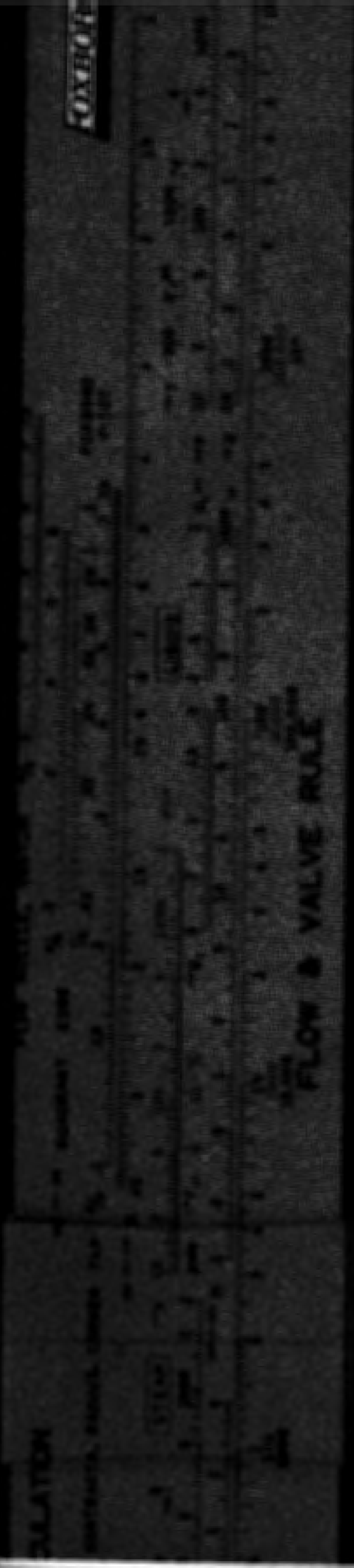

English Units

THE USE OF THE FOXBORO FLOW AND VALVE RULE

THE FOXBORO FLOW AND VALVE RULE

The Foxboro Flow and Valve Rule provides a quick, convenient means of accomplishing a wide variety of valve and flow calculations. Here is a precision-crafted product which will save you hours of time on your computation work.

Use of the Flow and Valve Rule is made simple by the numbered identification of scales on the rule and by color code identification. Operation of the rule follows the steps numbered on the rule in sequence, alternating cursor and slide operations. This, combined with color codes of Black (for liquid and certain common scales), Red (for steam and vapor), and Blue (for gas), enables use of the rule with a minimum of reference to the manual.

. . . Special conversion scales enable the use of units other than those found on the main scales of the rule.

. . . Corrections are included on the rule for superheated steam calculations, and for displaced columns of fluid in mercury meter calculations.

. . . The "FLOW" and "Cv" scales may be used as a conventional slide rule for multiplication and division.

. . . Equivalent values of specific volume and saturated steam pressures can be read directly.

. . . All fluids can be handled in terms of either volume or weight units.

The Flow and Valve Rule is 12 inches long and is solidly constructed of plastic free from the effects of thermal contraction or expansion. It comes complete with heavy brown leather carrying case.

For ordering information, contact the Foxboro office nearest you, or

THE FOXBORO COMPANY, FOXBORO, MA U.S.A. 02035

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CONTENTS

SECTION 1

THE FUNCTIONS OF THE FOXBORO FLOW AND VALVE RULE

This rule has been developed as a convenient means for determining the following:

1. A suitable d/D ratio for a selected set of flow parameters and differential pressure values.
2. A differential pressure value for a specific size primary device and a given set of flow parameters.
3. Control valve trim size.
4. Reynolds numbers.
5. An adequate and suitable meter run size.

In addition the rule may be used to convert flow units in a variety of engineering terms and to determine "S" values.

SPECIAL SCALES

The Foxboro Flow and Valve Rule is equipped with special scales for superheated steam calculations, and to enable the use of the rule when the flow is known in units other than those on the main scales. Instructions for the use of these scales are given below. For convenience, portions of these instructions are reprinted in various appropriate sections of this manual.

Volumetric Conversion Scale

This conversion scale is located near the right-hand end of the slide (see illustration page 10). This scale enables conversion of liquid flow from U.S. gallons per hour, Imperial gallons per hour, barrels per day, or U.S. gallons per day to U.S. gallons per minute. Gas flow may be converted from standard cubic feet per minute or standard cubic feet per day to standard cubic feet per hour.

To convert liquid flow to gpm:

a. Multiply the known gpd by 0.001 or
Multiply the known bbl/day by 0.1 or
Multiply the known gph by 0.1 or
Multiply the known IMP. gph by 0.1.

b. Set the *cursor* to the value obtained in step a. on the "FLOW" scale (black numbers), on the "FLOW CALCULATIONS" side of the rule.

c. Turn the rule over and move the *slide* so the black diamond (♦) on the conversion scale coincides with the hairline.

d. Move the *cursor* to the reference mark corresponding to the known units of flow (1000 gpd, 10 bbl/day, 10 gph, or 10 IMP. gph). This locates the *cursor* at the correct value of flow in gpm.

e. Turn the rule over again and read the value (black numbers) on the "FLOW" scale. This is the flow in gpm.

To convert gas flow to scfh:

a. Multiply the known scfm by 100 or
Multiply the known scfd by 0.1.

b. Set the *cursor* to the value obtained in step a on the "FLOW" scale (blue numbers).

c. Turn the rule over and move the *slide* so that the black diamond (♦) on the conversion scale coincides with the hairline.

d. Move the *cursor* to the reference mark corresponding to the known units of flow (10 scfd or .01 scfm). This locates the cursor at the correct value of flow in scfh.

e. Turn the rule over again and read the value (blue numbers) on the "FLOW" scale. This is the flow in scfh.

Weight to Volume Conversion Scale

The "THOUSAND lb/h LIQUID SP. GR." scale is located near the left-hand end of the slide on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule. This scale enables conversion of liquid flow from pounds per hour to gallons per minute (or from gallons per minute to pounds per hour), when the specific gravity of the liquid is known.

To convert to gpm:

a. Multiply the known flow in lb/h by 0.001.

b. Using the "FLOW" scale on the "FLOW CALCULATIONS" side of the rule (black numbers), set the *cursor* to the value obtained in step a.

c. Turn the rule over and move the *slide* so the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale coincides with the hairline.

d. Move the *cursor* to the value of specific gravity on the "THOUSAND lb/h LIQUID SP. GR." scale.

e. Turn the rule over again. Read the value (black numbers) on the "FLOW" scale. This is the flow in gpm.

To convert to pounds per hour:

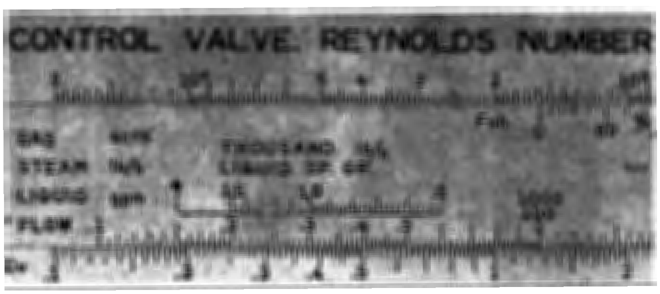
a. Set the *cursor* to the value of flow in gpm on the "FLOW" scale (black numbers) on the "FLOW CALCULATIONS" side of the rule.

b. Turn the rule over and move the *slide* so the value of specific gravity on the "THOUSAND lb/h LIQUID SP. GR." scale coincides with the hairline.

c. Move the *cursor* to the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale.

d. Turn the rule over again and read the value (black numbers) on the "FLOW" scale.

e. Multiply this value by 1000 to obtain the flow in pounds per hour.



"THOUSAND lb/h LIQUID SP. GR." Scale

Superheat Correction Factor Scale

The "F_{sh}" scales enable the use of the saturated steam scales on the rule for superheated steam calculations. The SUPERHEAT CORRECTION FACTOR (F_{sh}) is defined in the following equation:

$$F_{sh} = \left(1 - \frac{\text{sp. wt. of superheated steam}}{\text{sp. wt. of sat. steam at the same pressure}}\right) \times 100$$

F_{sh} values are listed in tabular form in Fig. 1. The F_{sh} value for saturated steam is ZERO.

In flow calculations, the "F_{sh}" scale is used as one of the numbered steps. Setting the cursor to ZERO on the scale allows for saturated steam calculations. Setting the cursor to another value corrects for superheat.

In control valve calculations, F_{sh} correction must be inserted as two extra steps between steps 3 and 4. After step 3, move the *slide* so ZERO on the "F_{sh}" scale coincides with the hairline. Then, move the *cursor* to the F_{sh} value determined from Fig. 1.

CURSOR HAIRLINES

Two small hairlines are located to the left of the major hairline on the "FLOW CALCULATION" side of the rule (see illustration on page 10). These hairlines enable correction for the weight of the column of fluid above the mercury in a mercury meter. This correction is necessary only when a mercury meter is used, and it is only necessary when the flowing fluid is liquid or steam, or when a liquid sealing fluid is used with gas flow. This correction is called "F_m" correction. It is not needed when air or gas purges are used with liquid flow measurements.

The specific gravity (G_s) of the liquid in the meter must be known. For water (or steam condensate), $G_s = 1$; for other liquids, it may be determined from engineering handbooks.

The correction is made when the cursor is set to the pipe diameter (D) in flow calculations. (For a convenient guide to values of line diameter, refer to Figure 4.) When no F_m correction is required the major hairline is set to the diameter. When $G_s = 1$, the small hairline immediately to the left of the major hairline is set to the diameter. When $G_s = 2$, the small hairline which is farther to the left of the major hairline is set to the diameter. Settings for other values of G_s may be estimated using the above as a reference. In any case, the d/D and r/D values are read as those numbers which coincide with the major hairline.

ADDITIONAL CORRECTION FACTORS

It will be obvious that some small correction factors generally included in precise flow calculations, when done manually or by computer, are not built into the rule. These include such corrections as:

a. viscosity and low flow effects (Reynolds number correction, F_c or F_r)

b. orifice area variations with temperature, F_a

c. isentropic expansion factor corrections (Y) for steam, vapor and gas flow calculations

d. use of standard conditions for gases other than 60F and 14.73 psia (F_{tb} and F_{pb})

e. gas supercompressibility (F_{pv})

When it is determined such factors are of a magnitude to require correction, it is only necessary to use an adjusted value of the desired flow rate. For instance:

a. Knowing flow rate and differential — and it is desired to find d/D; divide the flow rate by the correction factor and set the adjusted flow rate on the rule.

b. When flow rate is to be determined knowing d/D and differential pressure, read the indicated flow rate from the rule and multiply by the correction factors.

c. When the flow rate and d/D ratio are known and it is desired to find the differential pressure produced — divide the flow rate by the correction factors involved and set the adjusted rate on the rule.

Values of the correction factors may be taken from The Foxboro Company's handbook, **Principles and Practice of Flow Meter Engineering.**

SECTION 2

FLOW CALCULATIONS: RULES OF THUMB

Flow measurement problems for which flow calculations are made have so many possible variations and requirements that no hard and fast rules can be applied. For every rule that one brings forth, there are applications which are exceptions and which require special attention.

