Introduction

Standardization activities for control valve sizing can be traced back to the early 1960's when an American trade association, the Fluids Control Institute, published sizing equations for use with both compressible and incompressible fluids. The range of service conditions that could be accommodated accurately by these equations was quite narrow, and the standard did not achieve a high degree of acceptance. In 1967, the Instrument Society of America (ISA) established a committee to develop and publish standard equations. The efforts of this committee culminated in a valve sizing procedure that has achieved the status of American National Standard. Later, a committee of the International Electrotechnical Commission (IEC) used the ISA works as a basis to formulate international standards for sizing control valves. (Some information in this introductory material has been extracted from ANSI/ISA S75.01 standard with the permission of the publisher, the instrument Society of America.) Except for some slight differences in nomenclature and procedures, the ISA and IEC standards have been harmonized. ANSI/ISA Standard S75.01 is harmonized with IEC Standards 534-2-1 and 534-2-2. (IEC Publications 534-2, Sections One and Two for incompressible and compressible fluids, respectively.)

In the following sections, the nomenclature and procedures are explained, and sample problems are solved to illustrate their use.

Sizing Valves for Liquids

Following is a step-by-step procedure for the sizing of control valves for liquid flow using the IEC procedure. Each of these steps is important and must be considered during any valve sizing procedure. Steps 3 and 4 concern the determination of certain sizing factors that may or may not be required in the sizing equation depending on the service conditions of the sizing problem. If one, two, or all three of these sizing factors are to be included in the equation for a particular sizing problem, refer to the appropriate factor determination section(s) located in the text after the sixth step.

1. Specify the variables required to size the valve as follows:

- Desired design: refer to the appropriate valve flow coefficient table in this catalog.
- Process fluid (water, oil, etc.), and
- Appropriate service conditions
  q or w, P_1, P_2 or ΔP, T_1, G_f, P_v, Pc, and ν

The ability to recognize which terms are appropriate for a specific sizing procedure can only be acquired through experience with different valve sizing problems. If any of the above terms appears to be new or unfamiliar, refer to the table 1 for a complete definition.

2. Determine the equation constant N. N is a numerical constant contained in each of the flow equations to provide a means for using different systems of units. Values for these various constants and their applicable units are given in table 2.

Use N_1, if sizing the valve for a flow rate in volumetric units (gpm or m^3/h).

Use N_6 if sizing the valve for a flow rate in mass units (lb/h or kg/h).

3. Determine F_P, the piping geometry factor.

F_P is a correction factor that accounts for pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valve to be sized. If such fittings are attached to the valve, the F_P factor must be considered in the sizing procedure. If, however, no fittings are attached to the valve, F_P has a value of 1.0 and simply drops out of the sizing equation.

For rotary valves with reducers (swaged installations) and other valve designs and fitting styles, determine the F_P factors by using the procedure for *Determining F_P, the Piping Geometry Factor* on page 3.

Table 1. Abbreviations and Terminology

Symbol	Definition	Symbol	Definition
C_v	Valve sizing coefficient	P_2	Downstream absolute static pressure
Cv_{net}	Valve flow coefficient calculated from the net pressure loss through the valve only	P_C	Absolute thermodynamic critical pressure
d	Nominal valve size	P_V	Vapor pressure absolute of liquid at inlet temperature
D	Internal diameter of the piping	ΔP	Pressure drop (P_1-P_2) across the valve
F_d	Valve style modifier, dimensionless	$\Delta P_{max(L)}$	Maximum allowable liquid sizing pressure drop
F_F	Liquid critical pressure ratio factor, dimensionless	$\Delta P_{max(LP)}$	Maximum allowable sizing pressure drop with attached fittings
F_K	Ratio of specific heats factor, dimensionless	q	Volume rate of flow
F_L	Rated liquid pressure recovery factor, dimensionless	q_{max}	Maximum flow rate (choked flow conditions) at given upstream conditions
F_{Lnet}	Pressure recovery factor calculated from the net pressure loss through the valve only	Re_V	Valve Reynolds number, dimensionless
F_{LP}	Combined liquid pressure recovery factor and piping geometry factor of valve with attached fittings (when there are no attached fittings, F_{LP} equals F_L), dimensionless	T_1	Absolute upstream temperature (degrees K or degree R)
F_P	Piping geometry factor, dimensionless	w	Mass rate of flow
F_R	Reynolds number factor, dimensionless	x	Ratio of pressure drop to upstream absolute static pressure ($\Delta P/P_1$), dimensionless
G_F	Liquid specific gravity (ratio of density of liquid at flowing temperature to density of water at 60°F), dimensionless	x_T	Rated pressure drop ratio factor, dimensionless
G_G	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions(1), i.e., ratio of molecular weight of gas to molecular weight of air), dimensionless	x_{Tnet}	Pressure differential ratio factor calculate from the net pressure loss through the valve only
k	Ratio of specific heats, dimensionless	Y	Expansion factor (ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number), dimensionless
K	Head loss coefficient of a device, dimensionless	Z	Compressibility factor, dimensionless
M	Molecular weight, dimensionless	$\gamma 1$	Specific weight at inlet conditions
N	Numerical constant	ν	Kinematic viscosity, centistokes
P_1	Upstream absolute static pressure		

1. Standard conditions are defined as 60°F (15.5°C) and 14.7 psia (101.3kPa).

4. Determine q_{max} (the maximum flow rate at given upstream conditions) or ΔP_{max} (the allowable sizing pressure drop).

The maximum or limiting flow rate (q_{max}), commonly called choked flow, is manifested by no additional increase in flow rate with increasing pressure differential with fixed upstream conditions. In liquids, choking occurs as a result of vaporization of the liquid when the static pressure within the valve drops below the vapor pressure of the liquid.

The IEC standard requires the calculation of an allowable sizing pressure drop (ΔP_{max}), to account for the possibility of choked flow conditions within the valve. The calculated ΔP_{max} value is compared with the actual pressure drop specified in the service conditions, and the lesser of these two values is used in the sizing equation. If it is desired to use ΔP_{max} to account for the possibility of choked flow conditions, it can be calculated using the procedure for Determining Δq_{max}, the Maximum Flow Rate, or ΔP_{max}, the Allowable Sizing Pressure Drop on page 4. If it can be recognized that choked flow conditions will not develop within the valve, ΔP_{max} need not be calculated.

5. Determine F_R, the Reynolds number factor.

F_R is a correction factor to account for nonturbulent flowing conditions within the control valve to be sized. Such conditions might occur due to high viscosity fluid, very low pressure differential, low flow rate, or some combination of these. If nonturbulent flow is suspected, determine the F_R factor according to the procedure for Determining F_R on page 6. For most valve sizing applications, however, nonturbulent flow will not occur. If it is known that nonturbulent flow conditions will not develop within the valve, F_R has a value of 1.0 and simply drops out of the equation.

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Table 2. Equation Constants(1)

Numerical Constant with Subscript		N	w	q	p(2)	ρ	ν	T	d,D
N_1		0.0865	---	m^3/h	kPa	---	---	---	---
		0.865	---	m^3/h	bar	---	---	---	---
		1.00	---	gpm	psia	---	---	---	---
N_2		0.00214	---	---	---	---	---	---	mm
		890	---	---	---	---	---	---	inch
N_4		76000	---	m^3/h	---	---	centistokes	---	mm
		17300	---	gpm	---	---	centistokes	---	inch
N_5		0.00241	---	---	---	---	---	---	mm
		1000	---	---	---	---	---	---	inch
N_6		2.73	kg/h	---	kPa	kg/m^3	---	---	---
		27.3	kg/h	---	bar	kg/m^3	---	---	---
		63.3	lb/h	---	psia	lb/ft^3	---	---	---
N_7(3)	Normal Conditions $T_N = 0°C$	3.94	---	m^3/h	kPa	---	---	deg K	---
		394	---	m^3/h	bar	---	---	deg K	---
	Standard Conditions $T_s = 15.5°C$	4.17	---	m^3/h	kPa	---	---	deg K	---
		417	---	m^3/h	bar	---	---	deg K	---
	Standard Conditions $T_s = 60°F$	1360	---	scfh	psia	---	--- ---	deg R	---
N_8		0.948	kg/h	---	kPa	---	---	deg K	---
		94.8	kg/h	---	bar	---	---	deg K	---
		19.3	lb/h	---	psia	---	---	deg R	---
N_9(3)	Normal Conditions $T_N = 0°C$	21.2	---	m^3/h	kPa	---	---	deg K	---
		2120	---	m^3/h	bar	---	---	deg K	---
	Standard Conditions $T_s = 15.5°C$	22.4	---	m^3/h	kPa	---	---	deg K	---
		2240	---	m^3/h	bar	---	---	deg K	---
	Standard Conditions $T_S = 60°F$	7320	---	scfh	psia	---	---	deg R	---

1. Many of the equations used in these sizing procedures contain a numerical constant, N, along with a numerical subscript. These numerical constants provide a means for using different units in the equations. Values for the various constants and the applicable units are given in the above table. For example, if the flow rate is given in U.S. gpm and the pressures are psia, N_1 has a value of 1.00. If the flow rate is m^3/hr and the pressures are kPa, the N_1 constant becomes 0.0865.
2. All pressures are absolute.
3. Pressure base is 101.3 kPa (1.013 bar) (14.7 psia).

6. Solve for required C_v, using the appropriate equation:

- For volumetric flow rate units—

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

- For mass flow rate units—

$$C_v = \frac{w}{N_6 F_p \sqrt{(P_1 - P_2)\gamma}}$$

In addition to C_v, two other flow coefficients, K_v and A_v, are used, particularly outside of North America. The following relationships exist:

$K_v = (0.865)(C_v)$

$A_v = (2.40 \times 10^{-5})(C_v)$

7. Select the valve size using the appropriate flow coefficient table and the calculated C_v value.

Determining F_p, the Piping Geometry Factor

Determine an F_p factor if any fittings such as reducers, elbows, or tees will be directly attached to the inlet and outlet connections of the control valve that is to be sized. When possible, it is recommended that F_p factors be determined experimentally by using the specified valve in actual tests.

Calculate the F_p factor using the following equation.

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

N_2 = Numerical constant found in table 2

d = Assumed nominal valve size

C_v = Valve sizing coefficient at 100-percent travel for the assumed valve size

In the above equation, ΣK is the algebraic sum of the velocity head loss coefficients of all of the fittings that are attached to the control valve. To calculate ΣK, use the following formula:

$$\Sigma K = K_1 + K_2 + K_{B1} - K_{B2}$$

where,

K_1 = Resistance coefficient of upstream fittings

K_2 = Resistance coefficient of downstream fittings

K_{B1} = Inlet Bernoulli coefficient

K_{B2} = Outlet Bernoulli coefficient

The Bernoulli coefficients, K_{B1} and K_{B2}, are used only when the diameter of the piping approaching the valve is different from the diameter of the piping leaving the valve:

$$K_{B1} \text{ or } K_{B2} = 1 - \left(\frac{d}{D}\right)^4$$

where,

d = Nominal valve size

D = Internal diameter of piping

If the inlet and outlet piping are of equal size, then the Bernoulli coefficients are also equal, $K_{B1} = K_{B2}$, and therefore they are dropped from the equation to calculate ΣK.

The most commonly used fitting in control valve installations is the short-length concentric reducer. The equations necessary to calculate ΣK for this fitting are as follows:

- For an inlet reducer—

$$K_1 = 0.5\left(1 - \frac{d^2}{D^2}\right)^2$$

- For an outlet reducer—

$$K_2 = 1.0\left(1 - \frac{d^2}{D^2}\right)^2$$

- For a valve installed between identical reducers—

$$K_1 + K_2 = 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

Once you have ΣK, calculate F_P according to the equation at the beginning of this section. A sample problem that finds for F_P is on page 9.

Determining q_{max} (the Maximum Flow Rate) or ΔP_{max} (the Allowable Sizing Pressure Drop)

Determine either q_{max} or ΔP_{max} if possible for choked flow to develop within the control valve that is to be sized. The values can be determined by using the following procedures.

Determining q_{max} (the Maximum Flow Rate)

$$q_{max} = N_1 F_L C_v \sqrt{\frac{P_1 - F_F\ P_v}{G_f}}$$

Values for F_F, the liquid critical pressure ratio factor, can be obtained from the following equation:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_v}{P_c}}$$

Values for F_L, the recovery factor for valves installed without fittings attached, can be found in the flow coefficient tables. If the given valve is to be installed with fittings such as reducer attached to it, F_L in the equation must be replace by the quotient F_{LP}/F_p, where:

$$F_{LP} = \left[\frac{K_1}{N_2}\left(\frac{C_v}{d^2}\right)^2 + \frac{1}{F_L^{\,2}}\right]^{-1/2}$$

and

$K_1 = K_1 + K_{B1}$

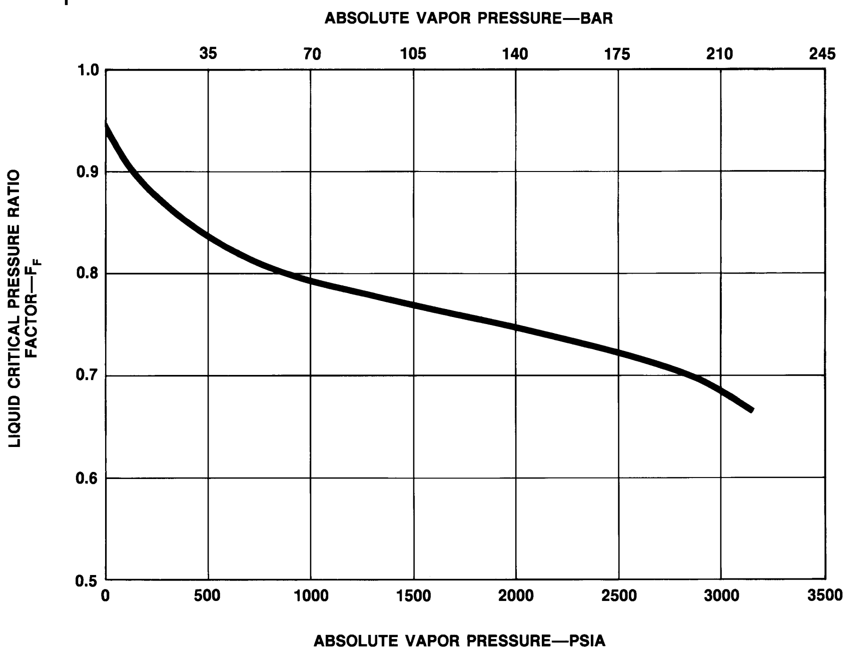
where,

K_1 = Resistance coefficient of upstream fittings

K_{B1} = Inlet Bernoulli coefficient

(See the procedure for Determining F_p, the Piping Geometry Factor, for definitions of the other constants and coefficients used in the above equations.)

Figure 1. Liquid Critical Pressure Ratio Factor for Water



USE THIS CURVE FOR WATER. ENTER ON THE ABSCISSA AT THE WATER VAPOR PRESSURE AT THE VALVE INLET. PROCEED VERTICALLY TO INTERSECT THE CURVE. MOVE HORIZONTALLY TO THE LEFT TO READ THE CRITICAL PRESSURE RATIO, F_F, ON THE ORDINATE.

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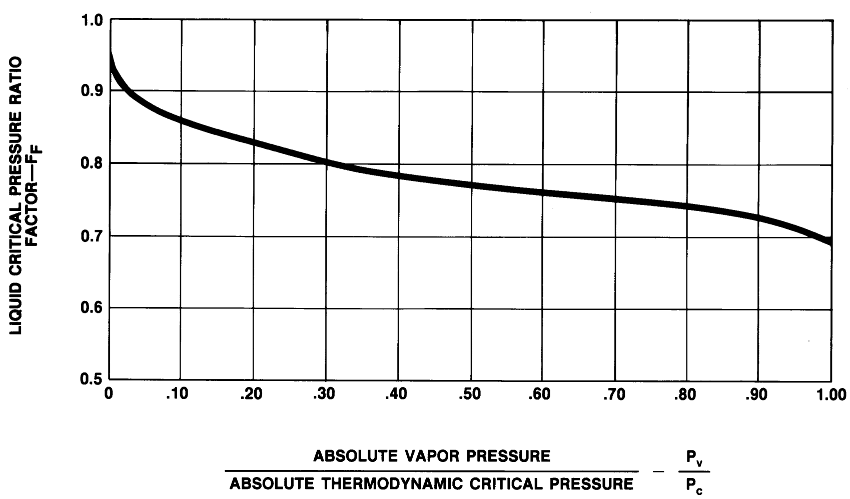
Figure 2. Liquid Critical Pressure Ratio Factor for All Fluids



USE THIS CURVE FOR LIQUIDS OTHER THAN WATER. DETERMINE THE VAPOR PRESSURE/CRITICAL PRESSURE RATIO BY DIVIDING THE LIQUID VAPOR PRESSURE AT THE VALVE INLET BY THE CRITICAL PRESSURE OF THE LIQUID. ENTER ON THE ABSCISSA AT THE RATIO JUST CALCULATED AND PROCEED VERTICALLY TO INTERSECT THE CURVE. MOVE HORIZONTALLY TO THE LEFT AND READ THE CRITICAL PRESSURE RATIO, F_F, ON THE ORDINATE.