Certain time-honored rules continue to apply to general "good practice". These are:

1. For gas-flow calculations, select a differential pressure (H) in inches of water for an H/P ratio equal to, or less than one (1), where P is the static pressure in psia. This minimizes coefficient variations.
2. Hold d/D ratios within the limits shown on the flow rule to maintain accepted tolerance values and to minimize disturbance effects from the approach piping configuration.
3. For liquid flow calculations, 100″ H_2O differential pressure is the most commonly used value.

4. In gas flow calculations, use the downstream pressure to minimize coefficient variations.

NOTE: If the maximum flow rate or the pipe diameter are too large to be entered on the rule, use as the flow rate 1/100 the actual flow rate, and use as the diameter 1/10 the actual diameter.

DETERMINATION OF THE "BETA RATIO" OR "d/D RATIO" FOR LIQUIDS

Required Information:

Q_m = Maximum volumetric flow rate corresponding to full scale on chart (gpm)

G_l = Specific Gravity of Fluid at reference temperature

D = Actual Pipe I.D. (inches)

G_f = Specific Gravity of Fluid at Flowing Temperature

H = Differential pressure (inches of water, dry calibration)

G_s = Specific gravity of the fluid on the mercury surface of a mercury type meter

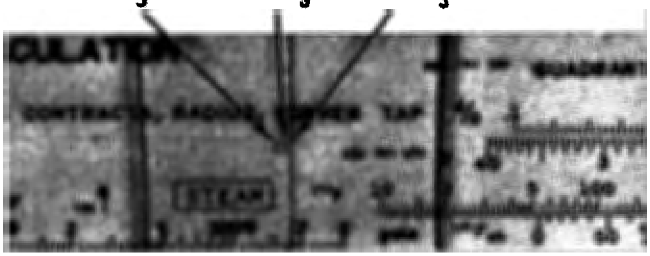
For a convenient guide to the location of steps on the rule, refer to Figure 6. Follow the steps in black parentheses (1), (2), (3), (4), (5), (6) on the "FLOW CALCULATION" side of the rule:

1. Set the *cursor* to the given value of flow (in gpm) on the "FLOW" scale (1) using the black numbers. (If flow is known in units other than gpm, see conversion instructions below.)
2. Move the *slide* so the given value of the differential pressure (H) on the "H" scale (2) coincides with the hairline.
3. Move the *cursor* to the given value of G_l on the "G_l" scale (3).
4. Move the *slide* so the given value of G_f on the "G_f" scale (4) coincides with the hairline.
5. Move the *cursor* to the given value of pipe inside diameter in inches on the "D" scale (5). (Note: For mercury meter calculations see F_m correction instructions below.)
6. Read the d/D Ratio from the appropriate "d/D"

scale on the upper portion of the rule. This group of three "d/D" scales is marked with a black (6): When the primary device is a quadrant edge orifice plate, the "r/D" ratio may also be read from the scale marked "r/D". If pipe taps are used, determine the flange d/D and then use Figure 3 to determine the equivalent pipe tap d/D. If a Penn Lo-Loss tube is used, determine Venturi d/D and refer to Figure 5 for correlation to Lo-Loss.

If the meter is a mercury meter, F_m correction is needed. Change step 5 (above) as follows: If $G_s = 2$, instead of setting the main hairline to the given value of D, set the short hairline which is farther from main hairline to the given value of D. If $G_s = 1$, set the short hairline which is nearer the main hairline to the given value of D. In either case, read d/D and r/D, as the quantities which coincide with the main hairline.

G_s=2 G_s=1 G_s=0

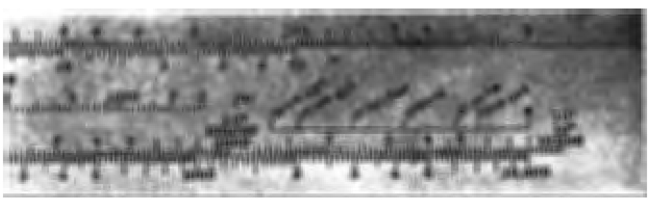


If flow is known in U.S. gph, IMP. gph, bbl/day, or gpd, conversion to gpm is made as a preliminary step in the following manner:

1a. Multiply the known gpd by 0.001 or
Multiply the known bbl/day by 0.1 or
Multiply the known gph by 0.1 or
Multiply the known IMP. gph by 0.1.

1b. Set the *cursor* to the value obtained in step 1a on the "FLOW" scale (black numbers), on the "FLOW CALCULATIONS" side of the rule.

1c. Turn the rule over and move the *slide* so the black diamond (♦) on the conversion scale coincides with the hairline.



Conversion Scale

1d. Move the *cursor* to the reference mark corresponding to the known units of flow (1,000 gpd, 10 bbl/day, 10 gph, or 10 IMP. gph). This locates the cursor at the correct value of flow in gpm.

1e. Turn the rule over again and continue with calculation steps 2 through 6.

If the flow is known in lb/hour and the specific gravity is known, conversion to gpm is made as a preliminary step in the following manner:

1a. Multiply the known lb/h by 0.001.

1b. Set the *cursor* to the value obtained in step 1a on the "FLOW" scale (black numbers).

1c. Turn the rule over and move the *slide* so the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale coincides with the hairline.

1d. Set the *cursor* to the specific gravity on the "THOUSAND lb/h LIQUID SP. GR." scale. This locates the cursor at the correct value of flow in gpm.

1e. Turn the rule over again and continue with steps 2 through 6.

DETERMINATION OF THE "BETA RATIO" OR "d/D RATIO" FOR STEAM

Required Information:

W_m = Maximum flow rate corresponding to full scale on chart (lb/h)

D = Pipe I.D. (Inches)

H = Differential Pressure (Inches of water, dry calibration)

P = Pressure (psia)

T = Temperature (F) (not required if steam is saturated)

For a convenient guide to the location of steps on the rule, refer to Figure 6. Follow the steps numbered in red parentheses (1), (2), (3), (4), (5), (6) on the "FLOW CALCULATION" side of the rule:

1. Set the *cursor* to the given value of flow in pounds per hour on the "FLOW" scale (1), using the red scale numbers.

2. Move the *slide* so the hairline coincides with the given value of differential pressure (H) in inches of water on the "H" scale (2).

3. Move the *cursor* to the F_{sh} value on the "F_{sh}" scale (3). For saturated steam, the F_{sh} value is zero (0); for superheated steam, the F_{sh} value is taken from the "SUPERHEAT CORRECTION FACTOR TABLE" (Fig. 1).

4. Move the *slide* so the value of pressure in psia on the red "P" scale (4) coincides with the hairline.

5. Move the *cursor* so that the hairline coincides with the actual pipe I.D. in inches on the "D" scale (5). (Note: For mercury meter calculations, see F_m correction instructions below.)

6. Read the d/D Ratio from the appropriate "d/D" scale on the upper portion of the rule. This group of three "d/D" scales is marked with a red (6).

   If pipe taps are used, determine the flange d/D and then use Figure 3 to determine the equivalent pipe d/D. If a Penn Lo-Loss tube is used, determine Venturi d/D and refer to Figure 5 for correlation to Lo-Loss.

If the meter is a mercury meter, F_m correction is needed. Change step 5 as follows: Instead of setting the main hairline to the given value of D, set the short hairline immediately to the left of the main hairline, to the given value of D. Read d/D as the quantity which corresponds with the main hairline.

CALCULATION OF "BETA RATIO" OR "d/D RATIO" FOR VAPORS OTHER THAN STEAM

A vapor is defined here as a gas which does not closely follow the Ideal Gas Laws. In many instances, vapors may be in the liquid phase at standard conditions. Sulfur dioxide, chlorine, and the freons are among such vapors, and are commonly calculated using weight units.

Calculation follows the procedure for steam using the steps numbered in red parentheses, with the following exception: do not use the actual pressure in step (4). Use instead, a quantity "P" which is determined in the following manner.

a. Using accepted engineering handbooks, determine the specific volume of the vapor in cubic feet per pound at the flowing conditions.

b. Locate, on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule, the "V" scale and the "STEAM P_2" scale.

c. Set the cursor to the specific volume (determined in "a" above) on the "V" scale.

d. Read the quantity "P" as the number on the "STEAM P_2" scale which coincides with the hairline. Use this quantity "P" in following the steps numbered in red parentheses on the "FLOW CALCULATION" side.

The quantity "P" is not the pressure of the vapor. It is merely a number which allows the user to enter the specific volume into the calculation even though there is no specific volume scale on the "FLOW CALCULATION" side of the rule. In actuality, "P" is the equivalent saturated steam pressure.

DETERMINATION OF THE "BETA RATIO" OR "d/D RATIO" FOR GASES

The accuracy of the results depends upon how closely the gas follows the Ideal Gas Law.

Required Information:

Q_m = Maximum volumetric flow rate corresponding to full scale of chart (scfh)

G = Specific Gravity (Relative to air)

D = Pipe I.D. (Inches)

T = Temperature (F)

H = Differential Pressure (Inches of Water, dry calibration)

P = Maximum Pressure (psia)

For a convenient guide to the location of steps on the rule, refer to Figure 6. Follow the steps numbered in blue parentheses (1), (2), (3), (4), (5), (6), (7), (8) on the "FLOW CALCULATION" side of the rule:

1. Set *cursor* to the given value of flow in scfh on the "FLOW" scale (1), using the blue scale numbers. (If flow is known in scfm or scfd, see conversion instructions below.)

2. Move *slide* so given value of the differential pressure (H) on the "H" scale (2) coincides with the hairline.

3. Move the *cursor* to the given value of specific gravity on the blue "G" scale (3). Note that there

are 2 sets of blue scales marked (3), (4), (5), (6), one at each end of the rule. Either set may be used, but *both* are not used in a given calculation. The magnitude of the quantities used in Steps (1) and (2) may position the slide so that one set cannot be used. Use the other.

4. Move the *slide* so the given value of absolute pressure on the blue "P" scale (4) coincides with the hairline.
5. Move the *cursor* to the given value of temperature in degrees Fahrenheit on the "T" scale (5).
6. Move the *slide* so the blue diamond (♦) which is marked (6) coincides with the hairline.
7. Move the *cursor* to the actual pipe I.D. on the "D" scale (7).
8. Read d/D from the appropriate "d/D" scale on the upper portion of the rule. This group of three "d/D" scales is marked with a blue "(8)": (Note: If AGA Report No. 3 procedures are being used, correction from Figure 2 should be added to this value.)

   If pipe taps are used, determine the flange d/D and then use Figure 3 to determine the equivalent pipe d/D.

If flow is known in scfm or scfd, conversion to scfh is made as a preliminary step in the following manner:

1a. Multiply the known scfm by 100 or
Multiply the known scfd by 0.1.

1b. Set the *cursor* to the value obtained in step 1a on the "FLOW" scale (blue numbers), on the "FLOW CALCULATIONS" side of the rule.

1c. Turn the rule over and move the *slide* so that the black diamond (♦) on the conversion scale coincides with the hairline.