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Determining ΔP_{max} (the Allowable Sizing Pressure Drop)

ΔP_{max} (the allowable sizing pressure drop) can be determined from the following relationships:

For valves installed without fittings—

$$\Delta P_{max(L)} = F_L^{\,2}\ (P_1 - F_F\,P_v)$$

For valves installed with fittings attached—

$$\Delta P_{max(LP)} = \left(\frac{F_{LP}}{F_p}\right)^2 (P_1 - F_F\,P_v)$$

where,

P_1 = Upstream absolute static pressure

P_2 = Downstream absolute static pressure

P_v = Absolute vapor pressure at inlet temperature

Values of F_F, the liquid critical pressure ratio factor, can be obtained from figure 1 for water, or figure 2 for all other liquids.

Values of F_L, the recovery factor for valves installed without fittings attached, can be found in the flow coefficient tables. An explanation of how to calculate values of F_{LP}, the recovery factor for valves installed with fittings attached, is presented in the procedure for determining q_{max} (the Maximum Flow Rate).

Once the ΔP_{max} value has been obtained from the appropriate equation, it should be compared with the actual service pressure differential (i.e., $\Delta P = P_1 - P_2$). If ΔP_{max} is less than ΔP, this is an indication that choked flow conditions will exist under the service conditions specified. If choked flow conditions do exist (i.e., $\Delta P_{max} < P_1 - P_2$), then step 6 of the procedure for Sizing Valves for Liquids must be modified by replacing the actual service pressure differential (i.e., $P_1 - P_2$) in the appropriate valve sizing equation with the calculated ΔP_{max} value.

Note

Once it is known that choked flow conditions will develop within the specified valve design (ΔP_{max} is calculated to be less than ΔP), a further distinction can be made to determine whether the choked flow is caused by cavitation or flashing. The choked flow conditions are caused by flashing if the outlet pressure of the given valve is less than the vapor pressure of the flowing liquid. The choked flow conditions are caused by cavitation if the outlet pressure of the valve is greater than the vapor pressure of the flowing liquid.

Determining F_R, the Reynolds Number Factor(3)

Nonturbulent flow conditions can occur in applications where there is high fluid viscosity, very low pressure differential, or some combination of these conditions. In those instances where nonturbulent flow exists, F_R, the Reynolds number factor, must be introduced. Determine F_R using the following procedure.

A. Calculate Re_v, the Reynolds number, using the equation:

$$Re_v = \frac{N_4\,F_d\,q}{\nu\,F_L^{\,1/2}\,C_v^{\,1/2}}\left[\frac{F_L^{\,2}\,C_v^{\,2}}{N_2\,D^4} + 1\right]^{1/4}$$

where,

N_2, N_4 = Numerical constants determined from table 2

D = Internal diameter of the piping

υ = Kinematic viscosity of the fluid

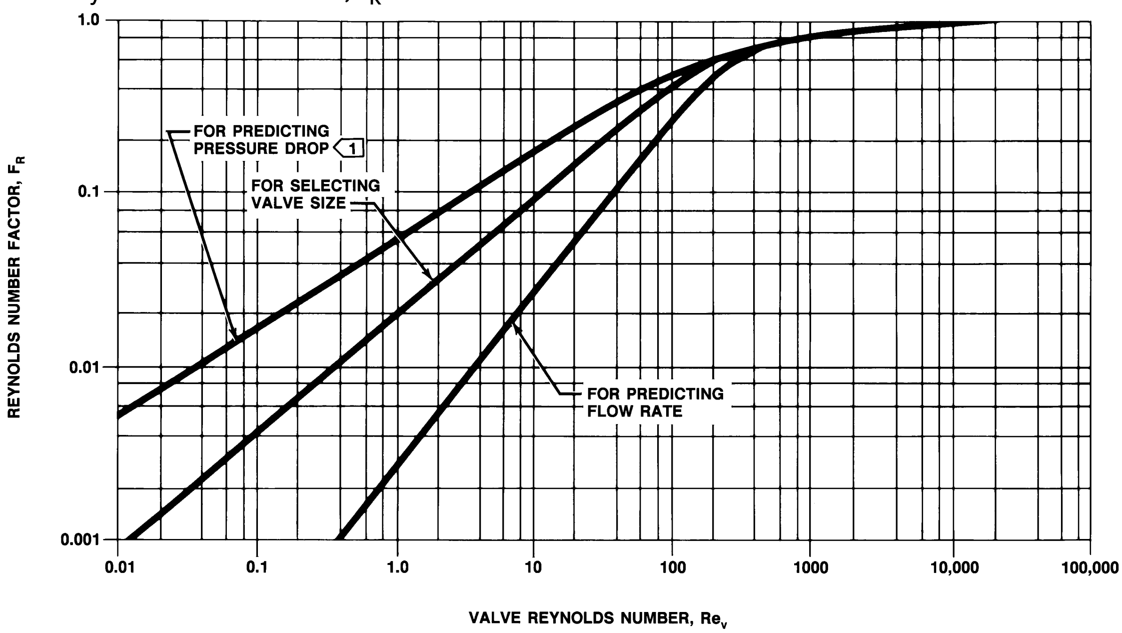
$C_v = C_{vt}$, the pseudo sizing coefficient

$$C_{vt} = \frac{q}{N_1\sqrt{\frac{P_1 - P_2}{G_f}}}$$

F_d = Valve style modifier that is dependent on the valve style used. Valves that use two parallel flow paths, such as double-ported globe-style valves, butterfly valves, or 8500 Series valves, use an F_d of 0.7. For any other valve style, use an F_d of 1.0.

B. Once Re_v is known, use one of the following three approaches to obtain the desired information.

Figure 3. Reynolds Number Factor, F_R



NOTE:
1 THIS CURVE IS IN THE ISA/IEC STANDARD.
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Determining Required Flow Coefficient for Selecting Valve Size

The following treatment is based on valves without attached fittings; therefore, F_p = 1.0.

1. Calculate a pseudo valve flow coefficient C_{vt}, assuming turbulent flow, using:

$$C_{vt} = \frac{q}{N_1 \sqrt{\frac{P_1 - P_2}{G_f}}}$$

2. Calculate Re_v, substituting C_{vt} from step 1 for C_v. For F_L, select a representative value for the valve style desired.

3. Find F_R as follows:

a. If Re_v is less than 56, the flow is laminar, and F_R can be found by using either the curve in figure 3 labeled "FOR SELECTING VALVE SIZE" or by using the equation:

$$F_R = 0.019(Re_v)^{0.67}$$

b. If Re_v is greater than 40,000, the flow can be taken as turbulent, and F_R = 1.0.

c. If Re_v lies between 56 and 40,000, the flow is transitional, and F_R can be found by using either the curve in figure 3 or the column headed "Valve Size Selection" in table 3.

Table 3. Reynolds Number Factor, F_R, for Transitional Flow

F_R (1)	Valve Reynolds Number, Re_v (1)		
	Valve Size Selection	Flow Rate Prediction	Pressure Drop Prediction
0.284	56	106	30
0.32	66	117	38
0.36	79	132	48
0.40	94	149	59
0.44	110	167	74
0.48	130	188	90
0.52	154	215	113
0.56	188	253	142
0.60	230	298	179
0.64	278	351	224
0.68	340	416	280
0.72	471	556	400
0.76	620	720	540
0.80	980	1100	870
0.84	1560	1690	1430
0.88	2470	2660	2300
0.92	4600	4800	4400
0.96	10,200	10,400	10,000
1.00	40,000	40,000	40,000

1. Linear interpolation between listed values is satisfactory.

4. Obtain the required C_V from:

$$C_v = \frac{C_{vt}}{F_R}$$

5. After determining C_V, check the F_L value for the selected valve size and style. If this value is significantly different from the value selected in step 2, use the new value, and repeat steps 1 through 4.

Predicting Flow Rate

1. Calculate q_t, assuming turbulent flow, using:

$$q_t = N_1 C_v \sqrt{\frac{P_1 - P_2}{G_f}}$$

2. Calculate Re_V, substituting qt for q from step 1.

3. Find F_R as follows:

a. If Re_V is less than 106, the flow is laminar, and F_R can be found by using the curve in figure 3 labeled "FOR PREDICTING FLOW RATE" or by using the equation:

$$F_R = 0.0027\, Re_v$$

b. If Re_V is greater than 40,000, the flow can be taken as turbulent, and F_R = 1.0.

c. If Re_V lies between 106 and 40,000, the flow is transitional, and F_R can be found by using either the curve in figure 3 or the column headed "Flow Rate Prediction" in table 3.

4. Obtain the predicted flow rate from:

$$q = F_R\, q_t$$

Predicting Pressure Drop

1. Calculate Re_V.

2. Find F_R as follows:

a. If Re_V is less than 30, the flow is laminar, and F_R can be found by using the curve in figure 3 labeled "FOR PREDICTING PRESSURE DROP" or by using the equation:

$$F_R = 0.052(Re_v)^{0.5}$$

b. If Re_V is greater than 40,000, the flow can be taken as turbulent, and F_R = 1.0.

c. If Re_V lies between 30 and 40,000, the flow is transitional, and F_R can be found by using the curve in figure 3 or the column headed "Pressure Drop Prediction" in table 3.

3. Calculate the predicted pressure drop from:

$$\Delta p = G_f \left(\frac{q}{N_1\, F_R\, C_v} \right)^2$$

Liquid Sizing Sample Problems

Liquid Sizing Sample Problem No. 1

Assume an installation that, at initial plant start-up, will not be operating at maximum design capability. The lines are sized for the ultimate system capacity, but there is a desire to install a control valve now which is sized only for currently anticipated requirements. The line size is NPS 8, and a Fisher CL300 ES valve with an equal percentage cage has been specified. Standard concentric reducers will be used to install the valve into the line. Determine the appropriate valve size.

1. Specify the necessary variables required to size the valve:

- Desired valve design—CL300 ES valve with equal percentage cage and an assumed valve size of NPS 3.
- Process fluid—liquid propane
- Service conditions—

q = 800 gpm
P_1 = 300 psig = 314.7 psia
P_2 = 275 psig = 289.7 psia
ΔP = 25 psi
T_1 = 70°F
G_f = 0.50
P_v = 124.3 psia
P_v = 616.3 psia

2. Determine an N_1 value of 1.0 from table 2.

3. Determine F_p, the piping geometry factor.

Because it is proposed to install an NPS 3 valve in an NPS 8 line, it will be necessary to determine the piping geometry factor, F_p, which corrects for losses caused by fittings attached to the valve.

$$F_p = \left[1 + \frac{\Sigma K}{N_2} \left(\frac{C_v}{d^2} \right)^2 \right]^{-1/2}$$

where,

N_2 = 890, from table 2
d = 3 in., from step 1
C_v = 121, from the flow coefficient table for a CL300, NPS 3 ES valve with equal percentage cage

To compute ΣK for a valve installed between identical concentric reducers:

$$\Sigma k = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{(3)^2}{(8)^2}\right)^2$$

$$= 1.11$$

where,

D = NPS 8, the internal diameter of the piping so,

$$F_p = \left[1 + \frac{1.11}{890}\left(\frac{121}{3^2}\right)^2\right]^{-1/2}$$

$$= 0.90$$

4. Determine ΔP_{max} (the Allowable Sizing Pressure Drop).

Based on the small required pressure drop, the flow will not be choked (i.e., $\Delta P_{max} > \Delta P$).

5. Determine F_R, the Reynolds number factor.

Under the specified service conditions, no correction factor will be required for Re_v (i.e., F_R = 1.0).

6. Solve for C_v using the appropriate equation.

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)(0.90)\sqrt{\frac{25}{0.5}}}$$

$$= 125.7$$

7. Select the valve size using the flow coefficient table and the calculated C_v value.

The required C_v of 125.7 exceeds the capacity of the assumed valve, which has a C_v of 121. Although for this example it may be obvious that the next larger size (NPS 4) would be the correct valve size, this may not always be true, and a repeat of the above procedure should be carried out.

Assuming an NPS valve, C_v = 203. This value was determined from the flow coefficient table for a CL300, NPS 4 ES valve with an equal percentage cage.

Recalculate the required C_v using an assumed C_v value of 203 in the F_p calculation.

where,

$$\Sigma k = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{16}{64}\right)^2$$

$$= 0.84$$

and

$$F_p = \left[1.0 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d_2}\right)^2\right]^{-1/2}$$

$$= \left[1.0 + \frac{0.84}{890}\left(\frac{203}{4^2}\right)^2\right]^{-1/2}$$

$$= 0.93$$

and

$$C_v = \frac{q}{N_q F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)(0.93)\sqrt{\frac{25}{0.5}}}$$

$$= 121.7$$

This solution indicates only that the NPS 4 valve is large enough to satisfy the service conditions given. There may be cases, however, where a more accurate prediction of the C_v is required. In such cases, the required C_v should be redetermined using a new F_p value based on the C_v value obtained above. In this example, C_v is 121.7, which leads to the following result:

$$F_p = \left[1.0 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

$$= \left[1.0 + \frac{0.84}{890}\left(\frac{121.7}{4^2}\right)^2\right]^{-1/2}$$

= 0.97

The required C_v then becomes:

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)(0.97)\sqrt{\frac{25}{0.5}}}$$

= 116.2

Because this newly determined C_v is very close to the C_v used initially for this recalculation (i.e., 116.2 versus 121.7), the valve sizing procedure is complete, and the conclusion is that an NPS 4 valve opened to about 75 percent of total travel should be adequate for the required specifications.

Liquid Sizing Sample Problem No. 2

Determine the appropriate valve size for the following application. A Fisher ED valve with a linear cage has been specified. Assume piping size will be the same as the valve size.

1. Specify the variables required to size the valve:

- Desired valve design—a CL300 ED valve with linear cage
- Process fluid—water
- Service conditions—

q = 2200 gpm
P_1 = 375 psig = 389.7 psia
P_2 = 100 psig = 114.7 psia
$\Delta P = P_1 - P_2$ = 275 psi
T_1 = 270°F
G_f = 0.93
P_v = 41.9 psia

2. Determine an N_1 value of 1.0 from table 2.

3. Determine F_p, the piping geometry factor.

Because valve size equals line size, F_p = 1.0

4. Determine ΔP_{max}, the allowable sizing pressure drop.

$$\Delta P_{max} = F_L{}^2(P_1 - F_F P_v)$$

where,

P_1 = 389.7 psia, given in step 1
P_2 = 114.7 psia, given in step 1
P_v = 41.9 psia, given in step 1
F_F = 0.90, determined from figure 1

Assume F_L = 0.84 (from the flow coefficient table, 0.84 appears to be a representative F_L factor for ED valves with a linear cage.) Therefore,

$$\Delta P_{max} = (0.84)^2\ [389.7 - (0.90)(41.9)]$$

= 248.4 psi

$\Delta P_{max} < \Delta P$ (i.e., 248.4 < 275.0) indicates that choked flow conditions will exist. Because, from the initial specifications, it is known that the outlet pressure (P_2 = 114.7 psia) is greater than the vapor pressure of the flowing water (P_v = 41.9 psia), the conditions of choked flow, in this case, are caused by cavitation. Therefore, some further consideration of valve style and trim selection might be necessary.

5. Determine F_R, the Reynolds number factor.

For water at the pressure drop given, no Re_v correction will be required (i.e., F_R = 1.0).