1d. Move the *cursor* to the reference mark corresponding to the known units of flow (10 scfd or .01 scfm). This locates the cursor at the correct value of flow in scfh.

1e. Turn the rule over again and continue with calculation steps 2 through 8.

OPTIONAL CALCULATIONS WHERE DIFFERENTIAL PRESSURE OR FLOW RATE IS THE UNKNOWN

The Foxboro Flow and Valve Rule may be used to determine the maximum flow rate or the maximum differential pressure when the d/D ratio is known. To determine flow, follow the numbered steps in reverse order, starting with a cursor operation and alternating slide and cursor operations. To determine differential pressure follow this same reverse procedure, but move the cursor to flow (rather than H) and read H (rather than flow) as the final two steps.

To determine H or flow when the primary device is a Foxboro Pitot Tube follow the above procedure, but set the cursor to the "FOXBORO PITOT" mark rather than to a "d/D Ratio".

When the primary device is a Penn Lo-Loss tube, see Figure 5.

LIQUID FLOW d/D RATIO

EXAMPLE 1

Fluid: Water

Max. Flow Rate: 2,000 U.S. gpm

Max. Differential: 100 inches of water

Specific Gravity at 60F (G_l) :1.0

Specific Gravity at Flowing Temperature (G_f) :1.0

Line Size: 10.02 inch I.D.

Primary Device: Square Edged Orifice Plate

Meter Type: d/p Cell® Transmitter

Taps: Flange

Follow the steps numbered in black parentheses on the "FLOW CALCULATION" side:

1. Set the *cursor* to 2000 (black numbers) on the "FLOW" scale.
2. Move the *slide* so 100 on the "H" scale coincides with the hairline.
3. Move the *cursor* to 1.0 on the "G_l" scale.
4. Move the *slide* so 1.0 on the "G_f" scale coincides with the hairline.
5. Move the *cursor* to 10.02 on the "D" scale.
6. Read .702 on the "FLANGE, etc. d/D" Scale as the d/D value.

To obtain the bore of the orifice plate, multiply d/D by Pipe I.D.:

.702 x 10.02" = 7.034"

LIQUID FLOW d/D RATIO

EXAMPLE 2

Fluid: Kerosene

Max. Flow Rate: 900 bbl/day (1 bbl = 42 U.S. Gallons)

Max. Differential: 100 inches of water

Specific Gravity at 60 F (G_l): .816

Flowing Temperature: 200 F

Specific Gravity at Flowing Temperature (G_f): .757

Line Size: 2.067" Pipe I.D.

Primary Device: Square Edged Orifice Plate

Meter Type: Mercury Meter using seal of Prestone liquid and water

Specific Gravity of Sealing Fluid (G_s): 1.06

Taps: Flange

Follow the steps numbered in black parentheses on the "FLOW CALCULATIONS" side. The conversion scale must be used to change bbl/day to gpm. The short cursor hairlines must be used to make "Fm" correction for the weight of the seal fluid above the Mercury.

1a. Multiply 900 by 0.1 to obtain 90.

1b. Set the *cursor* to 90 on the "FLOW" scale (black numbers).

1c. Turn the rule over to the "CONTROL VALVE, REYNOLDS NUMBER" side, and locate the conversion scale which is near the right-hand end of the slide. Move the *slide* so the black diamond (♦) on this scale coincides with the hairline.

1d. Move the *cursor* to the "10 bbl/day" mark on this conversion scale. Turn the rule over again. Note that the hairline is now located at 26.3 (black numbers) on the "FLOW" scale. This is the flow in gpm.

2. Move the *slide* so 100 on the "H" scale coincides with the hairline.

3. Move the *cursor* to .816 on the "G_l" scale.

4. Move the *slide* so .757 on the "G_f" scale coincides with the hairline.

5. Move the *cursor* to 2.067 on the "D" scale. Do not, however, set the main hairline on 2.067. Set the small hairline which is immediately to the left of the main hairline on 2.067. This makes an "F_m" correction for $G_s = 1$. The actual value of G_s is 1.06, but the difference between calculations based on $G_s = 1$ and $G_s = 1.06$ is too small to be detected.

6. Read .416 on the "FLANGE, etc. d/D" scale as the d/D value. Note that d/D value is taken as that which corresponds with the main hairline even though one of the small hairlines is set on the Pipe I.D.

To obtain the bore of the orifice plate, multiply d/D by Pipe I.D.:

.416 x 2.067" = 0.860"

LIQUID FLOW d/D RATIO

EXAMPLE 3

Fluid: Oil

Max. Flow Rate: 18,000 lb/h

Max. Differential: 100 inches of water

Flowing Temperature: 100F

Specific Gravity at Flowing Temperature (G_f): 0.82

Line Size: 2.900" I.D.

Primary Device: Quadrant Edged Orifice Plate

Meter Type: d/p Cell® Transmitter

Taps: Flange

Follow the steps numbered in black parentheses on the "FLOW CALCULATIONS" side. The "THOUSAND lb/h LIQUID SP. GR." scale must be used to convert lb/h to gpm.

1a. Multiply 18,000 by .001 to obtain 18.

1b. Set the *cursor* to 18 (black numbers) on the flow scale.

1c. Turn the rule over to the "CONTROL VALVE, REYNOLDS NUMBER" side and locate the

"THOUSAND lb/h LIQUID SP. GR." scale which is near the left-hand end of the slide. Move the *slide* so the black diamond (♦) on this scale coincides with the hairline.

1d. Move the *cursor* to 0.82 on this scale. Note the specific gravity at the flowing temperature (G_f) is used, not the specific gravity at 60F (G_l). Turn the rule over again. The hairline is now at 43.9 (black numbers) on the "FLOW" scale. This is the flow in gpm.

2. Move the *slide* so 100 on the "H" scale corresponds with the hairline.

3. Move the *cursor* to 0.82 on the "G_l" scale.

4. Move the *slide* so 0.82 on the "G_f" scale corresponds with the hairline.

5. Move the *cursor* to 2.900 on the "D" scale.

6. Read .327 on the "QUADRANT EDGE d/D" scale as the d/D value. Read .0347 on the "QUADRANT EDGE r/D" scale as the r/D value.

To obtain the bore diameter of the orifice, multiply d/D by Pipe I.D.:

.327 x 2.900″ = .948″

To obtain the edge radius, multiply r/D by the Pipe I.D.:

.0347 x 2.900″ = .101″

SATURATED STEAM FLOW d/D RATIO

EXAMPLE 4

Fluid: Saturated Steam

Max. Flow Rate: 40,000 lb/h

Max. Differential: 200 inches of water

Static Pressure: 335 psig (barometric pressure, 14.7 psia)

Line Size: 6.813″ I.D.

Primary Device: Square Edged Orifice Plate

Meter Type: d/p Cell® Transmitter

Taps: Flange

Follow the steps numbered in red parentheses on "FLOW CALCULATION" side:

1. Set the *cursor* to 40,000 (red numbers) on the "FLOW" scale.

NOTE: 40,000 (red) is the black "4" located between the red 10,000 and the red 100,000.

2. Move the *slide* so 200 on the "H" scale coincides with the hairline.

3. Move the *cursor* to zero (0) on the "F_{sh}" scale.

4. Move the *slide* so 349.7 psia (335 psig + 14.7) on the "P" scale coincides with the hairline.

5. Move the *cursor* to 6.813 on the "D" scale.

6. Read 0.552 from the "FLANGE, etc. d/D" scale as d/D value.

To obtain the bore diameter of the orifice, multiply d/D by the I.D.:

.552 x 6.813″ = 3.761″

SUPERHEATED STEAM FLOW d/D RATIO

EXAMPLE 5

Fluid: Superheated Steam at 460 F

Max. Flow Rate: 1000 lb/h

Max. Differential: 50 inches of water

Static Pressure: 150 psia

Line Size: 2.469″ I.D.

Primary Device: Square Edged Orifice Plate

Meter Type: d/p Cell® Transmitter

Taps: Flange

A superheat correction factor (F_{sh}) must be obtained from the "SUPERHEAT CORRECTION FACTOR TABLE" (Fig. 1). For 460 F the table gives F_{sh} values of 17 for 100 psia and 11 for 200 psia. Since the pressure is 150 psia, interpolate to obtain an F_{sh} value of 14.

Follow the steps numbered in red parentheses on the "FLOW CALCULATIONS" side:

1. Set the *cursor* to 1,000 (red numbers) on the "FLOW" scale.

2. Move the *slide* so 50 on the "H" scale coincides with the hairline.

3. Move the *cursor* to 14 on the "F_{sh}" scale.
4. Move the *slide* so 150 psia on the "P" scale coincides with the hairline.
5. Move the *cursor* to 2.469 on the "D" scale.
6. Read .442 from the "FLANGE, etc. d/D" scale as the d/D value.

To obtain the bore diameter of the orifice, multiply d/D by the I.D.:

.442 x 2.469″ = 1.091″

VAPOR FLOW d/D RATIO

EXAMPLE 6

Fluid: Chlorine Vapor

Max. Flow Rate: 4000 lb/h

Max. Differential: 50 inches of water

Static Pressure: 65 psig

Temperature of Flowing Fluid: 100 F

Line Size: 3.068 inch I.D.

Primary Device: Square Edged Orifice Plate

Meter Type: d/p Cell® Transmitter

Taps: Flange

From chlorine gas tables, determine specific volume = 0.9957 cu. ft/lb. Set the cursor to .9957 on the "V" scale on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule, and read 465 as P on the "STEAM P_2" scale.

Follow the steps in red parentheses on the "FLOW CALCULATIONS" side of the rule:

1. Set the *cursor* to 4000 (red numbers) on the "FLOW" scale.
2. Move the *slide* so 50 on the "H" scale coincides with the hairline.
3. Set the *cursor* to zero (0) on the "F_{sh}" scale.
4. Move the *slide* so 465 on the "P" scale coincides with the hairline. (Note that this is not the actual pressure of the vapor.)
5. Set the *cursor* to 3.068 on the "D" scale.
6. Read .515 from the "FLANGE, etc. d/D" scale as the d/D value.

To determine the bore diameter, multiply d/D by the Pipe I.D.:

.515 x 3.068″ = 1.580″

GAS FLOW d/D RATIO

EXAMPLE 7

Fluid: Air, Specific Gravity = 1

Max. Flow Rate: 40,000 scfh

Max. Differential: 20 inches of water

Static Pressure: 100 psig (barometric pressure, 14.7 psia)

Line Size: 4.026″ I.D.

Flowing Temperature: 90 F

Primary Device: Flow Nozzle

Meter Type: d/p Cell® Transmitter

Follow the steps numbered in blue parentheses on the "FLOW CALCULATIONS" side of the rule:

1. Set the *cursor* to 40,000 (blue numbers) on the "FLOW" scale.
2. Move the *slide* so 20 on the "H" scale coincides with the hairline.
3. Move the *cursor* to 1 on the blue "G" scale. Note: In this particular case either of the two blue "G" scales may be used. Once the user chooses one of the two blue "G" scales for step 3 he must use scales located at the same end of the slide for steps 4, 5 and 6.
4. Move the *slide* so 114.7 psia (100 psig + 14.7) on the blue "P" scale corresponds with the hairline.
5. Move the *cursor* to 90 on the "T" scale. (Note that there are five division lines between 0 and 500 F; these denote 60, 100, 200, 300 and 400 F.)
6. Move the *slide* so the blue diamond (♦) corresponds with the hairline.
7. Move the *cursor* to 4.026 on the "D" scale.
8. Read .397 as the d/D ratio of the flow nozzle on the "FLOW NOZZLE, VENTURI d/D" scale.

To obtain the throat diameter of the flow nozzle, multiply d/D by Pipe I.D.:

.397 x 4.026″ = 1.598″

GAS FLOW
d/D RATIO

EXAMPLE 8

Fluid: Fuel Gas, Specific Gravity 0.88

Max. Flow Rate: 5,000,000 scfd

Max. Differential: 20 inches of water

Static Pressure: 40 psia

Line Size: 10.02″ I.D.

Flowing Temperature: 60 F

Primary Device: Square Edged Orifice Plate

Meter Type: Diaphragm Type Meter

Taps: Flange

Follow steps numbered in blue parentheses on the "FLOW CALCULATION" side with steps to convert scfd into scfh.

- **1a.** Multiply 5,000,000 by 0.1, obtaining 500,000
- **1b.** Set *cursor* to 500,000 (blue numbers) on the "FLOW" scale.
- **1c.** Turn the rule over to the "CONTROL VALVE, REYNOLDS NUMBER" side, and locate the conversion scale which is near the right-hand end of the slide. Move the slide so the black diamond (♦) on this scale coincides with the hairline.
- **1d.** Move the *cursor* to the "10 scfd" mark. Turn the rule over again. Note that the hairline is now located at 208,000 (blue numbers) on the "FLOW" scale. This is the flow in scfh.

2. Move the *slide* so 20 on the "H" scale coincides with the hairline.
3. Move the *cursor* to .88 on the blue "G" scale near the left-hand end of the slide. (Note that it is impossible to move the cursor to .88 on the right-hand blue "G" scale. Therefore, the user must use the left-hand set of scales for steps 3, 4, 5 and 6 for this particular problem.)
4. Move the *slide* so 40 psia on the blue "P" scale coincides with the hairline.
5. Move the *cursor* to 60 F on the "T" scale. (60 F is the first minor scale line to the right of the 0 F major scale line.)

6. Move the *slide* so the blue diamond (♦) coincides with the hairline.
7. Move the *cursor* to 10.02 on the "D" scale.
8. Read .562 on the "FLANGE, etc. d/D" scale as the "d/D" value.

To obtain the bore diameter of the orifice, multiply d/D by the I.D.:

.562 x 10.02″ = 5.631″

LIQUID FLOW
FLOW RATE

EXAMPLE 9

Fluid: Water at 60 F

Max. Differential: 100 inches of water

Specific Gravity at 60 F (G_l): 1.0

Specific Gravity at Flowing Temperature (G_f): 1.0

Line Size: 19.00 inches Pipe I.D.

Primary Device: Square Edged Orifice Plate — 10.45 inch I. D. bore

d/D Ratio: .55 (10.45/19.00)

Meter Type: d/p Cell® Transmitter

Taps: Flange

Follow the steps numbered in black parentheses on the "FLOW CALCULATION" side of the rule. However, follow these steps in reverse order:

1. Set the *cursor* to .55 on the "FLANGE, etc. d/D" scale.
2. Move the *slide* so 19.00 on the "D" scale coincides with the main hairline. Note: If a mercury meter was used, "F_m" correction would have been made at this time by moving the slide so the diameter "D" coincided with the smaller hairline closest to the main hairline.
3. Move the *cursor* to 1.0 on the "G_f" scale.
4. Move the *slide* so 1.0 on the "G_l" scale coincides with the hairline.
5. Move the *cursor* to 100 on the "H" scale.
6. Read the flow as 4000 on the "FLOW" scale (black numbers)

Note: If the primary device is a Foxboro Pitot tube, the first step will be to set the cursor to the "FOXBORO PITOT" mark rather than to .55 on the "d/D" scale.

GAS FLOW DIFFERENTIAL PRESSURE "H"

EXAMPLE 10

Flowing Fluid: Compressed Air

Max. Flow: 1,000,000 scfh

Specific Gravity: 1.0

Static Pressure: 400 psia

Temperature: 60 F

Primary Device: Square Edged Orifice Plate — 4.789 inch I.D.

Meter Type: d/p Cell® Transmitter

Line Size: 7.981" I.D.

d/D Ratio: .60 (4.789/7.981)

Taps: Flange

Follow the steps numbered in blue parentheses on the "FLOW CALCULATIONS" side. However, follow these steps in reverse order, and interchange steps 2 and 1. (i.e. steps numbered 8, 7, 6, 5, 4, 3, 1 and 2 in that order)

1. Set the *cursor* to .60 on the "FLANGE, etc. d/D" scale.
2. Move the *slide* so 7.981 on the "D" scale coincides with the hairline.
3. Move the *cursor* to the blue diamond (♦) labeled with a blue "(6)". Note: There are two sets of blue scales labeled 3, 4, 5, 6 on the rule. Use whichever set is more convenient, but do not use both sets for the same calculation.
4. Move the *slide* so the 60 F line coincides with the hairline.
5. Move the *cursor* to 400 on the blue "P" scale.
6. Move the *slide* so 1.0 on the blue "G" scale coincides with the hairline.
7. Move the *cursor* to 10^6 (blue numbers) on the "FLOW" scale.
8. Read 96 as the value of H on the "H" scale. The meter chosen in this case must have a range equal to or greater than 96 inches of water. A 100 inch meter would probably be chosen.

SECTION 3

REYNOLDS NUMBER CALCULATIONS

Reynolds number is a dimensionless number that establishes the proportionality between fluid inertia and viscous forces. The flow coefficient data for conventional primary devices is customarily presented as a function of Reynolds number.

For many applications, the combination of flow rate, density and viscosity is such that coefficient consistency is satisfactory over the operating range, and Reynolds number corrections need not be applied.

In other applications, usually typified by low flow rates and/or high viscosities, the operating Reynolds number range must be examined with respect to coefficient variation.

Thus, the Reynolds number(s) is a most useful tool in selecting and sizing primary devices.

The Foxboro flow rule now enables you to accomplish Reynolds number calculations quickly and easily.

REYNOLDS NUMBER CALCULATIONS

Required Information:

W = Flow Rate (lb/h)

D = Pipe I.D. (inches)

μ **(mu)** = Absolute Viscosity (Centipoise)

For a convenient guide to the location of steps on the rule, refer to Figure 7. Follow the steps numbered in red circles ①,②,③,④ on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* hairline on absolute viscosity in centipoise on the "μ" scale①
2. Move the *slide* so the flow rate in lb/h (using blue numbers) on the flow scale ② coincides with the hairline.
3. Move the *cursor* to the pipe inside diameter on the "D" scale ③
4. Read the Reynolds number from the "R_e" scale④

Note: This procedure is applicable for all flowing fluids. When gas calculations are made, however, viscosities lower than the .1 cp lower limit of the scale are encountered. When the viscosity is lower than .1 cp, multiply the actual viscosity by 10 (or 100), and multiply the indicated Reynolds number by 10 (or 100) to determine actual Reynolds number.

If liquid flow is known in gpm, use the "THOUSAND lb/h LIQUID SP. GR." scale as a preliminary step to determine the flow in lb/hour. This conversion is the reverse of the lb/h to gpm operation used in flow calculations.

a. Set the *cursor* to the given value of flow (in gpm) on the "FLOW" scale on the "FLOW CALCULATION" side of the rule, using the black numbers.

b. Turn the rule over and move the *slide* so the specific gravity of the fluid on the "THOUSAND lb/h LIQUID SP. GR." scale coincides with the hairline.

c. Move the *cursor* to the left so that the hairline coincides with the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale.

d. Turn the rule over again. Read the value of flow (in black numbers) on the "FLOW" scale.

e. Multiply this value by 1,000 (the product is flow in pounds per hour), and determine the Reynolds number as previously described.

If liquid flow is known in gph, IMP. gph, bbl/day, or gpd, and the specific gravity is known, the flow must first be converted to gpm, and then from gpm to lb/h as preliminary steps. The operation makes use of both the "THOUSAND lb/h LIQUID SP. GR." scale at the left-hand side of the slide, and the conversion scale at the right-hand side of the slide.

OPERATION:

a. Multiply the known gpd by 0.001 or
Multiply the known bbl/day by 0.1 or
Multiply the known gph by 0.1 or
Multiply the known IMP. gph by 0.1.

b. Set the *cursor* to the value obtained in step a on the "FLOW" scale (black numbers).

c. Turn the rule over and move the *slide* so the black diamond (♦) on the conversion scale coincides with the hairline.

d. Move the *cursor* to the mark which corresponds to the given units of flow. (10 bbl/day, 1000 gpd, etc.)

e. Move the *slide* so the given value of specific gravity on the "THOUSAND lb/h LIQUID SP. GR." scale coincides with the hairline.

f. Move the *cursor* to the left so the hairline coincides with the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale.

g. Turn the rule over again. Read the value of flow (in black numbers) on the "FLOW" scale.

h. Multiply this value by 1,000 (the product is flow in pounds per hour), and determine the Reynolds number as previously described.

REYNOLDS NUMBER

EXAMPLE 11

Flowing Fluid: Water at 60 F

Viscosity: 1.14 cp

Flow Rate: 1400 gpm

Specific Gravity: 1.0

Line Size: 19.00 inch Pipe I.D.

Flow must be converted from gpm to lb/h as a preliminary step:

a. On the "FLOW CALCULATIONS" side, set the *cursor* to 1400 (black numbers) on the "FLOW" scale.

b. Turn the rule over and locate the "THOUSAND lb/h LIQUID SP. GR." scale. Move the *slide* so 1.0 on this scale coincides with the hairline.

c. Move the *cursor* to the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale.

d. Turn the rule over again. Read 703 as the value on the "FLOW" scale (black numbers).

e. Multiply this by 1,000 to obtain flow of 703,000 lb/h.

Using this value of flow, follow the steps numbered in red circles:

1. Set the *cursor* to 1.14 on the "μ" scale.

2. Move the *slide* so 703,000 (blue numbers) on the "FLOW" scale coincides with the hairline.

3. Move the *cursor* to 19.00 on the "D" scale.
4. Read 205,000 from the "R_e" scale as the Reynolds number.

REYNOLDS NUMBER

EXAMPLE 12

Flowing Fluid: Heavy Machine Oil

Viscosity: 660 cp

Flow Rate: 43,000 bbl/day (1 bbl = 42 gallons)

Specific Gravity: 0.90

Line Size: 6.813" Pipe I.D.