6. Solve for required C_v using ΔP_{max}.

$$C_v = \frac{q}{N_1 F_p F_R \sqrt{\frac{\Delta P_{max}}{G_f}}}$$

$$= \frac{2200}{\sqrt{\frac{248.4}{0.93}}}$$

$$= 134.6$$

7. Select the valve size using the flow coefficient table and the calculated C_v value.

An NPS 3 CL300 ED valve with a linear cage has a C_v of 133 at 80 percent travel and should be satisfactory from a sizing standpoint. However, F_L was assumed to be 0.84, whereas for the NPS 3 ED valve at maximum travel, F_L is 0.82. Reworking the problem using the actual value of F_L yields ΔP_{max} = 236.7 psi. These result in required C_v values of 137.6 (using the assumed F_L of 0.84) and 137.9 (using the actual F_L value of 0.82), which would require the valve to be 85 percent open.

Liquid Sizing Sample Problem No. 3

Assume there is a desire to use a Fisher V100 valve in a proposed system controlling the flow of a highly viscous Newtonian lubricating oil. The system design is not yet complete, and the line size has not been established. Therefore, assume that the valve will be line size. Determine valve size.

1. Specify the variables required to size the valve:

- Desired valve—V100 valve
- Process fluid—lubricating oil
- Service conditions—

$q = 300\ m^3/h$
$P_1 = 7.0$ bar gauge = 8.01 bar absolute
$P_2 = 5.0$ bar gauge = 6.01 bar absolute
$\Delta P = 2.0$ bar
P_v = negligible
$T_1 = 15.6°C = 289°K$
$G_f = 0.908$
$\upsilon = 8000$ centistokes

2. Determine N_1 from table 2.

For the specified units of m^3/h and bar, $N_1 = 0.865$

3. Determine F_p, the piping geometry factor.

Assuming valve size equals line size, $F_p = 1.0$.

4. Determine ΔP_{max}, the allowable sizing pressure drop.

Based on the required pressure drop, the flow will not be choked.

5. Determine F_R, the Reynolds number factor.

a. Calculate the pseudo sizing coefficient, C_{vt}:

$$C_{vt} = \frac{q}{N_1 \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{300}{0.865 \sqrt{\frac{2.0}{0.908}}}$$

= 234

b. Calculate Re_v, the Reynolds number:

$$Re_v = \frac{N_4 F_d q}{\nu F_L^{1/2} C_v^{1/2}} \left[\frac{(F_L C_v)^2}{N_2 D^4} + 1 \right]^{1/4}$$

where,

$N_2 = 0.00214$, from table 2
$N_4 = 7600$, from table 2
$C_v = 234$, the value determined for the pseudo sizing coefficient, C_{vc}.

D = 80 mm. The pseudo sizing coefficient of 234 indicates that an 80 mm (NPS 3) V100 valve, which has a C_v of 372 at 90 degrees of ball rotation, is required (see the flow coefficient table). Assuming that line size will equal body size, the 80 mm (NPS 3) V100 will be used with 80 mm piping

$q = 300\ m^3/h$
$\upsilon = 8000$ centistokes from step 1
$F_d = 1.0$ because the V100 valve has a single flow passage

From the flow coefficient table, the F_L value for an 80 mm (NPS 3) V100 valve is 0.68. Therefore,

$$Re_v = \frac{(7600)(1.0)(300)}{(8000)\sqrt{(0.68)(234)}} \left[\frac{(0.68)^2 (234)^2}{(0.00214)(80)^4} + 1 \right]^{1/4}$$

= 241

c. Read F_R off the curve, For Selecting Valve Size, in figure 3 using an Re_v of 241, $F_R = 0.62$.

6. Solve for required C_v using the appropriate equation.

$$C_v = \frac{q}{N_1 F_p F_R \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{300}{0.865(1.0)(0.62)\sqrt{\frac{2.0}{0.908}}}$$

= 377

7. Select the valve size using the flow coefficient table and the calculated C_v value.

The assumed valve (80 mm or NPS 3), which has a C_v of 372 at 90 degrees of ball rotation, is obviously too small for this application. For this example, it is also obvious that the next larger size (100 mm or NPS 4), which has a rated C_v of 575 and an F_L of 0.61, would be large enough.

To obtain a more precise valve sizing measurement, the problem can be reworked using the calculated C_v value of 377. For the required 100 mm (NPS 4) V100 valve, a C_v of 377 occurs at a valve travel of about 80 degrees, and this corresponds to an F_L value of 0.71. Reworking the problem using this corresponding value of

FL = 0.71 yields F_R = 0.61 and C_v = 383. Because the tabulated C_v value, 377, is very close to the recalculated C_v value, 383, the valve sizing procedure is complete, and the determined 100 mm (NPS 4) valve opened to 80 degrees valve travel should be adequate for the required specifications.

Sizing Valves for Compressible Fluids

Following is a six-step procedure for the sizing of control valves for compressible flow using the ISA standardized procedure. Each of these steps is important and must be considered during any valve sizing procedure. Steps 3 and 4 concern the determination of certain sizing factors that may or may not required in the sizing equation depending on the service conditions of the sizing problem. If it is necessary for one or both of these sizing factors to be included in the sizing equation for a particular sizing problem, refer to the appropriate factor determination section(s), which is referenced and located in the following text.

1. Specify the necessary variables required to size the valve as follows:

- Desired valve design (e.g., Fisher ED with linear cage); refer to the appropriate valve flow coefficient table in this catalog

- Process fluid (e.g., air, natural gas, steam, etc.) and

- Appropriate service conditions—

q, or w, P_1, P_2 or ΔP, T_1, G_g, M, k, Z, and γ_1

The ability to recognize which terms are appropriate for a specific sizing procedure can only be acquired through experience with different valve sizing problems. If any of the above terms appear to be new or unfamiliar, refer to table 1 for a complete definition.

2. Determine the equation constant, *N*.*N* is a numerical constant contained in each of the flow equations to provide a means for using different systems of units. values for these various constants and their applicable units are given in table 2.

Use either N_7 or N_9 if sizing the valve for a flow rate in volumetric units (i.e., scfh or m^3/h). Which of the two constants to use depends upon the specified service conditions. N_7 can be used only if the specific gravity, G_g, of the flowing gas has been specified along with the other required service conditions. N_9 can be used only if the molecular weight, *M*, of the gas has been specified.

Use either N_6 or N_8 if sizing the valve for a flow rate in mass units (i.e., lb/h or kg/h). Which of the two constants to use depends upon the specified service conditions. N_6 can be used only if the specific weight, γ_1 of the flowing gas has been specified along with the other required service conditions. N_8 can be used only if the molecular weight, M, of the gas has been specified.

3. Determine F_p, the piping geometry factor. F_p is a correction factor that accounts for any pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valves to be sized. If such fittings are attached to the valve, the F_p factor must be considered in the sizing procedure. If, however, no fittings are attached to the valve, F_p has a value of 1.0 and simply drops out of the sizing equation.

Also, for rotary valves valves with reducers, F_p factors are included in the appropriate flow coefficient table. For other valve designs and fitting styles, determine the F_p factors by using the procedure for Determining F_p the Piping Geometry Factor, which is located in the section for Sizing Valves for Liquids.

4. Determine Y, the expansion factor, as follows:

$$Y = 1 - \frac{x}{3\,F_k\,x_T}$$

where,

F_k = k/1.4 the ratio of specific heats factor

k = Ratio of specific heats

x = P/P1, the pressure drop ratio

x_T = The pressure drop ratio factor for valves installed without attached fittings. More definitively, x_T is the pressure drop ratio required to produce critical, or maximum, flow through the valve when F_k = 1.0.

If the control valve to be installed has fittings such as reducers or elbows attached to it, then their effect is accounted for in the expansion factor equation by replacing the x_T term with a new factor x_{TP}. A procedure for determining the x_{TP} factor is described in the section for Determining x_{TP}, the Pressure Drop Ratio Factor.

Note

Conditions of critical pressure drop are realized when the value of x become equal to or exceed the appropriate value of the product of either $F_k\,x_T$ or $F_k\,x_{TP}$ at which point:

$$y = 1 - \frac{x}{3\,F_k\,x_T} = 1 - 1/3 = 0.667$$

Although in actual service, pressure drop ratios can, and often will, exceed the indicated critical values, it should be kept in mind that this is the point where critical flow conditions develop. Thus, for a constant P_1, decreasing P_2 (i.e., increasing ΔP) will not result in an increase in the flow rate through the valve. Values of x, therefore, greater than the product of either $F_k x_T$ or $F_k x_{TP}$ must never be substituted in the expression for Y. This means that Y can never be less than 0.667. This same limit on values of x also applies to the flow equations that are introduced in the next section.

5. Solve for the required C_v using the appropriate equation:

For volumetric flow rate units—

- If the specific gravity, G_g, of the gas has been specified:

$$C_v = \frac{q}{N_7 F_p P_1 Y \sqrt{\frac{x}{G_g T_1 Z}}}$$

- If the molecular weight, M, of the gas has been specified:

$$C_v = \frac{q}{N_9 F_p P_1 Y \sqrt{\frac{x}{M T_1 Z}}}$$

For mass flow rate units—

- If the specific weight, γ_1, of the gas has been specified:

$$C_v = \frac{w}{N_6 F_p Y \sqrt{x P_1 \gamma_1}}$$

- If the molecular weight, M, of the gas has been specified:

$$C_v = \frac{w}{N_8 F_p P_1 Y \sqrt{\frac{x M}{T_1 Z}}}$$

In addition to C_v, two other flow coefficients, K_v and A_v, are used, particularly outside of North America. The following relationships exist:

$$K_v = (0.865)(C_v)$$

$$A_v = (2.40X10^{-5})(C_v)$$

6. Select the valve size using the appropriate flow coefficient table and the calculated C_v value.

Note

Once the valve sizing procedure is completed, consideration can be made for aerodynamic noise prediction. To determine the gas flow sizing coefficient (C_g) for use in the Fisher aerodynamic noise prediction technique, use the following equation:

$$\mathbf{C_g = 40C_v \sqrt{x_T}}$$

Determining x_{TP}, the Pressure Drop Ratio Factor

If the control valve is to be installed with attached fittings such as reducers or elbows, then their effect is accounted for in the expansion factor equation by replacing the x_T term with a new factor, x_{TP}.

$$x_{TP} = \frac{x_T}{F_p^{\,2}} \left[1 + \frac{x_T K_i}{N_5} \left(\frac{C_v}{d^2} \right)^2 \right]^{-1}$$

where,

N_5 = Numerical constant found in table 2

d = Assumed nominal valve size

C_v = Valve sizing coefficient from flow coefficient table at 100 percent travel for the assumed valve size

F_p = Piping geometry factor

x_T = Pressure drop ratio for valves installed without fittings attached. x_T values are included in the flow coefficient tables.

In the above equation, K_i, is the inlet head loss coefficient, which is defined as:

$$K_i = K_1 + K_{B1}$$

where,

K_1 = Resistance coefficient of upstream fittings (see the procedure for Determining F_p, the Piping Geometry Factor, which is contained in the section for Sizing Valves for Liquids).

K_{B1} = Inlet Bernoulli coefficient (see the procedure for Determining F_p the Piping Geometry Factor, which is contained in the section for Sizing Valves for Liquids).

Compressible Fluid Sizing Sample Problems

Compressible Fluid Sizing Sample Problem No. 1

Determine the size and percent opening for a Fisher V250 valve operating with the following service conditions. Assume that the valve and line size are equal.

1. Specify the necessary variables required to size the valve:

- Desired valve design—V250 valve
- Process fluid—Natural gas
- Service conditions—

P_1 = 200 psig = 214.7 psia
P_2 = 50 psig = 64.7 psia
ΔP = 150 psi
$x = \Delta P/P_1$ = 150/214.7 = 0.70
T_1 = 60°F = 520°R
M = 17.38
G_g = 0.60
k = 1.31
q = 6.0 x 10^6 scfh

2. Determine the appropriate equation constant, *N*, from table 2.

Because both G_g and *M* have been given in the service conditions, it is possible to use an equation containing either N_7 or N_9. In either case, the end result will be the same. Assume that the equation containing G_g has been arbitrarily selected for this problem. Therefore, N_7 = 1360.

3. Determine F_p, the piping geometry factor. Since valve and line size are assumed equal, F_p = 1.0.

4. Determine Y, the expansion factor.

$$F_k = \frac{k}{1.40}$$

$$= \frac{1.31}{1.40}$$

$$= 0.94$$

It is assumed that an NPS 8 V250 Valve will be adequate for the specified service conditions. From the flow coefficient table, x_T for an NPS 8 V250 valve at 100-percent travel is 0.137.

x = 0.70 (This was calculated in step 1.)

Since conditions of critical pressure drop are realized when the calculated value of x becomes equal to or exceeds the appropriate value of $F_k x_T$, these values should be compared.

$$F_k x_T = (0.94)(0.137)$$

$$= 0.129$$

Because the pressure drop ratio, x = 0.70 exceeds the calculated critical value, $F_k x_T$ = 0.129, choked flow conditions are indicated. Therefore, Y = 0.667and X_{LIM} to $F_k x_T$ = 0.129.

5. Solve for required C_v using the appropriate equation.

$$C_v = \frac{q}{N_7 \, F_p \, P_1 \, Y \sqrt{\frac{x}{G_g \, T_1 \, Z}}}$$

The compressibility factor, Z, can be assumed to be 1.0 for the gas pressure and temperature given and F_p = 1 because valve size and line size are equal.

So,

$$C_v = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\frac{0.129}{(0.6)(520)(1.0)}}}$$

= 1515

6. Select the valve size using the appropriate flow coefficient table and the calculated C_v value.

The above result indicates that the valve is adequately sized (i.e., rated C_v = 2190). To determine the percent valve opening, note that the required C_v occurs at approximately 83 degrees for the NPS 8 V250 valve. Note also that, at 83 degrees opening, the x_T value is 0.525, which is substantially different from the rated value of 0.137 used initially in the problem. The next step is to rework the problem using the x_T value for 83 degrees travel.

The $F_k x_T$ product must now be recalculated.

$$x = F_k x_T$$

$$= (0.94)(0.252)$$

$$= 0.237$$

The required C_v now becomes:

$$C_v = \frac{q}{N_7 \, F_p \, P_1 \, Y \sqrt{\frac{x}{G_g \, T_1 \, Z}}}$$

$$= \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\frac{0.237}{(0.6)(520)(1.0)}}}$$

$$= 1118$$

The reason that the required C_v has dropped so dramatically is attributable solely to the difference in the x_T values at rated and 83 degrees travel. A C_v of 1118 occurs between 75 and 80 degrees travel.

The appropriate flow coefficient table indicates that x_T is higher at 75 degrees travel than at 80 degrees travel. Therefore, if the problem were to be reworked using a higher x_T value, this should result in a further decline in the calculated required C_v.

Reworking the problem using the x_T value corresponding to 78 degrees travel (i.e., $x_T = 0.328$) leaves:

$$x = F_k\, x_T$$

$$= (0.94)(0.328)$$

$$= 0.308$$

and,

$$C_v = \frac{q}{N_7\, F_p\, P_1\, Y \sqrt{\frac{x}{G_g\, T_1\, Z}}}$$

$$= \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\frac{0.308}{(0.6)(520)(1.0)}}}$$

$$= 980$$

The above C_v of 980 is quite close to the 75 degree travel C_v. The problem could be reworked further to obtain a more precise predicted opening; however, at this point it can be stated that, for the service conditions given, an NPS 8 V250 valve installed in an NPS 8 line will be approximately 75 degrees open.

Compressible Fluid Sizing Sample Problem No. 2

Assume steam is to be supplied to a process designed to operate at 250 psig. The supply source is a header maintained at 500 psig and 500°F. An NPS 6 line from the steam main to the process is being planned. Also, make the assumption that if the required valve size is less than NPS 6, it will be installed using concentric reducers. Determine the appropriate Fisher ED valve with a linear cage.