Flow must be converted from bbl/day to gpm and then from gpm to lb/h as preliminary steps:

a. Multiply 43,000 bbl/day by 0.1 to obtain 4,300.
b. On the "FLOW CALCULATION" side, set the *cursor* to 4,300, (black numbers) on the "FLOW" scale.
c. Turn the rule over and locate the conversion scale which is near the right-hand end of the slide. Move the *slide* so the black diamond (♦) on this scale coincides with the hairline.
d. Move the *cursor* to the 10 bbl/day mark.
e. Locate the "THOUSAND lb/h LIQUID SP. GR." scale which is near the left-hand end of the slide. Move the *slide* so 0.90 on this scale coincides with the hairline.
f. Move the *cursor* to the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale.
g. Turn the rule over again and read 560 as the value on the "FLOW" scale (black numbers).
h. Multiply this value by 1,000 to obtain flow of 560,000 lb/h.

Using this value of flow, calculate the Reynolds number using the steps numbered in red circles:

1. Set the *cursor* to 660 on the "μ" scale.
2. Move the *slide* so 560,000 (blue numbers) on the "FLOW" scale coincides with the hairline.
3. Move the *cursor* to 6.813 on the "D" scale.
4. Read 786 from the "R_e" scale as the Reynolds number.

SECTION 4
CONTROL VALVE SIZING

The objectives of control valve sizing are:

1. To determine the smallest control valve trim size applicable to a process, in order to keep the cost to a minimum.
2. To select a trim size that will function within the middle part of its operating range, going neither wide open under maximum flow rate, nor closing down too near the seat under minimum conditions.
3. To determine body size by checking inlet velocity at the maximum flow rate. The Foxboro Company's recommendation is a maximum velocity of 20 fps for liquids and 20,000 fpm for gases and vapors.

Calculations are made to determine the magnitude of a valve capacity rating (called C_v) needed to meet the application requirements. Each calculation is made by using selected realistic data from the process. Once the C_v value is found, the trim size of the valve is selected from published tables of C_v versus body size. C_v is defined as the average test discharge in U.S. gallons per minute (gpm) of a wide-open valve handling water with a one pound per square inch (psi) pressure differential (pressure drop) across the valve body. American control valve manufacturers have standardized the method in which the flow tests for C_v are made.

SELECTION OF SIZING DATA

Rates of Flow

Selection of the proper flow rates to be used in the calculation should be made with care. Choice of rates in excess of those to be actually handled by the valve should be made with full knowledge that valve oversizing may result. There are no factors of safety in the published lists* of Foxboro C_v's.

There is no fixed rule about the relative magnitudes of maximum and normal flow rates, but it is noted that plant designers often do establish maximum rates of

*The C_v values issued for the Saunders type valves are representative only and are known to deviate widely under varying process conditions.

150 to 200 percent of the normal flow. Where it is known that a wide range of flow rates must be handled, it is advisable to make a calculation for a *minimum* C_v. This is done by using the *minimum* rate with *maximum* pressure drop. Compare this with the calculated *maximum* C_v by using *maximum* rate and *minimum* pressure drop to determine whether the valve rangeability is being exceeded. The wider the range requirements, the more carefully the sizing must be done.

Throttling Pressure Drop

Throttling Pressure drop has to be carefully chosen. Avoid using too small a value. An important function of the control valve is to absorb the surplus pressure which is not needed elsewhere. Any control valve will reduce its opening to that necessary to produce the required flow under the pressure drop conditions which are imposed upon it by the process. Use of too small a pressure drop merely oversizes the valve. See definition for Critical $\triangle$ P.

Line Sizes

Control valves perform best when installed in lines that are larger than the valve. This is particularly true where the wide range Stabilflo® valves are commonly applied, and is of first importance where the valve rangeability requirements are large. Line sizes should always be large enough so that a minimum of one-third to one-half of the system pressure drop is absorbed across the control valve.

DETERMINATION OF C_v VALUE FOR LIQUIDS

Required Information:

Q = Maximum volumetric flow rate required for sizing a control valve trim (gpm)

G = Specific Gravity at flowing conditions

$\triangle$**P** = Minimum pressure drop (psi)

For a convenient guide to the location of steps on the rule, refer to Figure 7. Follow the steps numbered in black parentheses (1), (2), (3), (4) on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* to the liquid specific gravity on the "LIQUID G" scale (1).
2. Move the *slide* so the value of pressure drop on the "$\triangle$P" scale (2) coincides with the hairline.
3. Set the *cursor* to the given value of flow (black numbers) in gpm on the "FLOW" scale (3).
4. Read the C_v value from the "C_v" scale (4).

If flow is known in gph, IMP. gph, bbl/day, or gpd, flow must be converted to gpm as a preliminary calculation using the conversion scale which is on the right-hand side of the slide on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule.

a. Multiply the known gpd by 0.001 or
Multiply the known bbl/day by 0.1 or
Multiply the known gph by 0.1 or
Multiply the known IMP. gph by 0.1.

b. Set the *cursor* to the value obtained in step a on the "FLOW" scale (black numbers).

c. Turn the rule over and move the *slide* so the black diamond (♦) on the conversion scale coincides with the hairline.

d. Move the *cursor* to the reference mark corresponding to the known units of flow (1,000 gpd, 10 bbl/day, 10 gph, or 10 IMP. gph). This locates the cursor at the correct value of flow in gpm.

e. Turn the rule over again and read the value of flow (black numbers) on the flow scale. Use this value to determine the C_v value as previously described.

If the flow is known in lb/hour and the specific gravity is known, conversion to gpm is made as a preliminary step in the following manner:

a. Multiply the known lb/hour by 0.001

b. Set the *cursor* to the value obtained in step a on the "FLOW" scale (black numbers).

c. Turn the rule over and move the *slide* so the black diamond (♦) on the "THOUSAND lb/h LIQUID SP. GR." scale coincides with the hairline.

d. Set the *cursor* to the specific gravity. This locates the cursor at the corect value of flow in gpm.

e. Turn the rule over again and read the value of flow (black numbers) on the "FLOW" scale.

f. Use this value of flow to determine the C_v value as previously described.

DETERMINATION OF C_v VALUE FOR STEAM

Required Information:

W = Maximum flow rate required for sizing a control valve trim (lb/h)

P_1 = Upstream pressure (psia)

P_2 = Downstream pressure (psia)

ΔP = $P_1 - P_2$

T = Temperature (F) (not required if steam is saturated)

For a convenient guide to the location of steps on the rule, refer to Figure 7. Follow the steps in red parentheses (1), (2), (3), (4) on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* to the given value of downstream pressure P_2 on the red "STEAM P_2" scale (1) (The downstream pressure setting cannot be less than 50 percent of the upstream pressure, P_1. If the given downstream pressure is less than 50 percent of P_1, use $P_2 = \frac{1}{2} P_1$ and $\Delta P = \frac{1}{2} P_1$.)
2. Move the *slide* so the value of the pressure drop (psi) on the "ΔP" scale (2) coincides with the hairline.
3. Move the *cursor* to the given value of flow (red numbers) in lb/h on the "FLOW" scale (3).
4. Read the C_v value on the "C_v" scale (4).

If steam is superheated, correction must be made between steps (3) and (4) using the "F_{sh}" scale which is located on the slide to the left of the "D" scale. This correction uses F_{sh} values obtained from the "SUPERHEAT CORRECTION FACTOR TABLE" (Fig. 1).

OPERATION

Steps 1, 2, 3: (Same as above)

3a. Move the *slide* so zero (0) on the "F_{sh}" scale coincides with the hairline.

3b. Move the *cursor* to the F_{sh} value on the "F_{sh}" scale.

4. Read C_v value from the "C_v" scale.

If pressure is not known, but specific volume is known, follow operation for vapors which follows.

DETERMINATION OF C_v VALUE FOR VAPORS

A vapor is defined as any gas which does not obey the Ideal Gas Laws. The following procedure may also be used for ideal gases, though it is likely that the "GAS" procedure will be more convenient. Likewise, it will usually be more convenient to calculate C_v for steam following the "STEAM" procedure since the "VAPOR" procedure requires that the specific volume be known.

Required Information:

V = Specific volume (the reciprocal of density), at downstream conditions. "V" may be determined from accepted engineering handbooks.

P_1 = Upstream pressure (psia)

P_2 = Downstream pressure (psia)

ΔP = $P_1 - P_2$

W = Maximum flow rate required for sizing a control valve trim (lb/h)

For a convenient guide to the location of steps on the rule, refer to Figure 7. Follow the steps in red parentheses (1), (2), (3), (4) on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule, with the exception of step 1.

1. Set the *cursor* to the downstream value of specific volume on the "V" scale. This scale is located immediately below the "STEAM P_2" scale (1).
2. Move the *slide* so the value of pressure drop on the "ΔP" scale (2) coincides with the hairline. (The downstream pressure setting cannot be less than 50 percent of the upstream pressure. Therefore, the pressure drop cannot be greater than 50 percent of the upstream pressure. When the given values indicate a pressure drop greater than 50 percent, use $\Delta P = \frac{1}{2} P_1$, and use $P_2 = \frac{1}{2} P_1$ to determine the downstream specific volume.)
3. Move the *cursor* to the given value (red numbers) in lb/h of flow on the "FLOW" scale (3).
4. Read the C_v value on the "C_v" scale (4).

DETERMINATION OF C_v VALUE FOR GASES

These "Gas" procedures apply only to those gases which closely follow ideal gas laws. The accuracy of the results are directly dependent on how closely the Ideal Gas Laws are followed. For steam or other non-ideal vapors, the "Steam" or "Vapor" procedures should be followed.

Required Information:

Q = Maximum volumetric flow rate required for sizing a control valve trim (scfh)

T = Temperature (F)

G = Specific Gravity

△P = Pressure Drop (psi)

P_1 = Upstream pressure (psia)

P_2 = Downstream pressure (psia)

For a convenient guide to the location of steps on the rule, refer to Figure 7. Follow the steps in blue parentheses (1), (2), (3), (4), (5), (6) on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* to the downstream pressure (P_2) on the blue "GAS P_2" scale (1). (The downstream pressure setting cannot be less than 50 percent of the upstream pressure, P_1. If the given pressure drop is greater than 50 percent of P_1, set $P_2 = \frac{1}{2} P_1$, and $\triangle P = \frac{1}{2} P_1$.)
2. Move the *slide* so the value of the pressure drop △P on the "△P" scale (2) coincides with the hairline.
3. Move the *cursor* to the given value of temperature in degrees fahrenheit on the blue "T" scale (3).
4. Move the *slide* so the gas specific gravity on the blue "G" scale (4) coincides with the hairline.
5. Move the *cursor* to the value of flow (blue numbers) in scfh on the "FLOW" scale (5).
6. Read the value of C_v from the "C_v" scale (6).

If flow is known in scfm or scfd, conversion to scfh is made as a preliminary step in the following manner:

a. Multiply the known scfm by 100 or
Multiply the known scfd by 0.1.

b. Set the *cursor* to the value obtained in step a on the "FLOW" scale (blue numbers).

c. Turn the rule over and move the *slide* so the black diamond (♦) on the conversion scale coincides with the hairline.

d. Move the *cursor* to the reference mark corresponding to the known units of flow (10 scfd or .01 scfm). This locates the cursor at the correct value of flow in scfh.

e. Turn the rule over again and read the value on the "FLOW" scale (blue numbers). Use this value to determine the C_v value as previously described.

LIQUID FLOW CONTROL VALVE TRIM SIZING

EXAMPLE 13

Fluid: Solvent

Max. Flow Rate: 400 gpm

Upstream Pressure: 30 psig

Downstream Pressure: 10 psig

Specific Gravity: 0.83

$$\begin{array}{r} P_1 = 30 \text{ psig} \\ P_2 = 10 \text{ psig} \\ \hline \text{Pressure Drop} = 20 \text{ psi} \end{array}$$

Follow the steps numbered in black parentheses on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* to .83 on the "LIQUID G" scale.
2. Move the *slide* so 20 on the "△P" scale coincides with the hairline.
3. Move the *cursor* to 400 (black numbers) on the "FLOW" scale.
4. Read 81 as the C_v value from the "C_v" scale.

SATURATED STEAM FLOW CONTROL VALVE TRIM SIZING

EXAMPLE 14

Fluid: Saturated Steam

Max. Flow Rate: 30,000 lb/h

Upstream Pressure: 40 psia

Downstream Pressure: 30 psia

$$\begin{array}{r} P_1 = 40 \text{ psia} \\ P_2 = 30 \text{ psia} \\ \hline \text{Pressure Drop} = 10 \text{ psi} \end{array}$$

10 psi is less than 50 percent of 40 psi, so use $\triangle P = 10$ psi and $P_2 = 30$ psia.

Follow the steps numbered in red parentheses on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* to 30 on the "STEAM P_2" scale.

2. Move the *slide* so 10 on the "$\triangle P$" scale coincides with the hairline.

3. Move the *cursor* to 30,000 (red numbers) on the "FLOW" scale.

4. Read 555 as the C_v value from the "C_v" scale.

SUPERHEATED STEAM FLOW CONTROL VALVE TRIM SIZING

EXAMPLE 15

Fluid: Superheated Steam

Max. Flow Rate: 30,000 lb/h

Upstream Pressure: 40 psia

Downstream Pressure: 30 psia

Temperature: 500 F

$$\begin{array}{r} P_1 = 40 \text{ psia} \\ P_2 = 30 \text{ psia} \\ \hline \text{Pressure Drop} = 10 \text{ psi} \end{array}$$

10 psi is less than 50 percent of 40 psi, so use $\triangle P =$ 10 psi and $P_2 = 30$ psia.

Follow the steps numbered in red parentheses on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule:

1. Set the *cursor* to 30 on the "STEAM P_2" scale.

2. Move the *slide* so 10 on the "$\triangle P$" scale coincides with the hairline.

3. Move the *cursor* to 30,000 (red numbers) on the "FLOW" scale.

3a. Move the *slide* so zero on the "F_{sh}" scale coincides with the hairline.

3b. Determine from the "SUPERHEAT CORRECTION FACTOR TABLE" (Fig. 1) the "F_{sh}" value of 27 for 500 F and 30 psia. Set the *cursor* to 27 on the "F_{sh}" scale.

4. Read 645 as the C_v value from the "C_v" scale.

VAPOR FLOW CONTROL VALVE TRIM SIZING

EXAMPLE 16

Fluid: Ammonia Vapor at 100 F

Flow Rate: 5,000 lb/h

$$\begin{array}{r} P_1 = 60 \text{ psia} \\ P_2 = 20 \text{ psia} \\ \hline \text{Pressure Drop} = 40 \text{ psi} \end{array}$$

40 psi is greater than 50 percent of 60 psia, so use $\triangle P = 30$ psi, and $P_2 = 30$ psia. From gas tables, find that specific volume of ammonia at 30 psia is 11.4 cu. ft./lb.

Follow the steps numbered in red parentheses on the "CONTROL VALVE, REYNOLDS NUMBER" side of the rule. However, substitute specific volume on the "V" scale for pressure on the "STEAM P_2" scale as step 1.

1. Set the *cursor* to 11.4 on the "V" scale.

2. Move the *slide* so 30 on the "$\triangle P$" coincides with the hairline.

3. Set the *cursor* to 5,000 (red numbers) on the "FLOW" scale.

4. Read 48.7 as the C_v value from the "C_v" scale.

GAS FLOW CONTROL VALVE TRIM SIZING

EXAMPLE 17

Fluid: Oxygen

Max. Flow Rate: 50,000 scfh

Specific Gravity: 1.105

Temperature: —50 F

Pressure Upstream: 75 psia

Pressure Downstream: 55 psia

$$\begin{array}{r} P_1 = 75 \text{ psia} \\ P_2 = 55 \text{ psia} \\ \hline \text{Pressure Drop} = 20 \text{ psi} \end{array}$$

20 psi is less than 50 percent of 75 psi, so use $\triangle P =$ 20 psi and $P_2 = 55$ psia.

Follow the steps numbered in blue parentheses on the "CONTROL VALVE, REYNOLDS NUMBER" side:

1. Set the *cursor* to 55 on the "GAS P_2" scale.

2. Move the *slide* so 20 on the "$\triangle P$" scale coincides with the hairline.

3. Move the *cursor* to —50 on the "T" scale.

4. Move the *slide* so 1.1 on the "GAS G" scale coincides with the hairline.

5. Move the *cursor* so that 50,000 (blue numbers) on the "FLOW" scale coincides with the hairline.
6. Read 24 as the C_v value on the "C_v" scale.

SECTION 5 EQUATIONS

Calculations with the Foxboro Flow and Valve Rule use the following equations.

LIQUID FLOW

$$S = \frac{1}{5.667} \times \frac{Q_m \times G_l}{D^2 \times F_m \times \sqrt{G_f} \times \sqrt{H}}$$

$$F_m = \sqrt{1 - 0.0737\, G_s}$$

See Note* below

STEAM OR VAPOR FLOW

$$S = \frac{1}{359} \frac{W_m \times \sqrt{v}}{D^2 \times \sqrt{H} \times F_m}$$

$$F_m = \sqrt{1 - 0.0737\, G_s}$$

See Note* below

IDEAL GAS FLOW

$$S = \frac{1}{7711.5} \frac{Q_m \times \sqrt{G} \times \sqrt{T\,(\text{absolute})}}{D^2 \times \sqrt{H} \times \sqrt{P_2}}$$

See Note* below

REYNOLDS NUMBER

$$Re = 6.32 \times \frac{W}{D \times \mu}$$

LIQUID C_v

$$C_v = Q_m \sqrt{\frac{G}{\Delta P}}$$

STEAM OR VAPOR C_v

$$C_v = \frac{1}{63.3} \frac{W_m \times \sqrt{v}}{\sqrt{\Delta P}}$$

GAS C_v

$$C_v = \frac{Q_m}{1360} \sqrt{\frac{T\,(\text{absolute}) \times G}{\Delta P \times P_2}}$$

Note* Values of d/D are read directly from the rule in place of "S" values, based on relationships established in The Foxboro Company's handbook "Principles and Practice of Flow Meter Engineering".

DEFINITION OF TERMS

bbl/day: Barrels per day liquid flow rate. One barrel = 42 U.S. gallons.

cp: Centipoise (unit of absolute viscosity)

C_v: Valve capacity rating defined as the average test discharge in U.S. gallons per minute (gpm) of a wide-open valve with a one psi pressure differential (pressure drop) across the valve body.

D: Internal pipe or conduit diameter, adjacent to the primary device, inches (Meter Run Size).

d: Orifice bore diameter, nozzle diameter, or Venturi throat diameter, inches.

d/D: (Also called Beta Ratio) The ratio of orifice bore diameter, nozzle or Venturi throat diameter to the internal pipe diameter.

FLANGE, VENA CONTRACTA, RADIUS, CORNER TAP d/D
refers to the location of the orifice pressure taps in a given installation.

FLOW NOZZLE, VENTURI d/D
refers to long radius nozzles and to Herschel style Venturi tubes, designed as recommended by the American Society of Mechanical Engineers Handbook "Fluid Meters, Their Theory and Application".

PIPE TAP d/D
refers to location of orifice differential pressure taps at 2 1/2 diameters upstream and 8 diameters downstream from the orifice plate.

QUADRANT EDGE d/D
refers to a concentric orifice whose inlet edge is made as the quarter of a circle.

F_m: Correction for the displaced column of fluid on the surface of the mercury in a mercury float type meter.

FOXBORO PITOT: Refers to the standard Foxboro Pitot tube design. It is required that the Pitot impact opening is located on the centerline of the pipe (the point of maximum velocity).

F_{sh}: Steam superheat correction factor

$$F_{sh} = \left(1 - \frac{\text{sp. wt. of superheated steam}}{\text{sp. wt. of sat. steam at the same pressure}}\right) \times 100$$

ft³/lb: Cubic feet per pound, units of specific volume (the reciprocal of density), defined at the downstream flowing conditions.

G also GAS G: The specific gravity of a gas; the ratio of the molecular weight of the gas to the molecular weight of air (also the ratio of weight of a volume of gas at a given temperature and pressure to the weight of an equal volume of air at the same temperature and pressure when the temperature and pressure are close to atmospheric conditions).

G_f also LIQUID G: The specific gravity of the liquid at the flowing conditions; the ratio of the weight of a volume of the liquid at the flowing conditions to the weight of an equal volume of water at 60 F.

G_l: The specific gravity of the liquid at the reference temperature; the ratio of the weight of a volume of the liquid at the reference temperature to the weight of an equal volume of water 60 F. The reference temperature is the temperature at which the gallons in the flow rate are defined. Often the reference temperature is 60 F.

gpd: U.S. gallons per day

gph: U.S. gallons per hour

gpm: U.S. gallons per minute

Gs: The specific gravity of the liquid above the mercury surface in a mercury meter; the ratio of the weight of a volume of the liquid at the conditions within the meter to the weight of an equal volume of water at 60 F.

H: Differential pressure, inches of water.

IMP. gph: Imperial gallons per hour. One Imperial gallon = 1.201 U.S. gallons.

in: Inches (on "D" scale), or
Inches of water, dry calibration (on "H" scale)

lb/h: Pounds per hour

LIQUID G: (see G_f)

P: Pressure, psia

P_2: Also *GAS* P_2 also *STEAM* P_2: Pressure (downstream) psia

psi: Pounds per square inch

psia: Pounds per square inch (absolute)

psig: Pounds per square inch (gage)

Q: Maximum volumetric flow rate required for sizing a control valve trim.

Q_m: Maximum volumetric flow rate corresponding to full scale on chart (gpm, or scfh).

QUADRANT EDGE: (see d/D and r/D)

r/D: The ratio of the radius of the quarter-circle inlet edge of a quadrant edge orifice plate to the internal pipe diameter.

Re: Reynolds number. If diameter values set on the "D" scale are internal pipe diameter, then Re is "based on pipe diameter" and further identified as R_D. If diameter values set on the "D" scale are orifice bore or venturi throat diameters, then Re is "based on throat diameter" and further identified as R_d.

S: Index for d/D. S may be read at the conclusion of d/D calculations as 0.001 times the quantity (black numbers) on the "FLOW" scale which coincides with the hairline.

scfd: Standard cubic feet per day

scfh: Standard cubic feet per hour

scfm: Standard cubic feet per minute

STANDARD CUBIC FOOT: That quantity of gas which occupies one cubic foot when at 14.73 psia and 60 F.