1. Specify the necessary variables required to size the valve:

a. Desired valve design—CL300 ED valve with a linear cage. Assume valve size is NPS 4.

b. Process fluid—superheated steam

c. Service conditions—

w = 125,000 lb/h
P_1 = 500 psig = 514.7 psia
P_2 = 250 psig = 264.7 psia
ΔP = 250 psi
$x = \Delta P/P_1 = 250/514.7 = 0.49$
T_1 = 500°F
γ_1 = 1.0434 lb/ft^3 (from steam properties handbook)
k = 1.28 (from steam properties handbook)

2. Determine the appropriate equation constant, N, from table 2.

Because the specified flow rate is in mass units, (lb/h), and the specific weight of the steam is also specified, the only sizing equation that can be used in that which contains the N_6 constant. Therefore,

$$N_6 = 63.3$$

3. Determine F_p, the piping geometry factor.

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

N2 = 890, determined from table 2
d = 4 in.
C_v = 236, which is the value listed in the flow coefficient table for an NPS 4 ED valve at 100-percent total travel.

and,

$$\Sigma k = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{4^2}{6^2}\right)^2$$

$$= 0.463$$

Finally:

$$F_p = \left[1 + \frac{0.463}{890}\left(\frac{(1.0)(236)}{(4)^2}\right)^2\right]^{-1/2}$$

$= 0.95$

4. Determine Y, the expansion factor.

$$Y = 1 - \frac{x}{3\,F_k\,x_{TP}}$$

where,

$$F_k = \frac{k}{1.40}$$

$$= \frac{1.28}{1.40}$$

$$= 0.91$$

$$x = 0.49 \text{(This was calculated in step 1.)}$$

Because the NPS 4 valve is to be installed in an NPS 6 line, the x_T term must be replaced by x_{TP},

$$x_{TP} = \frac{x_T}{F_p{}^2}\left[1 + \frac{x_T\,K_i}{N_5}\left(\frac{C_v}{d^2}\right)^2\right]^{-1}$$

where,

N_5 = 1000, from table 2
d = 4 in.
F_p = 0.95, determined in step 3
x_T = 0.688, a value determined from the appropriate listing in the flow coefficient table
C_v = 236, from step 3

and

$$K_i = K_1 + K_{B1}$$

$$= 0.5\left(1 - \frac{d^2}{D^2}\right)^2 + \left[1 - \left(\frac{d}{D}\right)^4\right]$$

$$= 0.5\left(1 - \frac{4^2}{6^2}\right)^2 + \left[1 - \left(\frac{4}{6}\right)^4\right]$$

$$= 0.96$$

where D = 6 in.

so:

$$x_{TP} = \frac{0.69}{0.95^2}\left[1 + \frac{(0.69)(0.96)}{1000}\left(\frac{236}{4^2}\right)^2\right]^{-1}$$

$$= 0.67$$

Finally:

$$Y = 1 - \frac{x}{3\,F_k\,x_{TP}}$$

$$= 1 - \frac{0.49}{(3)(0.91)(0.67)}$$

$$= 0.73$$

5. Solve for required C_v using the appropriate equation.

$$C_v = \frac{w}{N_6\,F_p\,Y\sqrt{x\,P_1\,\gamma_1}}$$

$$C_v = \frac{125,000}{(63.3)(0.95)(0.73)\sqrt{(0.49)(514.7)(1.0434)}}$$

$$= 176$$

6. Select the valve size using the appropriate flow coefficient table and the calculated C_v value.

Refer to the flow coefficient tables for ED valves with linear cage. Because the assumed NPS 4 valve has a C_v of 236 at 100-percent travel and the next smaller size (NPS 3) has a C_v of only 148, it can be surmised that the assumed size is correct. In the event that the calculated required C_v had been small enough to have been handled by the next smaller size or if it had been larger than the rated C_v for the assume size, it would have been necessary to rework the problem again using values for the new assumed size.

Version 1.4 of the Fisher Sizing Program offers the ability to estimate the vapor pressure of fluids at the given service temperature. These estimations are based on a correlation of actual P_V data for the specified fluid to the following form of the Wagner equation:

$$\ln P_{vpr} = \frac{a\tau + b\tau^{1.5} + c\tau^{3} + d\tau^{6}}{T_r} \quad T_{r\text{-}min} \leq T_r \leq T_{r\text{-}max} \tag{1}$$

where,
P_{vpr} = reduced vapor pressure = P_V/P_C
T_r = reduced temperature = T/T_C
P_V = saturated vapor pressure
P_C = thermodynamic critical pressure
$\tau = 1 - T_r$
$T_{r\text{-}min}$ = reduced minimum temperature - T_{min}/T_C
$T_{r\text{-}max}$ = reduced maximum temperature = T_{max}/T_C
T_{min} = minimum valid calculation temperature
T_{max} = maximum valid calculation temperature

This equation was selected because of it's overall superiority to more widely used but simpler equations. This equation replicates the actual shape of the vapor pressure curve well and yields accurate results over a fairly broad temperature range. For the fluids contained in the FSP v1.4 internal (non-editable) library, typical results fall within the lessor of $\pm$1% or $\pm$1 psi of the reference values for the individual fluids. Worst case results are usually within the lessor of $\pm$3% or $\pm$5 psi. While the Antoine equation is widely used for vapor pressure correlations, it is, in general, more limited in range over which accurate results can be obtained. Furthermore it is strictly limited to use within the prescribed temperature range.

The coefficients a, b, c, and d have been determined for all of the fluids contained in the internal fluids library (non-editable) by curve fitting to published data. Provisions to input these values for user defined fluids are provided in the external library (editable). While these coefficients can be found for some fluids in the general literature, they are not widely available. For select cases considered to be commercially strategic, support is available to determine these coefficients for customer fluids. To obtain this support, please complete the data form on the reverse side of this sheet and send to Applications Engineering. Please note that a minimum of ten data points are recommended to define a good baseline curve.

As is evident on inspection of equation (1), the value of the thermodynamic critical pressure is used in calculating the value of the vapor pressure. The P_V coefficients supplied in the internal library are based on the value of the critical pressure contained in the library. Therefore, in order to preserve the integrity of the P_V calculation, the value of P_C cannot be changed within a calculation case if the vapor pressure is being calculated. If it is desired to use an alternate value of P_C in lieu of the value supplied by the fluid library, it will be necessary to disable the “calculate P_V” option and manually input both the P_C and P_V values.

The temperatures T_{min} and T_{max} establish the limits of the temperature range over which the calculation is considered valid (this version of the program will not contend with extrapolations beyond these limits). Typically the upper temperature limit coincides with the thermodynamic critical pressure, although there are instances where this is not the case and $T_{max} < T_C$. In no case is T_{min} less than the triple point temperature.

The following information is required in order to determine the vapor pressure coefficients, a, b, c, and d, for use in the external fluids library. Please supply all required information and FAX or mail to your sales office.

Fluid Name: ____________

Chemical Formula: ________

Physical Constants:
- Critical Temperature, T_c = ____________
- Critical Pressure, P_c = ____________
- Triple Point Temperature, T_{tp} = ____________
- Molecular Weight, MW = ____________
- Specific Heat Ratio, k_o = ____________

Data Source*:
- ☐ Lab Data ________
- ☐ Technical Ref. ________ ____________
- ☐ Other ____________

*Optional information not required for coefficient determination

Customer ____________
Representative ____________
Office ____________

May this information be share with other Fisher Sizing Program users? ☐Yes ☐No

Vapor Pressure Data(1)

Data Point	T, (units)	P_V, (units)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

1. A minimum of ten data points are recommended.

Introduction

The behavior of flowing pulp stock is different from water or viscous Newtonian flows. It is necessary to account for this behavior when determining the required valve size. Methods have been developed to aid in determining correct valve size for these types of applications. The purpose of the following pages is to provide an overview of the current recommended sizing method and discuss specific implementations of the technology in the Fisher Sizing Program, Rev. 1.4.

Basic Method

The pulp stock sizing calculation uses the following modified form of the basic liquid sizing equation:

$$Q = C_v K_p \sqrt{\Delta P} \qquad (1)$$

where:
ΔP = sizing pressure drop, psid
C_v = valve flow coefficient
K_p = pulp stock correction factor
Q = volumetric flow rate, gpm

The crux of this calculation is the pulp stock correction factor, K_p. This factor is the ratio of the pulp stock flow rate to water flow rate under the same flowing conditions. It therefore modifies the relationship between Q, C_v, and ΔP to account for the effects of the pulp stock relative to that for water. The value of this parameter in theory depends on many factors such as pulp stock type, consistency, freeness, fiber length, valve type and pressure drop. However, in practice it appears that the dominant effects are due to three primary factors: pulp type, consistency and pressure differential. Values of K_p for three different pulp stock types are shown in Figures 1-3. These methods are based on the technology presented in reference (1).

Once the value of the pulp stock correction factor is known, determining the required flow coefficient or flow rate is equivalent to basic liquid sizing. For example, consider the following:

Q = 1000 gpm of 8% consistency kraft pulp stock
ΔP = 16 psid
P_1 = 150 psia

Kp $\approx$ 0.83 (from Figure 2), therefore,

$$C_v = \frac{Q}{K_p \sqrt{\Delta P}} = \frac{1000}{(0.83)\sqrt{16}} = 301$$

Effect of fluid vaporization and choked flow of pulp stock on the effective pulp stock correction factor is not known as of this writing. The effects of pulp stock on sound pressure level and cavitation are discussed below.

The uncertainty of this calculation is currently unknown, but should be considered to be greater than for normal liquid sizing. As noted above, only the major effects of stock type and consistency and pressure drop are accounted for. Tests conducted by Emerson Automation Solutions at Western Michigan University on low consistency stock affirm the general behavior reported in (1), although in some cases the degree of correction was not as significant. This suggests that the overall variance of this relatively simple method may be moderate (e.g., estimated to be in excess of $\pm$10%).

Fisher Sizing Program Implementation

The pulp stock correction factor is automatically calculated and utilized in sizing when Pulp Stock Sizing is selected. This value is determined on the basis of the pulp stock type, consistency and pressure drop. The equations used to calculate this value were used to generate the curves in Figures 1-3. This value is displayed in the Intermediate Results area of the screen and cannot be manually overridden. Checks for valid consistency range and minimum pressure drop are conducted. The calculation is aborted and an appropriate warning message is displayed if either of these conditions is not satisfied.

The sizing calculations are carried out in a manner equivalent to basic liquid sizing. The sizing ΔP is determined in the conventional manner, i.e., it is the lessor of ΔP_{actual} or $\Delta P_{allowable}$. [Note that for best accuracy the allowable pressure differential computations should be based on the K_m (F_L^2) associated with the valve at the actual opening.] The fluid vapor pressure and critical pressure drop ratio (P_V, r_c) are based on the properties of fresh water. The fluid vapor pressure may be input, but the critical pressure used in calculating r_c is that of fresh water. Whereas the effect of choked flow on K_p is unknown, the sizing program defaults to the conservative alternative and bases K_p on ΔP_{sizing} as determined above.

Pressure differential (ΔP) calculations are not currently offered because of the dependency of the Kp factor on ΔP. If this value is desired it will be necessary to estimate it manually. It may be included in future revisions of the program if this is perceived to be a critical calculation.

The basic sizing calculations are referenced to water, and therefore to not require a value of the specific gravity for the pulp stock. However, other calculations supported by the program, such as sound pressure level and velocity calculations do require this value. To satisfy the needs of these calculations, an estimate of the specific gravity is also produced and displayed in the Intermediate Results area of the basic calculation screen. This estimate is a function only of stock consistency (at 50 °F) and is shown graphically in Figure 4.

If the stock consistency is less than two percent (2%), there is no difference from conventional hydrodynamic noise prediction methods. The noise level is calculated in the same manner as for normal liquid sizing. If the consistency is greater than two percent, then the calculated noise level is adjusted by a constant value:

$$\text{Predicted } L_{pA} = \text{Calculated } L_{pA} - 5\text{dBA} \qquad (2)$$

The cavitation behavior of low consistency pulp stock (e.g., < 4%) is treated as equivalent to that of water. Generally, pulp stock of a consistency greater than four percent is not known to be problematic. Therefore, the sizing program indicates that $A_r > K_c$, but that no cavitation problems are likely to occur.

References:

1. Andrews, E. and M. Husu, “Sizing and Cavitation Damage Reduction for Stock and White Water Control Valves”, 1991 Process Control Conference, TAPPI Proceedings, pp. 65-73.

Figure 1. Pulp Stock Correction Factors for Kraft Pulp

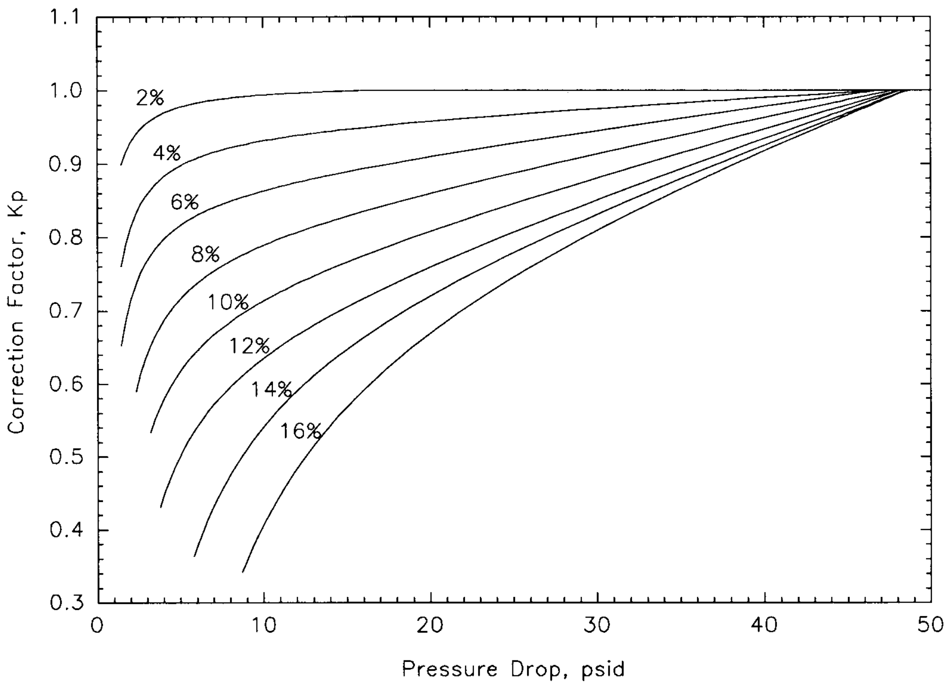


Figure 2. Pulp Stock Correction Factors for Mechanical Pulp

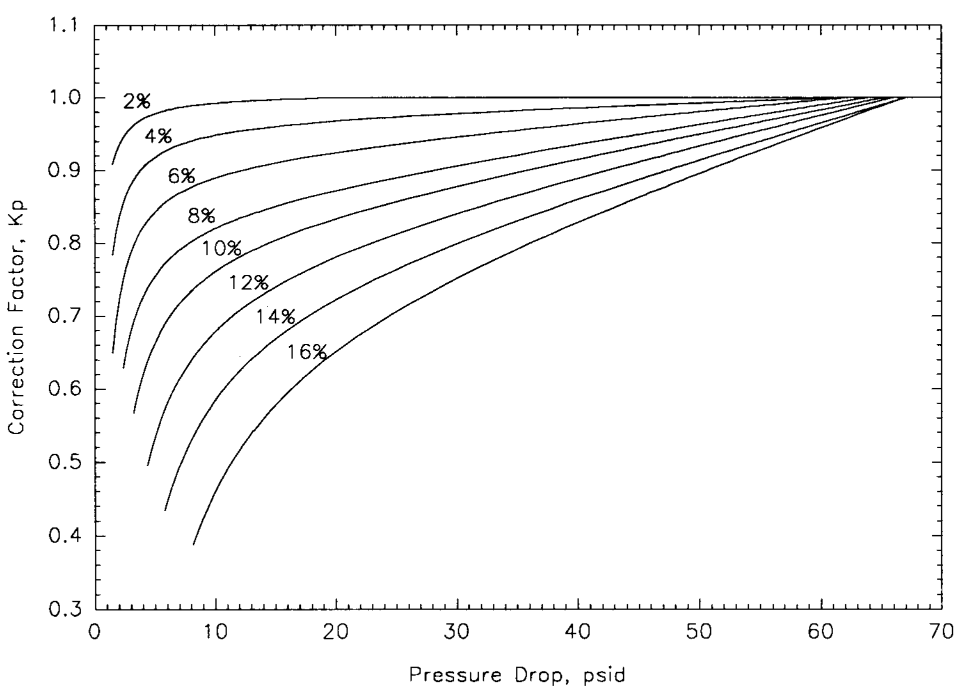


Figure 3. Pulp Stock Correction Factors for Recycled Pulp

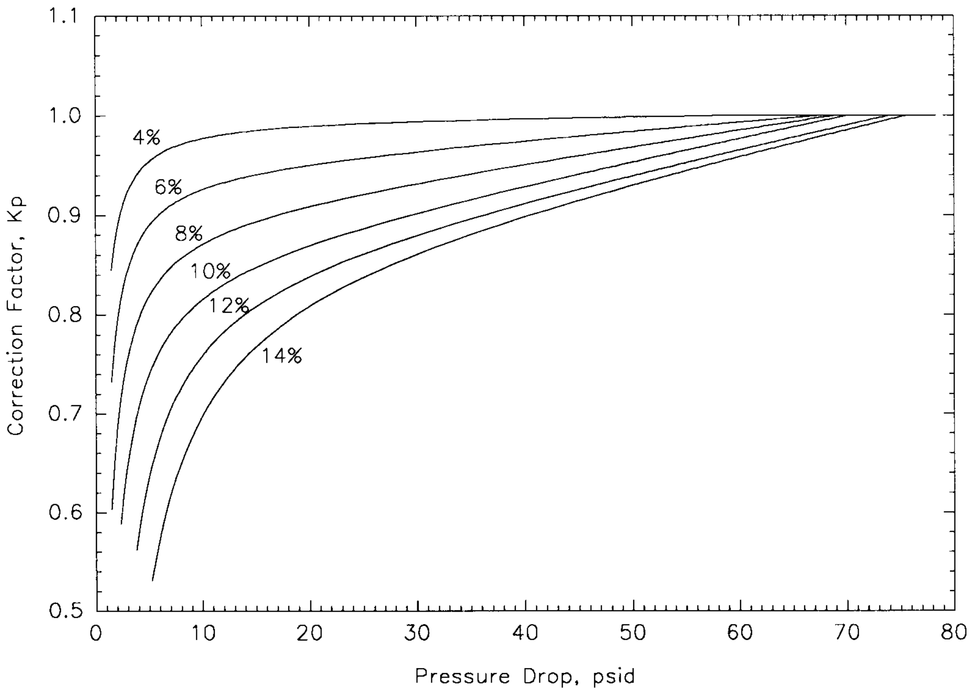
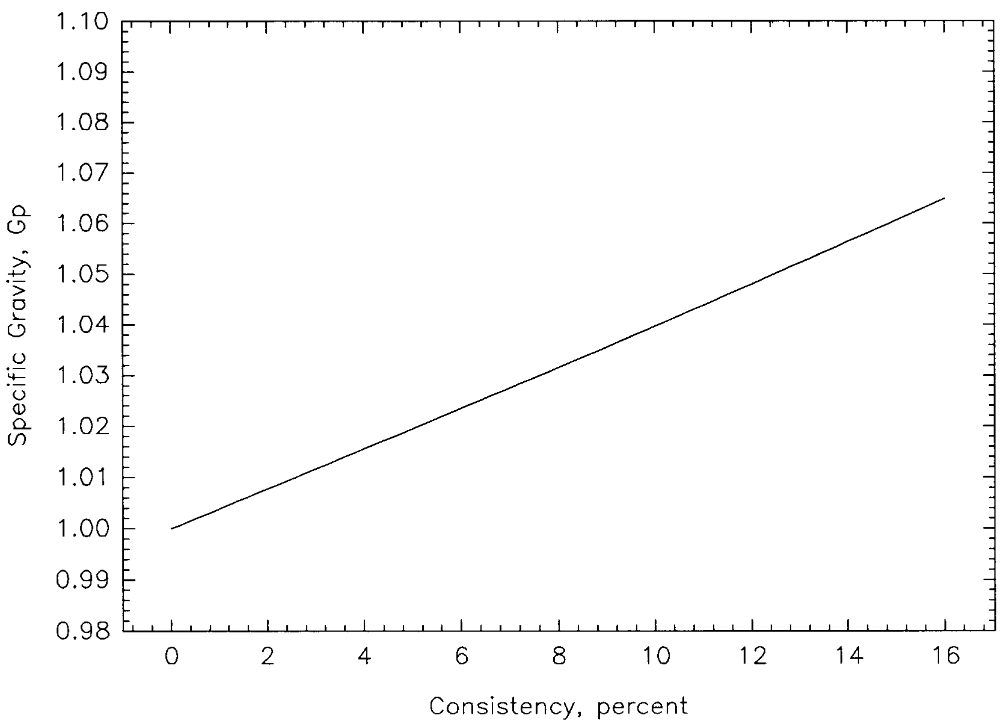


Figure 4. Specific Gravity for All Pulp Types

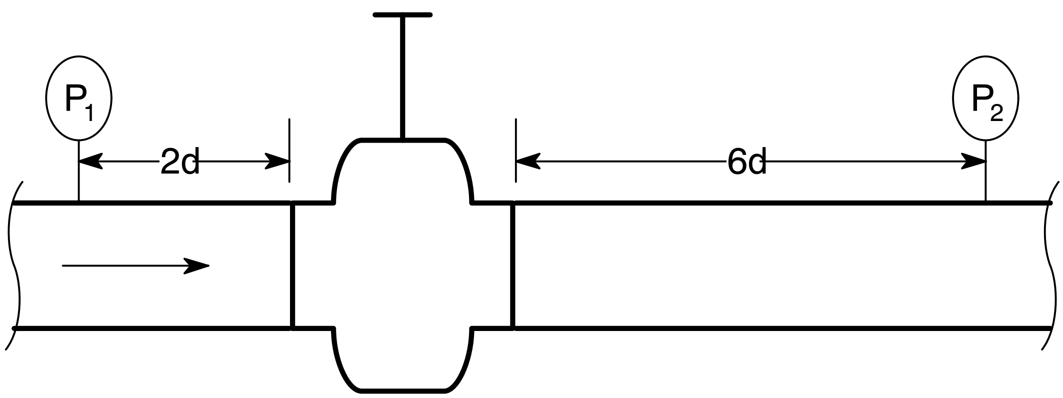


Full Bore Ball Valve Sizing Discussion

Cv_{net}, F_{Lnet}, and X_{Tnet} values presented in Catalog 12, Section 1 for the V260C and V270 valves are adjusted valve coefficients that differ from traditional ISA/IEC standards for C_V, F_L, and X_T as defined in ISA 75.01.01 and ISA 75.02.01, or, equivalently, IEC 60534-2-1 and IEC 60534-2-3.

The control valve sizing standard ISA 75.01.01 defines its limitations at a $C_V/d^2 \leq 30$. Most full bore ball valves above about 80° open fall outside the scope of this limitation, with 90° greatly exceeding this ratio. At wide open a full bore ball valve is not a throttling device, so care must be used when attempting to determine valve flow or pressure drop using flow coefficients determined by direct implementation of ISA 75.01.01 and 75.02.01

Figure 1. ISA/IEC Valve Flow Test Manifold



The control volume as defined by ISA 75.01.01 includes two diameters of piping upstream of the valve and six diameters downstream. This allows the fluid to fully develop prior to entry into the valve and enough time to recover downstream of the valve when $C_V/d^2 \leq 30$. For these cases where $C_V/d^2 > 30$, alternative methods need to be considered.

The basis of this alternative method is to analytically remove the additional pressure drop due to frictional losses in the upstream and downstream piping from the calculation of C_V, F_L, and X_T. The impacts of these frictional losses become significant when the C_V/d^2 ratio of the valve is greater than 30 with no inlet or outlet reducers.

The following equations are used to calculate Cv_{net}, F_{Lnet}, and X_{Tnet} given C_V, F_L, and X_T calculated using the standard ISA 75.02.01 test methods.

$$C_{Vnet} = \sqrt{\frac{1}{1 - \frac{f}{112}\left(\frac{C_V}{d^2}\right)^2}} \cdot C_V \qquad F_{Lnet} = \sqrt{\frac{1 - \frac{f}{112}\left(\frac{C_V}{d^2}\right)^2}{1 - \frac{f}{447}\left(\frac{C_V}{d^2}\right)^2 F_L^{\,2}}} \cdot F_L \qquad x_{Tnet} = \frac{1 - \frac{f}{112}\left(\frac{C_V}{d^2}\right)^2}{\left[1 - \frac{f}{1004}\left(\frac{C_V}{d^2}\right)^2 x_T\right]^2} \cdot x_T$$

The friction factor values for schedule 40 clean commercial steel pipe provided in Crane Technical Paper 410 were used in calculating the net flow coefficients at various valve sizes.

The methods suggested align with ISA RP75.23-1995, Considerations for Evaluating Control Valve Cavitation, with an extension to support calculation of $F_L$net , and $X_T$net

Conversions for Units of Measure

Table 1. Length

Multiply Number of / by / To Obtain	millimeter mm	meter m	inch in	feet ft	yard yd
millimeters	1	0.001000	0.03937	0.003281	0.001094
meters	1000	1	39.37	3.281	1.094
inches	25.40	0.02540	1	0.08333	0.02778
feet	304.8	0.3048	12.00	1	0.3333
yards	914.4	0.9144	36.00	3.00	1

Note: 1 meter = 10 decimeters = 100 centimeters = 1000 millimeters = 0.001 kilometers = 1 x 10^6 microns

Table 2. Area

Multiply Number of / by / To Obtain	square meter m^2	square millimeter mm^2	square inch in^2	square feet ft^2	square yard yd^2
square meters	1	1,000,000	1550	10.76	1.196
square millimeters	0.000001	1	0.001550	0.00001076	0.000001196
square inches	0.0006452	645.1	1	0.006944	0.0007716
square feet	0.09290	92,900	144.0	1	0.1111
square yards	0.8361	836,100	1296	9.000	1

Table 3. Volume

Multiply Number of / by / To Obtain	cubic meter m^3	cubic centimeter cm^3	liter l	cubic inch in^3	cubic foot ft^3	Imperial gallon Imp gal	U.S. gallon U.S. gal
m^3	1	1,000,000	1000	61,020	35.31	220.0	264.2
cm^3	0.000001000	1	0.001000	0.06102	0.00003531	0.0002200	0.0002642
liter	0.001000	1000	1	61.02	0.03531	0.2200	0.2642
in^3	0.00001639	16.39	0.01639	1	0.0005787	0.003605	0.004329
ft^3	0.02832	28,320	28.32	1728	1	6.229	7.480
Imp gal	0.004546	4546	4.546	277.4	0.1605	1	1.201
U.S. gal	0.003785	3785	3.785	231.0	0.1337	0.8327	1

Table 4. Mass

Multiply Number of by To Obtain	Ounce oz	Pound lb	Short ton sh ton	Long ton L ton	Kilogram Kg	Metric ton tonne
Ounces	1	0.06250	0.00003125	0.00002790	0.02835	0.00002835
Pounds	16.00	1	0.0005000	0.0004464	0.4536	0.0004536
Short tons	32,000	2000	1	0.8929	907.2	0.9072
Long tons	35,840	2240	1.120	1	1016	1.016
Kilograms	35.27	2.205	0.001102	0.0009842	1	0.001000
Metric tons	35,270	2205	1.102	0.9842	1000	1

Table 5. Density

Multiply Number of by To Obtain	gram per milliliter g/ml	kilogram per cubic meter kg/m^3	pound per cubic foot lb/ft^3	pound per cubic inch lb/in^3
g/ml	1	1000	62.43	0.03613
kg/m^3	0.001000	1	0.06243	0.00003613
lb/ft^3	0.01602	16.02	1	0.0005787
lb/in^3	27.68	27,680	1728	1

Table 6. Velocity

Multiply Number of by To Obtain	feet per second ft/sec	feet per minute ft/min	miles per hour mi/hr	meter per second m/sec	meter per minute m/min	kilometer per hour km/hr
ft/sec	1	60.00	0.6818	0.3048	18.29	1.097
ft/min	0.01667	1	0.01136	0.005080	0.3048	0.01829
mi/hr	1.467	88.00	1	0.4470	26.82	1.609
m/sec	3.280	196.9	2.237	1	60.00	3.600
m/min	0.05468	3.281	0.03728	0.01667	1	0.06000
km/hr	0.9113	54.68	0.6214	0.2778	16.67	1

Table 7. Heat Flow Rate

Multiply Number of by To Obtain	Watts W	calorie per second cal/sec	kilocalorie per hour kcal/hr	British thermal unit per hour Btu/hr
W	1	0.2390	0.8604	3.412
cal/sec	4.184	1	3.600	14.28
kcal/hr	1.162	0.2778	1	3.966
Btu/hr	0.2831	0.07000	0.2522	1

Table 8. Force

Multiply Number of by To Obtain	kilonewton KN	kilogram force kgf	pound force lbf	poundal pdl
kilonewtons	1	102.0	224.8	7233
kilogram force	0.009807	1	2.205	70.93
pound force	0.004448	0.4536	1	32.17
poundal	0.0001383	0.01410	0.03108	1

EMERSON

Table 9. Power

To Obtain / by / Multiply Number of	Watt W	kilogram force meter per second kgf m/sec	metric horsepower	foot pound force per second ft lbf/sec	horsepower hp
W	1	0.1020	.001360	0.7376	0.001341
kgfm/sec	9.807	1	0.01333	7.233	0.01315
metric hp	735.5	75.00	1	542.5	0.9863
ft lb/sec	1.356	0.1383	0.001843	1	0.001818
horsepower	745.7	76.04	1.014	550.0	1

Table 10. Torque

To Obtain / by / Multiply Number of	Newton Meter Nm	kilogram force meter kgf m	foot pound ft lb	inch pound in lb
Nm	1	0.1020	0.7376	8.851
kgf m	9.807	1	7.233	86.80
ft lb	1.356	0.1383	1	12.00
in lb	0.1130	0.01152	0.08333	1

Table 11. Pressure and Liquid Head

To Obtain / by / Multiply Number of	bar(1)	kilogram force per square centimeter kgf/cm^2(2)	pound per square inch psi or lbf/in^2	International Standard Atmosphere atm	foot of water (4 °C) ft H_2O	inch of water (4 °C) in H_2O	meter of water (4 °C) m H_2O	centimeter of Mercury (0 °C) cm Hg	inch of Mercury (0 °C) in Hg	millimeter of Mercury (0 °C) torr or mm Hg
bar	1	1.020	14.50	0.9869	33.45	401.5	10.20	75.01	29.53	750.1
kgf/cm^2	0.9807	1	14.22	0.9678	32.81	393.7	10.00	73.56	28.96	735.5
psi	0.06895	0.0703	1	0.06805	2.307	27.68	0.7031	5.171	2.036	51.71
atm	1.013	1.033	14.69	1	33.90	406.8	10.33	76.00	29.92	760.0
ft H_2O	0.02989	0.0305	0.4335	0.02950	1	12	0.3048	2.242	0.8826	22.42
in H_2O	0.002491	0.002540	0.0361	0.002458	0.8333	1	0.2540	0.1868	0.07355	1.868
m H_2O	0.09806	0.1000	1.422	0.09678	3.281	39.37	1	7.356	2.896	73.56
cm Hg	0.01333	0.01360	0.1934	0.01316	0.4460	5.352	0.1360	1	0.3937	10.00
in Hg	0.03386	0.03453	0.4911	0.03342	1.133	13.60	0.3453	2.540	1	25.40
torr	0.001333	0.001359	0.01934	0.001316	0.04460	0.5352	0.0136	0.1000	0.03937	1

1. The unit of pressure in the International System of Units (SI) is the pascal (Pa), which is 1 Newton per square meter (N/m^2). 1 bar = 10^5 Pa
2. Technical (metric) atmosphere (at)

Table 12. Volumetric Rate of Flow

To Obtain / by / Multiply Number of	liter per second l/sec	liter per minute l/min	cubic meter per hour m^3/hr	cubic foot per hour ft^3/hr	cubic foot per minute ft^3/min	Imp gallon per minute Imp gal/min	US gallon per minute US gal/min	US barrel per day (42 US gal) US barrel/d
l/sec	1	60	3.600	127.1	2.119	13.20	15.85	543.4
l/min	0.01667	1	0.06000	2.119	0.03532	0.2200	0.2642	9.057
m^3/hr	0.2778	16.67	1	35.31	0.5886	3.666	4.403	150.9
ft^3/hr	0.007865	0.4719	0.02832	1	0.01667	0.1038	0.1247	4.275
ft^3/min	0.4719	28.32	1.699	60.00	1	6.229	7.481	256.5
Imp gal/min	0.07577	4.546	0.2727	9.633	0.1606	1	1.201	41.17
US gal/min	0.06309	3.785	0.2271	8.021	0.1337	0.8327	1	34.29
US barrel/d	0.001840	0.1104	0.006624	0.2339	0.003899	0.02428	0.02917	1