STEAM P_2: (see P_2)

T: Temperature of flowing gas, degrees Fahrenheit

T (absolute): Temperature, degrees Rankine (F + 460)

U.S. gph: United States gallons per hour

V: Specific volume (the reciprocal of density) defined at downstream conditions (Ft³/lb)

W: Maximum flow rate required for sizing a control valve trim (lb/h), or Operating flow rate, lb/h, (for Reynolds number calculations).

W_m: Flow rate (pounds per hour) corresponding to full scale of chart.

β RATIO (BETA RATIO): d/D ratio

△P (DELTA P): Throttling pressure drop across the valve (Not to be confused with shutoff pressure drop); upstream pressure minus downstream pressure, psi.

△P CRITICAL: Critical pressure drop is 50 percent of upstream absolute pressure. In determining control valve C_v for stream, gas and vapors, the maximum throttling pressure drop used should never exceed critical.

μ (MU): Absolute viscosity, centipoise

FIGURE 1
SUPERHEAT CORRECTION FACTOR TABLE

PSIA \ F	250	280	300	320	340	360	380	400	420	440	460	480
15	5	10	12	14	17	19	21	23	24	26	28	29
25	1	5	8	10	13	15	17	19	21	23	25	26
50			3	6	9	11	13	15	18	19	21	23
100					2	5	8	10	13	15	17	19
200								3	6	9	11	14
300									1	4	7	10
500												3
700												
1000												
1300												
1500												
1700												
2000												

PSIA \ F	500	520	540	560	580	600	620	640	660	680	700	720	740	760	780	800	850	900	950	1000
15	31	32	34	35	36	37	39	40	41	42	43	43	45	46	46	47	49	51	53	55
25	28	30	31	32	34	35	35	38	39	40	41	42	43	44	45	46	48	49	51	52
50	25	27	28	30	31	32	34	35	36	37	38	39	40	41	42	43	45	47	49	51
100	21	22	24	26	27	29	30	32	33	34	35	36	37	38	39	40	43	45	47	49
200	16	18	20	22	24	25	27	28	30	31	32	33	35	36	37	38	41	43	45	47
300	13	15	17	19	21	23	25	26	28	29	31	32	33	34	36	37	39	42	44	46
500	7	10	13	15	17	20	22	24	26	27	29	30	32	33	34	36	38	41	43	45
700		4	8	12	15	17	20	22	24	26	28	29	31	32	34	35	38	41	43	46
1000				4	9	13	17	20	22	25	27	29	31	32	34	35	39	41	44	46
1300					1	8	13	17	20	23	27	28	31	32	34	36	39	43	45	49
1500						2	9	15	19	23	26	28	31	33	35	36	40	44	46	49
1700							4	11	17	22	25	28	31	33	35	37	41	45	48	50
2000								3	13	20	25	28	32	34	37	39	43	47	50	52

FIGURE 2
CORRECTION FACTORS TO FOLLOW AGA REPORT #3

The orifice d/D scales for Flange, Vena Contracta, Radius and Corner Taps are based on The Foxboro Company S versus d/D relationships. They provide accurate plant calculations and sizing for most non-viscous flow problems.

For those using the methods and constants from the American Gas Association, AGA Report No. 3 Manual (whose coefficients are based on infinite Reynolds number values) we recommend the following supplementary procedure.

From the proper table, select the column corresponding to the existing pipe size. Follow down this column to the next higher d/D than the value to be corrected. Follow across the space above this value and read the correction from the right-hand column.

Pipe Size

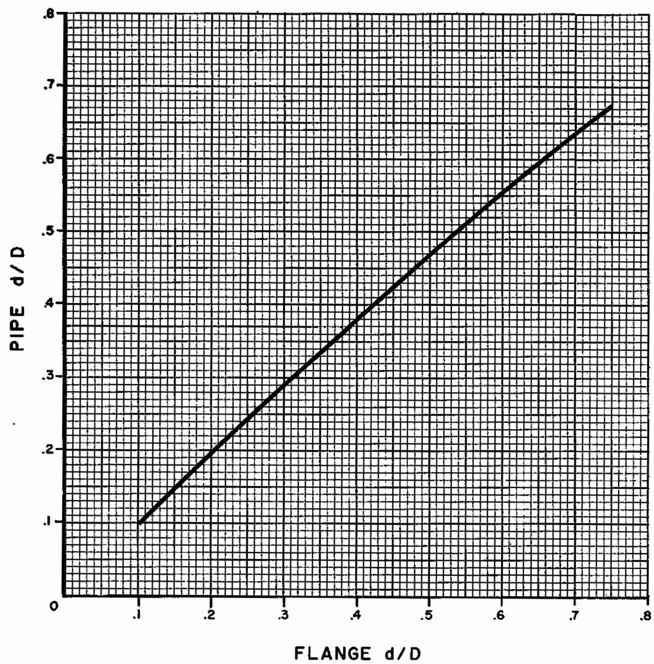
	2"	3"	4"	6"	8"	10"	20"	30"	Correction
	.10	.10	.10	.10	.10	.10	—	—	.000
	.20	.16	.13	.13	.13	.13	.10	.10	.001
	.54	.52	.50	.48	.48	.48	.48	.47	.002
Flange	.59	.55	.55	.54	.54	.54	.53	.52	.003
Tap	.63	.61	.59	.58	.58	.57	.56	.56	.004
d/D	.66	.64	.62	.60	.60	.60	.59	.59	.005
	.68	.66	.65	.64	.63	.62	.62	.61	.006
	.74	.68	.67	.66	.65	.65	.64	.63	.007
		.70	.69	.68	.67	.67	.66	.65	.008
		.75	.71	.70	.69	.69	.67	.67	.009
			.75	.72	.71	.71	.69	.69	.010
				.75	.73	.73	.71	.71	.011
					.75	.75	.73	.73	.012
							.75	.74	

Pipe Size

	2"	3"	4"	6"	8"	10"	20"	30"	Correction
	.10								.000
	.12	.10	.10	.10	.10	.10	.10	.10	.001
Pipe	.17	.15	.14	.14	.13	.13	.13	.11	.002
Tap	.56	.55	.55	.55	.55	.55	.54	.54	.003
d/D	.61	.64	.64	.66	.66	.66	.66	.66	.002
	.66	.68	.68	.69	.69	.69	.69	.70	.001
	.69	.70	.70	.71	.71	.71	.71		.000

Add the correction factor to the calculated d/D ratio.

FIGURE 3
ORIFICE PLATE TAPS



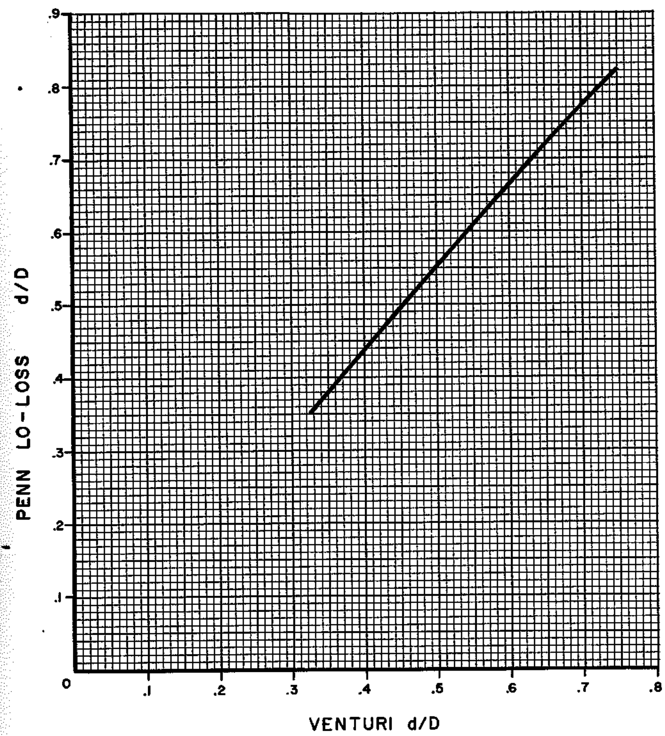
The Foxboro Flow and Valve Rule does not include a pipe tap d/D reference. When pipe taps are used, do the calculation on the rule using flange taps. Then use this curve to convert to equivalent pipe tap d/D. The curve may be entered from either direction.

FIGURE 4
PIPE SIZE DATA
VALUES OF LINE DIAMETER

Nom. Diam.	Sched.	Wt.	D	Nom. Diam.	Sched.	Wt.	D
1"	40	S	1.049	1½"	40	S	1.610
	80	XH	.957		80	XH	1.500
	160		.815		160		1.338
		XXH	.599			XXH	1.100
1¼"	40	S	1.380	2"	40	* S	2.067
	80	XH	1.278		80	XH	1.939
	160		1.160		160		1.689
		XXH	.896			XXH	1.503
2½"	40	S	2.469	10"	30	* S	10.136
	80	XH	2.323		40	S	10.020
	160		2.125		60	XH	9.75
		XXH	1.771		80		9.564
3"	40	* S	3.068		100		9.314
	80	XH	2.900		120		9.064
	160		2.624		140		8.75
		XXH	2.300		160		8.50
3½"	40	S	3.548	12"		S	12.00
	80	XH	3.364		30	* S	12.09
		XXH	2.728		40		11.938
4"	40	* S	4.026			XH	11.75
	80	XH	3.826		60		11.626
	120		3.626		80		11.376
	160		3.438		100		11.064
		XXH	3.152		120		10.750
5"	40	S	5.047		140		10.500
	80	XH	4.813		160		10.126
	120		4.563	14"	30	S	13.250
	160		4.313			XH	13.000
		XXH	4.063	16"	30	* S	15.250
6"	40	* S	6.065		40	XH	15.000
	80	XH	5.761		60		14.688
	120		5.501		80		14.314
	160		5.189	18"		S	17.182
		XXH	4.897		30		17.126
8"	30	* S	8.071		40		16.876
	40	S	7.981	20"		S	19.182
	60		7.813		30		19.000
	80	XH	7.625		40		18.814
	100		7.439		60		18.376
	120		7.189	24"	30		22.879
	160		6.813		40		22.626
		XXH	6.875	30"	30		28.750

S = Standard Weight Pipe, XH = Extra Heavy Weight Pipe
XXH = Double Extra Heavy Weight Pipe * A.G.A. Standard Sizes

FIGURE 5
CORRELATION OF LO-LOSS d/D AND VENTURI d/D



Perform the calculations on the rule using steps for the Venturi tube. Then determine the equivalent Lo-Loss d/D from this curve.