Table 13. Temperature

degrees Celsius[1] °C	Kelvin K	degrees Fahrenheit °F	degrees Rankine °R
°C	K-273.15	5/9(°F-32)	5/9(°R-491.67)
°C + 273.15	K	5/9(°F + 459.67)	5/9°R
9/5°C + 32	9/5K-459.67	°F	°R-459.67
9/5°C + 491.67	9/5K	°F + 459.67	°R

1. Formerly called Centigrade.

Table 14. Abbreviated Conversions of Degrees Fahrenheit to Degrees Celsius

°F	°C	°F	°C	°F	°C
–50	–45.6	220	104	670	354
–45	–42.8	230	110	680	360
–40	–40	240	116	690	366
–35	–37.2	250	121	700	371
–30	–34.4	260	127	710	377
–25	–31.7	270	132	720	382
–20	–28.9	280	138	730	388
–15	–26.1	290	143	740	393
–10	–23.3	300	149	750	399
–5	–20.6	310	154	760	404
0	–17.8	320	160	770	410
5	–15	330	166	780	416
10	–12.2	340	171	790	421
15	–9.4	350	177	800	427
20	–6.7	360	182	810	432
25	–3.9	370	188	820	438
30	–1.1	380	193	830	443
32	0	390	199	840	449
35	1.7	400	204	850	454
40	4.4	410	210	860	460
45	7.2	420	216	870	466
50	10	430	221	880	471
55	12.8	440	227	890	477
60	15.6	450	232	900	482
65	18.3	460	238	910	488
70	21.1	470	243	920	493
75	23.9	480	249	930	499
80	26.7	490	254	940	504
85	29.4	500	260	950	510
90	32.2	510	266	960	516
95	35	520	271	970	521
100	37.8	530	277	980	527
110	43	540	282	990	532
120	49	550	288	1000	538
130	54	560	293	1050	566
140	60	570	299	1100	593
150	66	580	304	1150	621
160	71	590	310	1200	649
170	77	600	316	1250	677
180	82	610	321	1300	704
190	88	620	327	1350	732
200	93	630	332	1400	760
210	99	640	338	1450	788
212	100	650	343	1500	816
		660	349		

Useful Equivalents

1 US Gallon of Water	= 8.33 pounds @ 60°F
1 Cubic Foot of Water	= 62.36 pounds @ 60°F
1 Cubic Meter of Water	= 1000 Kilograms @ 4°C
1 Cubic Foot of Air	= .076 pounds (Std. Press. and Temp.)
1 Pound of Air	= 13.1 Cubic Feet (Std. Press. and Temp.)
1 Kilogram of Air	= .77 Cubic Meters (Normal Press. and Temp.)
1 Cubic Meter of Air	= 1.293 Kilograms (Normal Press. and Temp.)

$$\frac{\text{Gas Molecular Weight}}{29} = \text{Sp. Gravity of that gas}$$

Molecular Wt. of Air = 29

1/Density = Specific Volume

Mass Rate

Where:
Standard Conditions (scfh) are 14.7 psia and 60°F
Normal Conditions (norm) are 760 mm Hg and 0°C
SG_1 Water = 1 at 60°F. SG_2 Water = 1 at 4°C
M = Molecular Weight
ρ_1 = Density lb/ft^3 (std); ρ_2 = Density kg/m^3 (norm)
G_1 = sp. gr. Air = 1 at (std); G_2 = sp. gr. Air. = 1 at (norm)

Gases

$$\text{scfh} = \frac{\text{lb/hr x 379}}{M} \qquad \text{m}^3\text{/hr (norm)} = \frac{\text{kg/hr x 22.40}}{M}$$

$$\text{scfh} = \frac{\text{lb/hr}}{\rho_1} \qquad \text{m}^3\text{/hr (norm)} = \frac{\text{kg/hr}}{\rho_2}$$

$$\text{scfh} = \frac{\text{lb/hr x 13.1}}{G_1} \qquad \text{m}^3\text{/hr (norm)} = \frac{\text{kg/hr x 0.773}}{G_2}$$

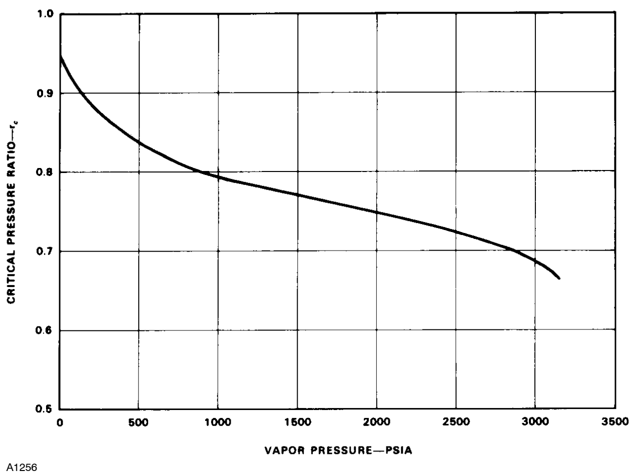
Liquids

$$\text{US gal/min} = \frac{\text{lb/hr}}{500 \times SG_1} \qquad \text{m}^3\text{/hr} = \frac{\text{.001 kg/hr}}{SG_2}$$

The test classifications listed below are for factory acceptance tests under the conditions shown. Because of the complex interaction of many physical properties, extrapolation of very low leakage rates to other than test conditions can be extremely misleading. Consult the appropriate product bulletin for individual valve body leak classifications.

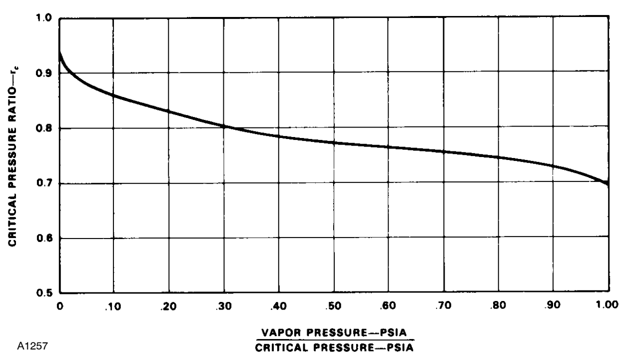
<table>
<tr><th>ANSI/FCI 70-2</th><th colspan="4">Maximum Leakage(1)</th><th>Test Medium</th><th>Pressure and Temperature</th></tr>
<tr><td>Class II</td><td colspan="4">0.5% valve capacity at full travel</td><td>Air</td><td>Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50 to 125°F (10 to 52°C)</td></tr>
<tr><td>Class III</td><td colspan="4">0.1% valve capacity at full travel</td><td>Air</td><td>Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50 to 125°F (10 to 52°C)</td></tr>
<tr><td>Class IV</td><td colspan="4">0.01% valve capacity at full travel</td><td>Air</td><td>Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50 to 125°F (10 to 52°C)</td></tr>
<tr><td>Class V</td><td colspan="4">5 x 10^{-4} mL/min/psid/in. port dia.
(5 x 10^{-12} m^3/sec/bar differential/mm port dia)</td><td>Water</td><td>Service ΔP at 50 to 125°F (10 to 52°C)</td></tr>
<tr><td rowspan="10">Class VI</td><td colspan="2">Nominal Port Diameter</td><td rowspan="2">Bubbles per Minute</td><td rowspan="2">mL per Minute</td><td rowspan="10">Air</td><td rowspan="10">Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50 to 125°F (10 to 52°C)</td></tr>
<tr><td>Inch</td><td>mm</td></tr>
<tr><td>1</td><td>25</td><td>1</td><td>0.15</td></tr>
<tr><td>1-1/2</td><td>38</td><td>2</td><td>0.30</td></tr>
<tr><td>2</td><td>51</td><td>3</td><td>0.45</td></tr>
<tr><td>2-1/2</td><td>64</td><td>4</td><td>0.60</td></tr>
<tr><td>3</td><td>76</td><td>6</td><td>0.90</td></tr>
<tr><td>4</td><td>102</td><td>11</td><td>1.70</td></tr>
<tr><td>6</td><td>152</td><td>27</td><td>4.00</td></tr>
<tr><td>8</td><td>203</td><td>45</td><td>6.75</td></tr>
</table>

Figure 1. Critical Pressure Ratios for Water



Use this curve for water. Enter on the abscissa at the water vapor pressure at the valve inlet. Proceed vertically to intersect the curve. Move horizontally to the left to read the critical pressure ratio, r_c, on the ordinate.

Figure 2. Critical Pressure Ratios for Liquids Other than Water



Use this curve for liquids other than water. Determine the vapor pressure/critical pressure ratio by dividing the liquid vapor pressure at the valve inlet by the critical pressure of the liquid. Enter on the abscissa at the ratio just calculated and proceed vertically to intersect the curve. Move horizontally to the left and read the critical pressure ratio, r_c, on the ordinate.

Critical Pressure of Various Fluids, Psia*

Ammonia	1636
Argon	705.6
Butane	550.4
Carbon Dioxide	1071.6
Carbon Monoxide	507.5
Chlorine	1118.7
Dowtherm A	465
Ethane	708
Ethylene	735
Fluorine	808.5
Helium	33.2
Hydrogen	188.2
Hydrogen Chloride	1198
Isobutane	529.2
Isobutylene	580
Methane	673.3
Nitrogen	492.4
Nitrous Oxide	1047.6
Oxygen	736.5
Phosgene	823.2
Propane	617.4
Propylene	670.3
Refrigerant 11	635
Refrigerant 12	596.9
Refrigerant 22	716
Water	3206.2

* For values not listed, consult an appropriate reference book.

Introduction

Special consideration is required when sizing valves handling mixtures of liquid and gas or liquid and vapor. The equation for required valve C_v for liquid-gas or liquid-vapor mixtures is:

$$C_{vr} = (C_{vl} + C_{vg})(1 + F_m) \quad (1)$$

The value of the correction factor, F_m, is given in figure 1 as a function of the gas volume ratio, V_r. The gas volume ratio for liquid-gas mixtures may be obtained by the equation:

$$V_r = \frac{V_g}{V_l + V_g} = \frac{Q_g}{\frac{284Q_1P_1}{T_1} + Q_g} \quad (2)$$

or for liquid-vapor mixtures:

$$V_r = \frac{v_g}{v_g + v_l\left(\frac{1-x}{x}\right)} \quad (3)$$

If the pressure drop ratio ($\Delta P/P_1$) exceeds the ratio required to give 100% critical gas flow as determined from figure 2, the liquid sizing drop should be limited to the drop required to give 100% critical gas flow.

Because of the possibility of choked flow occurring, the liquid sizing drop may also have to be limited by the equation:

$$\Delta P_{(allow)} = K_m(P_1 - r_c P_v)\ *$$

Nomenclature
C_v =Standard liquid sizing coefficient
C_{vr} =C_v required for mixture flow
C_{vl} =C_v for liquid phase
C_g =C_g for gas phase
C_{vg} = C_v required for gas phase = C_g/C_1
C_1 = C_g/C_v ratio for valve
F_m = C_v correction factor
K_m = Valve recovery coefficient
ΔP =Valve pressure drop, psi
P_1 =Valve inlet pressure, psia
P_v =Liquid vapor pressure, psia
Q_g= Gas flow, scfh
Q_l = Liquid flow, gpm
Q_s = Steam or vapor flow, lb/hr
r_c =Critical pressure ratio
T_1 =Inlet Temperature, °Rankine (°R = °F + 460°)
V_g = Gas flow, ft^3/sec
V_l = Liquid flow, ft^3/sec
V_r = Gas volume ratio
v_g = Specific volume of gas phase, ft^3/lb
v_l =Specific volume of liquid phase, ft^3/lb
x =Quality, lb vapor/lb mixture

Figure 1. C_v Correction Factor, F_m

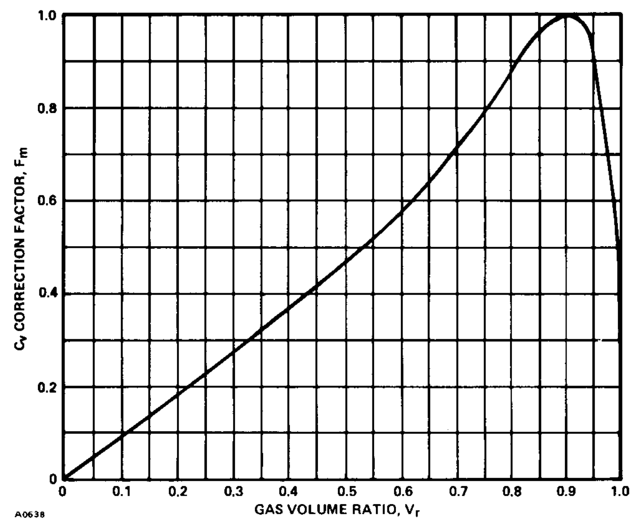
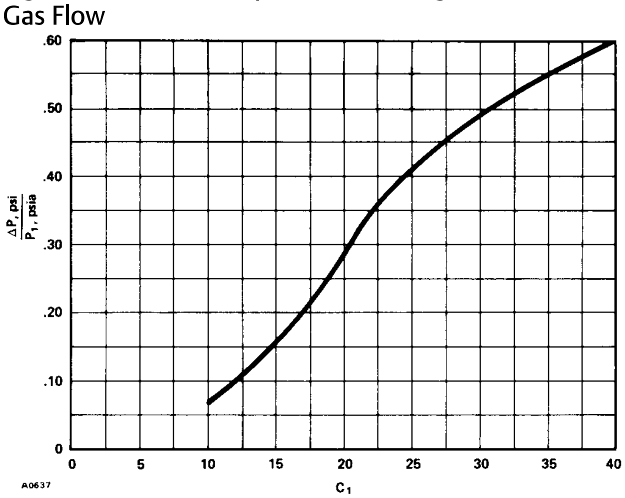


Figure 2. Pressure Drop Ratio Resulting in Critical Gas Flow



* See equation 1 of “Valve Sizing for Cavitating and Flashing Liquids” in this section.

Sizing Examples

Liquid-Gas Mixture

Given:

Liquid flow (Q_l) = 3000 gpm
Gas flow (Q_g) = 625,000 scfh
Inlet temperature (T_1) = 100°F = 560°R
Inlet pressure (P_1) = 414.7 psia (400 psig)
Pressure drop (ΔP) = 40 psi
Liquid specific gravity (G_l) = 1.5
Vapor pressure of liquid (P_v) = 30 psia
Critical pressure of liquid = 200 psia
Gas specific gravity (G_g) = 1.4
C_1 of valve under consideration = 24.7
K_m of valve under consideration = 0.40

Solution:

1. The pressure drop ratio of the application ($\Delta P/P_1$ = 40/414.7 - 0.096) does not exceed that required for 100% critical flow (0.40 from figure 2). Check the maximum allowable liquid pressure drop:

$$\Delta P_{(allow)} = K_m(P_1 - r_c P_v)$$

The critical pressure ratio (r_c) is 0.84 from figure 2 of “Valve Sizing for Cavitating and Flashing Liquids” at Vapor Pressure/Critical Pressure = 30/200 = 0.15.

$$\Delta P_{(allow)} = 0.40\,[414.7 - (0.84)(30)]$$
$$= 156 \text{ psi}$$

Since the pressure drop ratio is less than that required for 100% critical gas flow and the pressure drop is less than the maximum allowable liquid pressure drop, use the given pressure drop of 40 psi in the remaining steps.

2. Using the Universal Valve Sizing Slide Rule or sizing nomographs, the calculated required liquid sizing coefficient for the liquid phase (C_{vl}) is 581 and the calculated required gas sizing coefficient for the gas phase (C_g) is 2710.

3. Calculate the C_v required for gas phase:

$$C_{vg} = C_g/C_1$$
$$= \frac{2710}{24.7}$$
$$= 110$$

4. Calculate the gas volume ratio:

$$V_r = \frac{Q_g}{\frac{284Q_lP_1}{T_1} + Q_g} \qquad (2)$$
$$= \frac{625,000}{\frac{(284)(3000)(414.7)}{560} + 625,000}$$
$$= 0.498$$

Then from figure 1 at Vr = 0.498:

$$F_m = 0.475$$

5. Calculate the C_v required for the mixture:

$$C_{vr} = (C_{vl} + C_{vg})(1 + F_m) \qquad (1)$$
$$= (581 + 110)(1 + 0.475)$$
$$= 1020$$

Liquid-Vapor Mixture

Given:

Mixture flow (Q) = 200,000 lb/hr of wet steam
Quality (x) = 0.05
Inlet pressure (P_1) = 84.7 psia (70 psig)
Pressure drop (ΔP) = 50 psi
C_1 of valve under consideration = 21.0
K_m of valve under consideration = 0.50

Solution:

1. Calculate the flow of vapor (Q_s) and of liquid (Q_l):

Q_s = (x) (Mixture Flow)
= (0.05) (200,000)
= 10,000 lb/hr of steam
Q_l = Mixture Flow - Q_s
= 200,000 - 10,000
= 190,000 lb/hr of water
= 417 gpm

2. Using the sizing slide rule or the steam, vapor, and gas flow equation shown with the Universal Sizing Nomograph, find the calculated required gas sizing coefficient (C_g) for the vapor phase. Steam inlet density (0.193 lb/ft^3) can be calculated from steam table data.

$$C_g = 2330$$

3. Calculate C_v required for the vapor phase:

$$C_{vg} = C_g/C_1$$
$$= \frac{2300}{21.0}$$
$$= 111$$

4. Before determining the C_v required for the liquid phase, calculate the maximum allowable liquid pressure drop:

$$\Delta P_{(allow)} = K_m\,(P_1 - r_c P_v)$$

Since this is a mixture of a liquid and its vapor, vapor pressure (P_v) equals inlet pressure (P_1). Find the critical pressure ratio (r_c) from figure 1 of “Valve Sizing for Cavitating and Flashing Liquids” in this section.

$$\Delta P_{(allow)} = 0.50[84.7 - (.92)(84.7)]$$
$$= 3.39 \text{ psi}$$

Use this pressure drop and the specific gravity of the water (from steam tables) with the sizing slide rule or liquid nomograph to determine the required liquid sizing coefficient of the liquid phase (C_{vl}):

$$C_{vl} = 216$$

5. Calculate the gas volume ratio. specific volumes (v_g and v_l) can be found in steam tables:

$$V_r = \frac{v_g}{v_g\ v_l\left(\frac{1-x}{x}\right)} \qquad (3)$$

$$= \frac{5.185}{5.185 + 0.0176\left(\frac{1-0.05}{0.05}\right)}$$

$$= 0.939$$

The from figure 1 at V_r = 0.939:

$$F_m = 0.97$$

6. Calculate the C_v required for the mixture:

$$C_{vr} = (C_{vl} + C_{vg})(1 + F_m) \qquad (1)$$
$$= (216 + 111)\ (1 + 0.97)$$
$$= 644$$

Saturated Steam
Pressure and Temperature

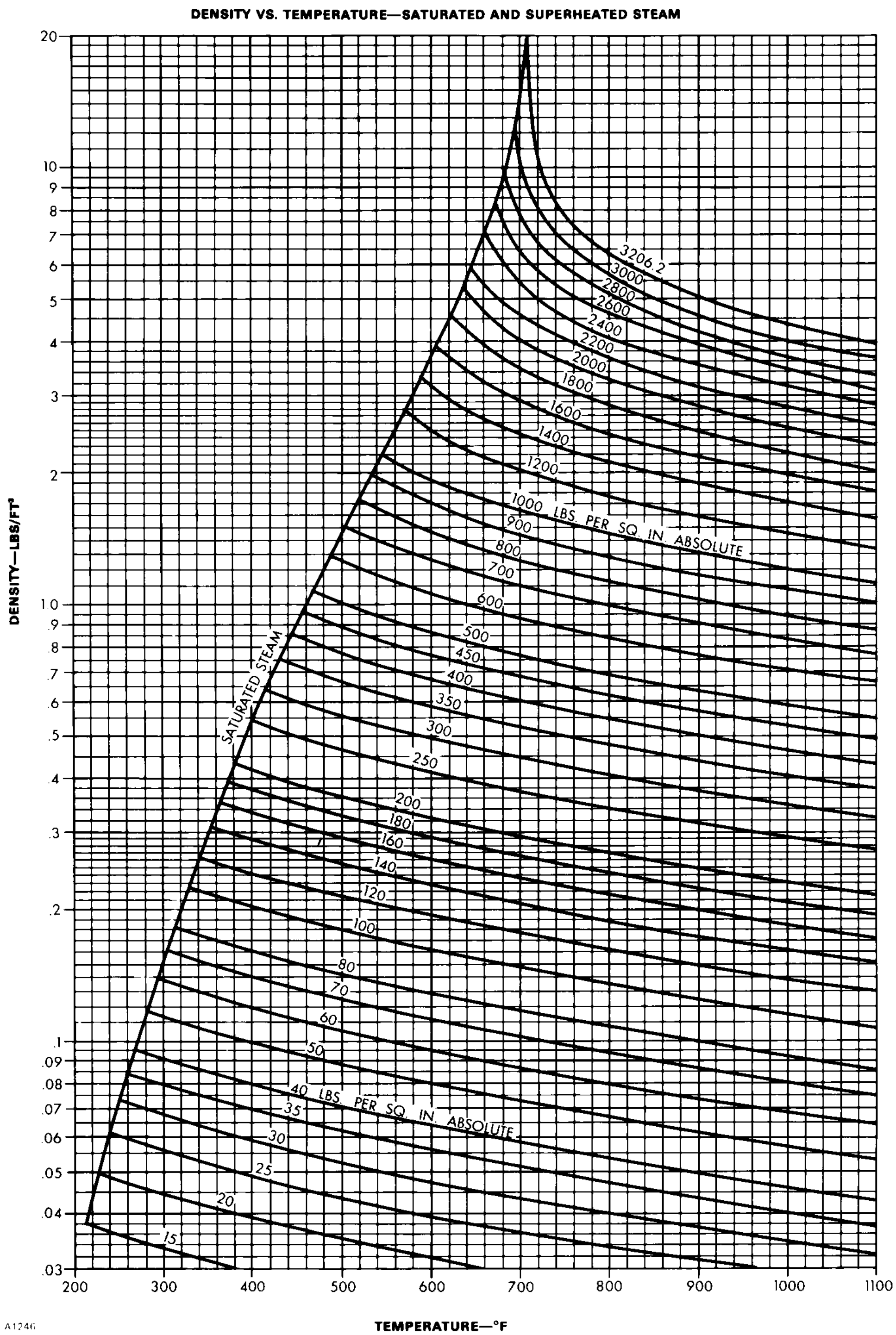
VAPOR PRESSURE		TEMPERATURE DEGREES F	STEAM DENSITY LBS/CU.FT.	WATER SPECIFIC GRAVITY
Absolute, Psia	Vacuum, In. Hg.			
0.20	29.51	53.14	.000655	1.00
0.25	29.41	59.30	.000810	1.00
0.30	29.31	64.47	.000962	1.00
0.35	29.21	68.93	.00111	1.00
0.40	29.11	72.86	.00126	1.00
0.45	29.00	76.38	.00141	1.00
0.50	28.90	79.58	.00156	1.00
0.60	28.70	85.21	.00185	1.00
0.70	28.49	90.08	.00214	1.00
0.80	28.29	94.38	.00243	1.00
0.90	28.09	98.24	.00271	.99
1.0	27.88	101.74	.00300	.99
1.2	27.48	107.92	.00356	.99
1.4	27.07	113.26	.00412	.99
1.6	26.66	117.99	.00467	.99
1.8	26.26	122.23	.00521	.99
2.0	25.85	126.08	.00576	.99
2.2	25.44	129.62	.00630	.99
2.4	25.03	132.89	.00683	.99
2.6	24.63	135.94	.00737	.99
2.8	24.22	138.79	.00790	.98
3.0	23.81	141.48	.00842	.98
3.5	22.79	147.57	.00974	.98
4.0	21.78	152.97	.0110	.98
4.5	20.76	157.83	.0123	.98
5.0	19.74	162.24	.0136	.98
5.5	18.72	166.30	.0149	.98
6.0	17.70	170.06	.0161	.98
6.5	16.69	173.56	.0174	.97
7.0	15.67	176.85	.0186	.97
7.5	14.65	179.94	.0199	.97
8.0	13.63	182.86	.0211	.97
8.5	12.61	185.64	.0224	.97
9.0	11.60	188.28	.0236	.97
9.5	10.58	190.80	.0248	.97
10.0	9.56	193.21	.0260	.97
11.0	7.52	197.75	.0285	.97
12.0	5.49	201.96	.0309	.96
13.0	3.45	205.88	.0333	.96
14.0	1.42	209.56	.0357	.96

VAPOR PRESSURE		TEMPERATURE DEGREES F	STEAM DENSITY LBS/CU.FT.	WATER SPECIFIC GRAVITY
Absolute, Psia	Gauge, Psig			
14.696	0.0	212.00	.0373	.96
15.0	0.3	213.03	.0380	.96
16.0	1.3	216.32	.0404	.96
17.0	2.3	219.44	.0428	.96
18.0	3.3	222.41	.0451	.96
19.0	4.3	225.24	.0474	.95
20.0	5.3	227.96	.0498	.95
21.0	6.3	230.57	.0521	.95
22.0	7.3	233.07	.0544	.95
23.0	8.3	235.49	.0567	.95
24.0	9.3	237.82	.0590	.95
25.0	10.3	240.07	.0613	.95
26.0	11.3	242.25	.0636	.95
27.0	12.3	244.36	.0659	.95
28.0	13.3	246.41	.0682	.94
29.0	14.3	248.40	.0705	.94
30.0	15.3	250.33	.0727	.94
31.0	16.3	252.22	.0750	.94
32.0	17.3	254.05	.0773	.94
33.0	18.3	255.84	.0795	.94
34.0	19.3	257.38	.0818	.94
35.0	20.3	259.28	.0840	.94
36.0	21.3	260.95	.0863	.94
37.0	22.3	262.57	.0885	.94
38.0	23.3	264.16	.0908	.94
39.0	24.3	265.72	.0930	.94

VAPOR PRESSURE		TEMPERATURE DEGREES F	STEAM DENSITY LBS/CU.FT.	WATER SPECIFIC GRAVITY
Absolute, Psia	Gauge, Psig			
40.0	25.3	267.25	.0953	.94
41.0	26.3	268.74	.0975	.93
42.0	27.3	270.21	.0997	.93
43.0	28.3	271.64	.102	.93
44.0	29.3	273.05	.104	.93
45.0	30.3	274.44	.106	.93
46.0	31.3	275.80	.109	.93
47.0	32.3	277.13	.111	.93
48.0	33.3	278.45	.113	.93
49.0	34.3	279.74	.115	.93
50.0	35.3	281.01	.117	.93
51.0	36.3	282.26	.120	.93
52.0	37.3	283.49	.122	.93
53.0	38.3	284.70	.124	.93
54.0	39.3	285.90	.126	.93
55.0	40.3	287.07	.128	.93
56.0	41.3	288.23	.131	.93
57.0	42.3	289.37	.133	.93
58.0	43.3	290.50	.135	.92
59.0	44.3	291.61	.137	.92
60.0	45.3	292.71	.139	.92
61.0	46.3	293.79	.142	.92
62.0	47.3	294.85	.144	.92
63.0	48.3	295.90	.146	.92
64.0	49.3	296.94	.148	.92
65.0	50.3	297.97	.150	.92
66.0	51.3	298.99	.152	.92
67.0	52.3	299.99	.155	.92
68.0	53.3	300.98	.157	.92
69.0	54.3	301.96	.159	.92
70.0	55.3	302.92	.161	.92
71.0	56.3	303.88	.163	.92
72.0	57.3	304.83	.165	.92
73.0	58.3	305.76	.168	.92
74.0	59.3	306.68	.170	.92
75.0	60.3	307.60	.172	.92
76.0	61.3	308.50	.174	.91
77.0	62.3	309.40	.176	.91
78.0	63.3	310.29	.178	.91
79.0	64.3	311.16	.181	.91
80.0	65.3	312.03	.183	.91
81.0	66.3	312.89	.185	.91
82.0	67.3	313.74	.187	.91
83.0	68.3	314.59	.189	.91
84.0	69.3	315.42	.191	.91
85.0	70.3	316.25	.193	.91
86.0	71.3	317.07	.196	.91
87.0	72.3	317.88	.198	.91
88.0	73.3	318.68	.200	.91
89.0	74.3	319.48	.202	.91
90.0	75.3	320.27	.204	.91
91.0	76.3	321.06	.206	.91
92.0	77.3	321.83	.209	.91
93.0	78.3	322.60	.211	.91
94.0	79.3	323.36	.213	.91
95.0	80.3	324.12	.215	.91
96.0	81.3	324.87	.217	.91
97.0	82.3	325.61	.219	.91
98.0	83.3	326.35	.221	.91
99.0	84.3	327.08	.224	.90
100.0	85.3	327.81	.226	.90
101.0	86.3	328.53	.228	.90
102.0	87.3	329.25	.230	.90
103.0	88.3	329.96	.232	.90
104.0	89.3	330.66	.234	.90
105.0	90.3	331.36	.236	.90
106.0	91.3	332.05	.238	.90
107.0	92.3	332.74	.241	.90
108.0	93.3	333.42	.243	.90
109.0	94.3	334.10	.245	.90

VAPOR PRESSURE		TEMPERATURE DEGREES F	STEAM DENSITY LBS/CU.FT.	WATER SPECIFIC GRAVITY
Absolute, Psia	Gauge, Psig			
110.0	95.3	334.77	.247	.90
111.0	96.3	335.44	.249	.90
112.0	97.3	336.11	.251	.90
113.0	98.3	336.77	.253	.90
114.0	99.3	337.42	.255	.90
115.0	100.3	338.07	.258	.90
116.0	101.3	338.72	.260	.90
117.0	102.3	339.36	.262	.90
118.0	103.3	339.99	.264	.90
119.0	104.3	340.62	.266	.90
120.0	105.3	341.25	.268	.90
121.0	106.3	341.88	.270	.90
122.0	107.3	342.50	.272	.90
123.0	108.3	343.11	.275	.90
124.0	109.3	343.72	.277	.90
125.0	110.3	344.33	.279	.90
126.0	111.3	344.94	.281	.89
127.0	112.3	345.54	.283	.89
128.0	113.3	346.13	.285	.89
129.0	114.3	346.73	.287	.89
130.0	115.3	347.32	.289	.89
131.0	116.3	347.90	.292	.89
132.0	117.3	348.48	.294	.89
133.0	118.3	349.06	.296	.89
134.0	119.3	349.64	.298	.89
135.0	120.3	350.21	.300	.89
136.0	121.3	350.78	.302	.89
137.0	122.3	351.35	.304	.89
138.0	123.3	351.91	.306	.89
139.0	124.3	352.47	.308	.89
140.0	125.3	353.02	.311	.89
141.0	126.3	353.57	.313	.89
142.0	127.3	354.12	.315	.89
143.0	128.3	354.67	.317	.89
144.0	129.3	355.21	.319	.89
145.0	130.3	355.76	.321	.89
146.0	131.3	356.29	.323	.89
147.0	132.3	356.83	.325	.89
148.0	133.3	357.36	.327	.89
149.0	134.3	357.89	.330	.89
150.0	135.3	358.42	.332	.89
152.0	137.3	359.46	.336	.89
154.0	139.3	360.49	.340	.89
156.0	141.3	361.52	.344	.88
158.0	143.3	362.53	.349	.88
160.0	145.3	363.53	.353	.88
162.0	147.3	364.53	.357	.88
164.0	149.3	365.51	.361	.88
166.0	151.3	366.48	.365	.88
168.0	153.3	367.45	.370	.88
170.0	155.3	368.41	.374	.88
172.0	157.3	369.35	.378	.88
174.0	159.3	370.29	.382	.88
176.0	161.3	371.22	.387	.88
178.0	163.3	372.14	.391	.88
180.0	165.3	373.06	.395	.88
182.0	167.3	373.96	.399	.88
184.0	169.3	374.86	.403	.88
186.0	171.3	375.75	.407	.88
188.0	173.3	376.64	.412	.88
190.0	175.3	377.51	.416	.88
192.0	177.3	378.38	.420	.87
194.0	179.3	379.24	.424	.87
196.0	181.3	380.10	.429	.87
198.0	183.3	380.95	.433	.87
200.0	185.3	381.79	.437	.87
205.0	190.3	383.86	.448	.87
210.0	195.3	385.90	.458	.87
215.0	200.3	387.89	.469	.87
220.0	205.3	389.86	.479	.87
225.0	210.3	391.79	.490	.87
230.0	215.3	393.68	.500	.87
235.0	220.3	395.54	.511	.86
240.0	225.3	397.37	.522	.86
245.0	230.3	399.18	.532	.86