Lo-Loss — Registered Trademark of
Penn/Measure-Rite Division
Badger Meter Company
Milwaukee, Wisconsin

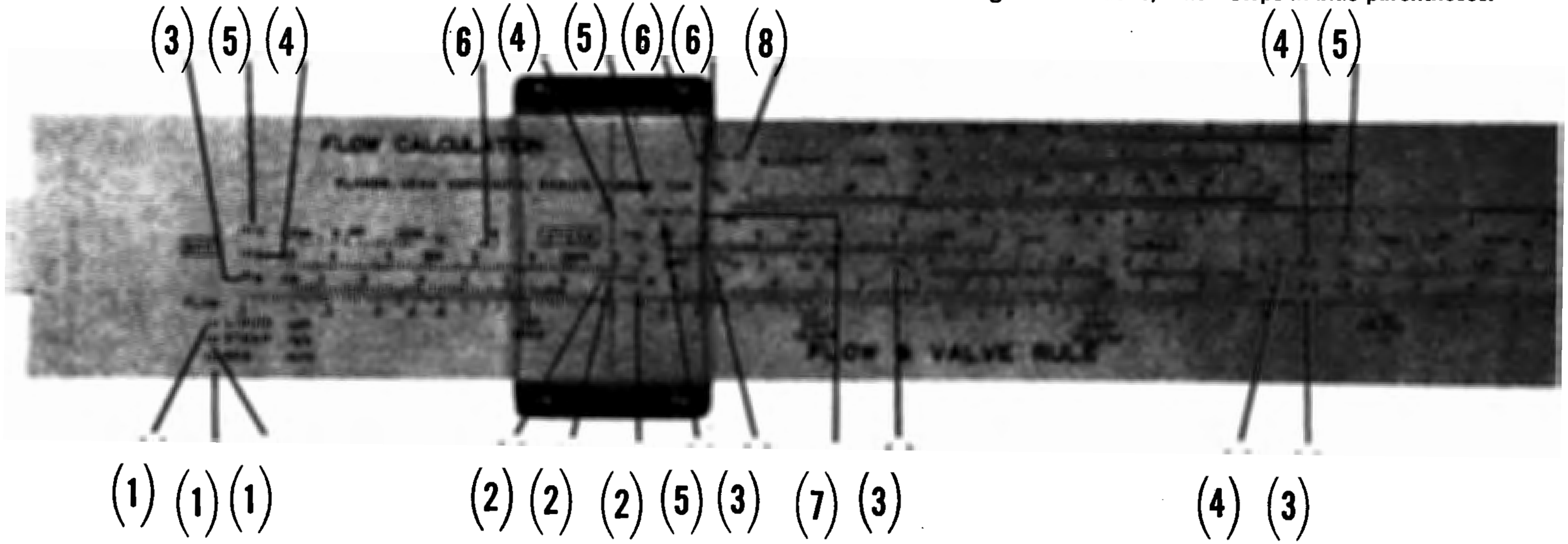


FIGURE 6 For liquid calculations, follow steps in black parentheses.
For steam calculations, follow steps in red parentheses.
For gas calculations, follow steps in blue parentheses.

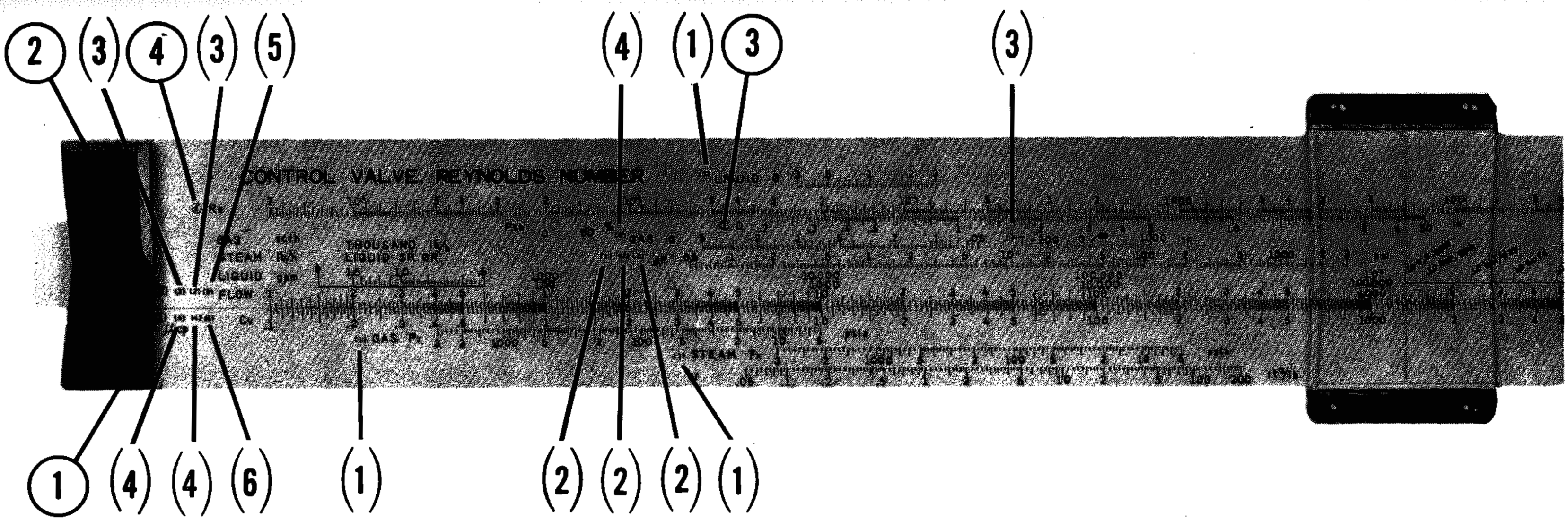


FIGURE 7 For liquid calculations, follow steps in black parentheses.
For steam calculations, follow steps in red parentheses.
For gas calculations, follow steps in blue parentheses.
For Reynolds number calculations, follow steps in red circles.

CARE OF THE RULE

ADJUSTMENT

The construction of the Foxboro Flow and Valve Rule is such that the scales can never get out of alignment and therefore never need adjustment. It may be desirable at times, however, to check the alignment of the cursor hairline. The hairline should be placed so that the following pairs of points coincide with the hairline at the same time:

"CONTROL VALVE, REYNOLDS NUMBER" side

2,000,000 on "R_e" scale coincides with .1 on the C_v scale.

20 on "R_e" scale coincides with 10,000 on the "C_v" scale

"FLOW CALCULATION" side

.1 on "Flange, Vena Contracta (etc) d/D" scale coincides with 5.99 (black numbers) on the "FLOW" scale. "Foxboro Pitot" coincides with 676.5 (black numbers) on the "FLOW" scale.

If a hairline requires adjustment, the following procedure should be followed:

1. Be sure that the edges of the slide rule (the surfaces upon which the cursor travels) are clean.
2. Loosen slightly (1/4 turn is usually enough) the four (4) screws which attach the transparent face to the green ends of the cursor. Loosen only one face at a time.
3. Note that one of the green ends of the cursor contains a spring. Holding the *other* end firmly against the edge of the rule, move the transparent face until the hairline lines up with both points of one of the pairs listed above.
4. Tighten the four screws taking care not to upset the position of the cursor pieces.
5. Check the hairline alignment again to confirm the adjustment.

If both hairlines require alignment, adjust one at a time. Adjustment of one hairline does not disturb the other.

CLEANING

The Foxboro Flow and Valve Rule can be kept clean with a damp cloth. It is wise to keep the long edges of the rule clean because dirt can disturb the alignment of the cursor. If necessary, the cursor assembly may be removed to facilitate cleaning.

CAUTION

The Foxboro Flow and Valve Rule should not be exposed to temperatures greater than 200 F.

SPARE CURSOR

If the cursor assembly of the Foxboro Flow and Valve Rule becomes damaged, a spare cursor assembly may be obtained from The Foxboro Company.

NOTES

FLOW METER HANDBOOK

For nearly forty years, through eight previous editions, "Principles and Practice of Flow Meter Engineering" has been used throughout the world as a standard text on flow measurement. It has gained a high reputation both as an industry handbook and a college reference text.

The new ninth edition in hard cover textbook size (6" x 9") contains 575 pages of revised and reorganized 8th edition data plus a variety of new, useful information. It contains complete sections on Liquid, Steam and Gas flow measurement; the latest data on flange taps, radius taps and corner taps; data on eccentric, segmental and quadrant edge orifices, Venturi tubes and flow nozzles; new sections on target meters, integral orifices and "Lo-Loss" tubes; practical methods for applying A.G.A. Report Number 3; and a descriptive analysis of gas measurement contracts. Additional sections include: physical dimensions for viscosity and Reynolds number calculations based on pipe or throat values; a complete list of working equations for ready reference; coefficient data for pipeline sizes through 30 inches; empirical equations for discharge coefficients for use with electronic computing systems; and the most comprehensive data published on installation and choice of primary devices and tap locations.

Here in *one* handbook is complete, up-to-date, authoritative information on all phases of head-type flow meter application engineering. It is carefully organized in every detail and is easier to use than ever before.

Whether your contact with flow engineering is every day or once a year, you will find your copy of *"Principles and Practice of Flow Meter Engineering"* invaluable to have around.

For ordering information, contact the Foxboro office nearest you, or

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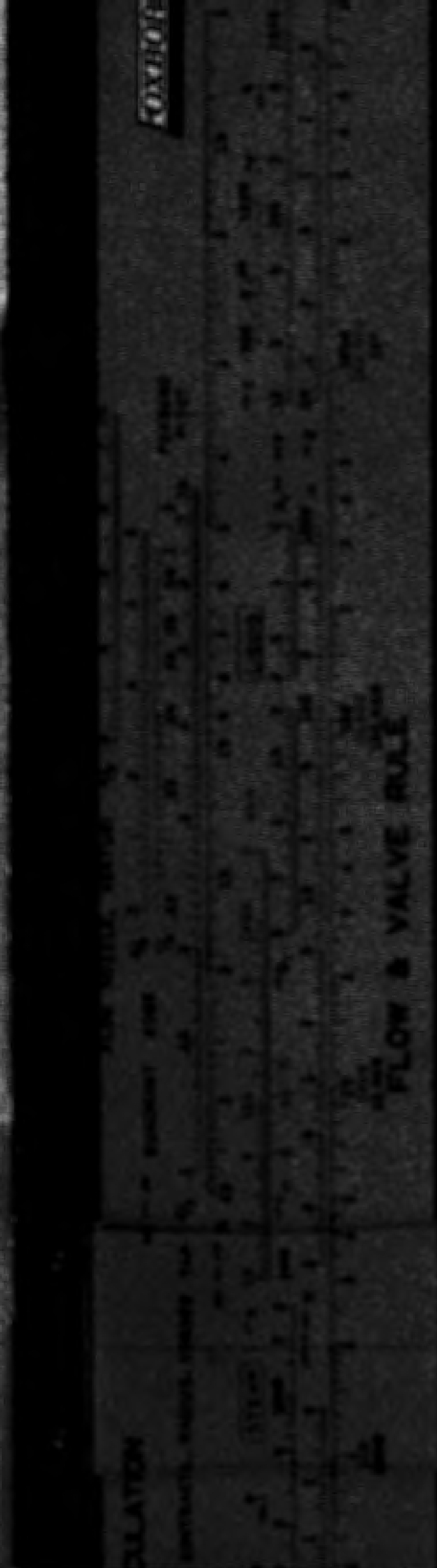

English Units

THE USE OF THE FOXBORO FLOW AND VALVE RULE