VAPOR PRESSURE		TEMPERATURE DEGREES F	STEAM DENSITY LBS/CU.FT.	WATER SPECIFIC GRAVITY
Absolute, Psia	Gauge, Psig			
250.0	235.3	400.95	.542	.86
255.0	240.3	402.70	.553	.86
260.0	245.3	404.42	.563	.86
265.0	250.3	406.11	.574	.86
270.0	255.3	407.78	.585	.86
275.0	260.3	409.43	.595	.85
280.0	265.3	411.05	.606	.85
285.0	270.3	412.65	.616	.85
290.0	275.3	414.23	.627	.85
295.0	280.3	415.79	.637	.85
300.0	285.3	417.33	.648	.85
320.0	305.3	423.29	.690	.85
340.0	325.3	428.97	.733	.84
360.0	345.3	434.40	.775	.84
380.0	365.3	439.60	.818	.83
400.0	385.3	444.59	.861	.83
420.0	405.3	449.39	.904	.83
440.0	425.3	454.02	.947	.82
460.0	445.3	458.50	.991	.82
480.0	465.3	462.82	1.03	.81
500.0	485.3	467.01	1.08	.81
520.0	505.3	471.07	1.12	.81
540.0	525.3	475.01	1.17	.81
560.0	545.3	478.85	1.21	.80
580.0	565.3	482.58	1.25	.80
600.0	585.3	486.21	1.30	.80
620.0	605.3	489.75	1.34	.79
640.0	625.3	493.21	1.39	.79
660.0	645.3	496.58	1.43	.79
680.0	665.3	499.88	1.48	.79
700.0	685.3	503.10	1.53	.78
720.0	705.3	506.25	1.57	.78
740.0	725.3	509.34	1.62	.77
760.0	745.3	512.36	1.66	.77
780.0	765.3	515.33	1.71	.77
800.0	785.3	518.23	1.76	.77
820.0	805.3	521.08	1.81	.77
840.0	825.3	523.88	1.85	.76
860.0	845.3	526.63	1.90	.76
880.0	865.3	529.33	1.95	.76
900.0	885.3	531.98	2.00	.76
920.0	905.3	534.59	2.05	.75
940.0	925.3	537.16	2.10	.75
960.0	945.3	539.68	2.14	.75
980.0	965.3	542.17	2.19	.75
1000.0	985.3	544.61	2.24	.74
1050.0	1035.3	550.57	2.37	.74
1100.0	1085.3	556.31	2.50	.73
1150.0	1135.3	561.86	2.63	.73
1200.0	1185.3	567.22	2.76	.72
1250.0	1235.3	572.42	2.90	.71
1300.0	1285.3	577.46	3.04	.71
1350.0	1335.3	582.35	3.18	.70
1400.0	1385.3	587.10	3.32	.69
1450.0	1435.3	591.73	3.47	.69
1500.0	1485.3	596.23	3.62	.68
1600.0	1585.3	604.90	3.92	.67
1700.0	1685.3	613.15	4.25	.66
1800.0	1785.3	621.03	4.59	.65
1900.0	1885.3	628.58	4.95	.64
2000.0	1985.3	635.82	5.32	.62
2100.0	2085.3	642.77	5.73	.61
2200.0	2185.3	649.46	6.15	.60
2300.0	2285.3	655.91	6.61	.59
2400.0	2385.3	662.12	7.11	.57
2500.0	2485.3	668.13	7.65	.56
2600.0	2585.3	673.94	8.24	.54
2700.0	2685.3	679.55	8.90	.53
2800.0	2785.3	684.99	9.66	.51
2900.0	2885.3	690.26	10.6	.49
3000.0	2985.3	695.36	11.7	.46
3100.0	3085.3	700.31	13.3	.43
3200.0	3185.3	705.11	17.2	.36
3206.2	3191.5	705.40	19.9	.32



The degree of superheat is the difference between the actual temperature and the saturation steam temperature.

Sonic Velocity

Sonic velocity for a fluid that obeys the perfect gas law can be found by using the flowing equation:

$$c = \sqrt{kgRT}$$

Mach Numbers

Inlet and outlet Mach numbers for a control valve can be calculated from:

$$\overline{M}_1 = \sqrt{\frac{5.97}{k+1}\left(\frac{2}{k+1}\right)^{1/k-1}}\left(\frac{1}{1900}\right)\left(\frac{C_g}{A_1}\right)\sin\left(\frac{3417}{C_1}\sqrt{\frac{\Delta P}{P_1}}\right)\text{ deg.}$$

$$\overline{M}_2 = \left\{\left[\left(\frac{1}{k-1}\right)^2 + \left(\frac{M_1}{1-\Delta P/P_1}\right)^2\left(\frac{A_1}{A_2}\right)^2\left(M_1^2 + \frac{2}{k-1}\right)\right]^{1/2} - \left(\frac{1}{k-1}\right)\right\}^{1/2}$$

Calculate Mean Velocity

Actual velocity at valve inlet or outlet can be determined by multiplying the sonic velocity times the Mach number.

$$\overline{V} = c\overline{M}$$

Simplified Steam Flow Velocity Equation

The following equation can be used to determine the velocity of steam at either the inlet or outlet of a valve.

$$\overline{V} = \frac{Q_v}{25\,A}$$

Note

To solve the equation, use steam tables to find the steam specific volume (v) for the pressure and temperature at the flow stream location where it is desired to determine velocity. Use the flow stream cross-sectional area at the same location.

Definition of Terms

A = Cross sectional area of the flow stream, square inches-- see tables 2, 3, 4, 5, and 6
c = Speed of sound in the fluid, feet per second
C_g = Gas Sizing Coefficient
C_v = Liquid Sizing Coefficient
C_1 = C_g/C_v
ΔP = Pressure drop
g = Gravitational constant, 32.2 feet per second squared
k = Specific heat ratio $\frac{\text{Specific heat at constant pressure}}{\text{Specific heat at constant volume}}$ see table 1 for common values
$\overline{M}$ = Mean Mach number
P = Pressure, psia
Q = Vapor flow rate, pounds per hour
R = Individual gas constant, $\frac{1545}{\text{molecular weight}}$
T = Temperature, Rankine—°R = °F + 460°
v = Vapor specific volume, cubic feet per pound
$\overline{V}$ = Mean velocity, feet per second
sub 1 = Upstream or inlet conditions
sub 2 = Downstream or outlet conditions

Table 1. Specific Heat Ratio (k)

Gas	Specific Heat Ratio (k)
Acetylene	1.38
Air	1.40
Argon	1.67
Butane	1.17
Carbon Monoxide	1.40
Carbon Dioxide	1.29
Ethane	1.25
Helium	1.66
Hydrogen	1.40
Methane	1.26
0.6 Natural Gas	1.32
Nitrogen	1.40
Oxygen	1.40
Propane	1.21
Propylene	1.15
Steam(1)	1.33

1. Use property tables if available for greater accuracy.

Table 2. Flow Area for easy-e™ Valves(1) (Square Inches), Not Appropriate for FB, EH, and HP Valves

VALVE SIZE, NPS	PRESSURE RATING								
	CL150 and 300			CL600			CL900(2)		
	Flow Area, $Inch^2$	Valve Diameter (dv)		Flow Area, $Inch^2$	Valve Diameter (dv)		Flow Area, $Inch^2$	Valve Diameter (dv)	
		mm	Inch		mm	Inch		mm	Inch
1	0.79	25.4	1.00	0.79	25.4	1.00	---	---	---
1-1/2	1.8	38.1	1.50	1.8	38.1	1.50	---	---	---
2	3.1	50.8	2.00	3.1	50.8	2.00	---	---	---
2-1/2	4.9	63.5	2.50	4.9	63.5	2.50	---	---	---
3	7.1	76.2	3.00	7.1	76.2	3.00	---	---	---
4	13	102	4.00	13	102	4.00	---	---	---
6	28	152	6.00	28	152	6.00	---	---	---
8	50	203	8.00	49	200	7.87	44	190	7.50
10	79	254	10.00	75	248	9.75	---	---	---
12	113	305	12.00	108	298	11.75	97	283	11.12
14	138	337	13.25	130	327	12.87	---	---	---
16	171	375	14.75	171	375	14.75	154	356	14.00
18	227	432	17.00	214	419	16.50	---	---	---
20	284	483	19.00	262	464	18.25	---	---	---
24	415	584	23.00	380	559	22.00	---	---	---
30	660	737	29.00	660	737	29.00	---	---	---
36	962	889	35.00	962	889	35.00	---	---	---

1. Use class rating of valve body shell. For example, an easy-e NPS 6, butt weld valve schedule 80 is available in CL600, 1500 and 2500 shells. Likewise, a Fisher easy-e NPS 8 x 6 butt weld valve body, schedule 80, is available in either shell CL600 or 900.
2. easy-e CL900, NPS 3 through 6 flanged valve body uses a CL1500 shell.

Table 3. Flow Area for ED-J and ET-J Valves (Square Inches)

VALVE SIZE, NPS	PRESSURE RATING		
	CL300		
	Flow Area, $Inch^2$	Valve Diameter (dv)	
		mm	Inch
10	79	254	10.00
12	113	305	12.00
16	183	387	15.25

Table 4. Flow Area for Pipe (Square Inches)

Valve Size, NPS	Schedule								
	10	20	30	40	80	120	160	XS	XXS
1/2	- - -	- - -	- - -	0.30	0.23	- - -	0.17	0.23	0.05
3/4	- - -	- - -	- - -	0.53	0.43	- - -	0.30	0.43	0.15
1	- - -	- - -	- - -	0.86	0.72	- - -	0.52	0.72	0.28
1-1/2	- - -	- - -	- - -	2.0	1.8	- - -	1.4	1.8	0.95
2	- - -	- - -	- - -	3.4	3.0	- - -	2.2	3.0	1.8
2-1/2	- - -	- - -	- - -	4.8	4.2	- - -	3.5	4.2	2.5
3	- - -	- - -	- - -	7.4	6.6	- - -	5.4	6.6	4.2
4	- - -	- - -	- - -	13	11	10	9.3	11	7.8
6	- - -	- - -	- - -	29	26	24	21	26	19
8	- - -	52	51	50	46	41	36	46	37
10	- - -	83	81	79	72	65	57	75	- - -
12	- - -	118	115	112	102	91	81	108	- - -
16	189	186	183	177	161	144	129	177	- - -
20	299	291	284	278	253	227	203	284	- - -
24	434	425	411	402	378	326	291	415	- - -

Table 5. Fisher FB Outlet Flow Area, Inch^2

OUTLET SIZE, NPS	PRESSURE RATINGS											
	CL150			CL300			CL600			CL900		
	Flow Area, Inch^2	Valve Diameter (dv)		Flow Area, Inch^2	Valve Diameter (dv)		Flow Area, Inch^2	Valve Diameter (dv)		Flow Area, Inch^2	Valve Diameter (dv)	
		mm	Inch		mm	Inch		mm	Inch		mm	Inch
10	75	248	9.75	72	243	9.56	65	230	9.06	57	216	8.5
12	108	298	11.75	102	289	11.37	91	273	10.75	81	257	10.13
16	177	381	15.00	161	363	14.31	145	344	13.56	129	325	12.81
18	224	429	16.88	204	409	16.12	183	387	15.25	164	367	14.44
20	278	478	18.81	253	456	17.94	227	432	17.00	203	408	16.06
24	402	575	22.62	365	548	21.56	326	518	20.38	293	490	19.31
30	638	724	28.50	594	699	27.50	521	654	25.75	- - -	- - -	- - -
36	921	870	34.25	855	838	33.00	755	787	31.00	- - -	- - -	- - -

Table 6. Fisher EH Flow Area, Inch^2

VALVE SIZE, NPS		PRESSURE RATINGS					
Globe	Angle	CL1500			CL2500		
		Flow Area, Inch^2	Valve Diameter (dv)		Flow Area, Inch^2	Valve Diameter (dv)	
			mm	Inch		mm	Inch
1, 1 1/2 x 1, or 2 x 1	1, 2	0.6	22.2	0.87	0.44	19.0	0.75
2 or 3 x 2	3	2.8	47.6	1.87	1.8	38.1	1.50
3 or 4 x 3	4	5.9	69.9	2.75	4.0	57.2	2.25
4 or 6 x 4	6	10	92.1	3.62	6.5(1)	73(1)	2.87(1)
					10(2)	92.1(2)	3.62(2)
6 or 8 x 6	8	23	137	5.37	15(1)	111(1)	4.37(1)
					26(2)	146(2)	5.75(2)
8 or 10 x 8	- - -	38	178	7.00	26	146	5.75
12 or 14 x 12	- - -	85	264	10.37	58	219	8.62

1. For Globe valve constructions (EH)
2. For Angle valve constructions (EHA)

Table 7. Fisher CHP Flow Area, $Inch^2$

VALVE SIZE, NPS	PRESSURE RATINGS		
	CL2500		
	Flow Area, $Inch^2$	Valve Diameter (dv)	
		mm	Inch
8	26	144	5.75

Table 8. Fisher HP Flow Area, $Inch^2$

VALVE SIZE, NPS		PRESSURE RATINGS					
Globe	Angle	CL900 & 1500			CL2500		
		Flow Area, $Inch^2$	Valve Diameter (dv)		Flow Area, $Inch^2$	Valve Diameter (dv)	
			mm	Inch		mm	Inch
1	1	0.61	22.2	0.87	0.44	19.0	0.75
2	2, 3	2.8	47.6	1.87	1.77	38.1	1.50
3(1)	- - -	6.5	73.1	2.88	- - -	- - -	- - -
3(2) or 4 x 3(1,2)	4	5.9	69.9	2.75	- - -	- - -	- - -
4 or 6 x 4	6	10.3	92.1	3.62	- - -	- - -	- - -
6 or 8 x 6	8	22.7	136.5	5.37	- - -	- - -	- - -

1. Manufactured in U.S.A.
2. Manufactured in Europe and Japan.

Table 9. Diffuser Tube Cross-Sectional Area

Diffuser Tube Size, Inch	O.D., Inch	Area, $Inch^2$
2	2.375	4.43
2-1/2	2.875	6.49
3	3.500	9.62
3-1/2	4.000	12.60
4	4.500	15.9
5	5.563	24.3
6	6.625	34.5
8	8.625	58.4
10	11	90.8
12	13	128.0
14	14	154
16	16	201
18	18	254
20	20	314
24	24	452

EMERSON

Table 10. Flow Area for Pipe, Inch^2

VALVE SIZE, NPS	SCHEDULE									
	10	20	30	40	80	120	160	STD	XS	XXS
1/2	- - -	- - -	- - -	0.30	0.23	- - -	0.17	0.30	0.23	0.05
3/4	- - -	- - -	- - -	0.53	0.43	- - -	0.30	0.53	0.43	0.15
1	- - -	- - -	- - -	0.86	0.72	- - -	0.52	0.86	0.72	0.28
1-1/2	- - -	- - -	- - -	2.0	1.8	- - -	1.4	2.0	1.8	0.95
3	- - -	- - -	- - -	3.4	3.0	- - -	2.2	3.4	3.0	1.8
2-1/2	- - -	- - -	- - -	4.8	4.2	- - -	3.5	4.8	4.2	2.5
3	- - -	- - -	- - -	7.4	6.6	- - -	5.4	7.4	6.6	4.2
4	- - -	- - -	- - -	13	11	10	9.3	13	11	7.8
6	- - -	- - -	- - -	29	26	24	21	29	26	19
8	- - -	52	51	50	46	41	36	50	46	37
10	- - -	83	81	79	72	65	57	79	75	- - -
12	- - -	118	115	112	102	91	81	113	108	- - -
16	189	186	183	177	161	144	129	183	177	- - -
20	299	291	284	278	253	227	203	290	284	- - -
24	434	425	411	402	378	326	291	425	415	- - -
30	678	661	649	- - -	- - -	- - -	- - -	672	661	- - -
36	983	962	948	935	- - -	- - -	- - -	976	962	- - -