Valve Sizing Calculations (Traditional Method)

Introduction

Fisher® regulators and valves have traditionally been sized using equations derived by the company. There are now standardized calculations that are becoming accepted worldwide. Some product literature continues to demonstrate the traditional method, but the trend is to adopt the standardized method. Therefore, both methods are covered in this application guide.

Improper valve sizing can be both expensive and inconvenient. A valve that is too small will not pass the required flow, and the process will be starved. An oversized valve will be more expensive, and it may lead to instability and other problems.

The days of selecting a valve based upon the size of the pipeline are gone. Selecting the correct valve size for a given application requires a knowledge of process conditions that the valve will actually see in service. The technique for using this information to size the valve is based upon a combination of theory and experimentation.

Sizing for Liquid Service

Using the principle of conservation of energy, Daniel Bernoulli found that as a liquid flows through an orifice, the square of the fluid velocity is directly proportional to the pressure differential across the orifice and inversely proportional to the specific gravity of the fluid. The greater the pressure differential, the higher the velocity; the greater the density, the lower the velocity. The volume flow rate for liquids can be calculated by multiplying the fluid velocity times the flow area.

By taking into account units of measurement, the proportionality relationship previously mentioned, energy losses due to friction and turbulence, and varying discharge coefficients for various types of orifices (or valve bodies), a basic liquid sizing equation can be written as follows

$$Q = C_V \sqrt{\Delta P / G} \tag{1}$$

where:

- Q = Capacity in gallons per minute
- C_v = Valve sizing coefficient determined experimentally for each style and size of valve, using water at standard conditions as the test fluid
- ΔP = Pressure differential in psi
- G = Specific gravity of fluid (water at 60°F = 1.0000)

Thus, C_v is numerically equal to the number of U.S. gallons of water at 60°F that will flow through the valve in one minute when the pressure differential across the valve is one pound per square inch. C_v varies with both size and style of valve, but provides an index for comparing liquid capacities of different valves under a standard set of conditions.

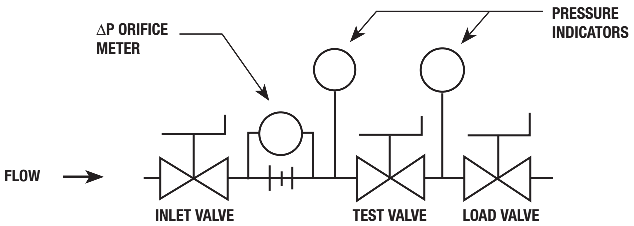

Figure 1. *Standard FCI Test Piping for C_v Measurement*

To aid in establishing uniform measurement of liquid flow capacity coefficients (C_v) among valve manufacturers, the Fluid Controls Institute (FCI) developed a standard test piping arrangement, shown in Figure 1. Using such a piping arrangement, most valve manufacturers develop and publish C_v information for their products, making it relatively easy to compare capacities of competitive products.

To calculate the expected C_v for a valve controlling water or other liquids that behave like water, the basic liquid sizing equation above can be re-written as follows

$$C_V = Q \sqrt{\frac{G}{\Delta P}} \tag{2}$$

Viscosity Corrections

Viscous conditions can result in significant sizing errors in using the basic liquid sizing equation, since published C_v values are based on test data using water as the flow medium. Although the majority of valve applications will involve fluids where viscosity corrections can be ignored, or where the corrections are relatively small, fluid viscosity should be considered in each valve selection.

Emerson Process Management has developed a nomograph (Figure 2) that provides a viscosity correction factor (F_v). It can be applied to the standard C_v coefficient to determine a corrected coefficient (C_{vr}) for viscous applications.

Finding Valve Size

Using the C_v determined by the basic liquid sizing equation and the flow and viscosity conditions, a fluid Reynolds number can be found by using the nomograph in Figure 2. The graph of Reynolds number vs. viscosity correction factor (F_v) is used to determine the correction factor needed. (If the Reynolds number is greater than 3500, the correction will be ten percent or less.) The actual required C_v (C_{vr}) is found by the equation:

$$C_{vr} = F_V\, C_V \tag{3}$$

From the valve manufacturer's published liquid capacity information, select a valve having a C_v equal to or higher than the required coefficient (C_{vr}) found by the equation above.

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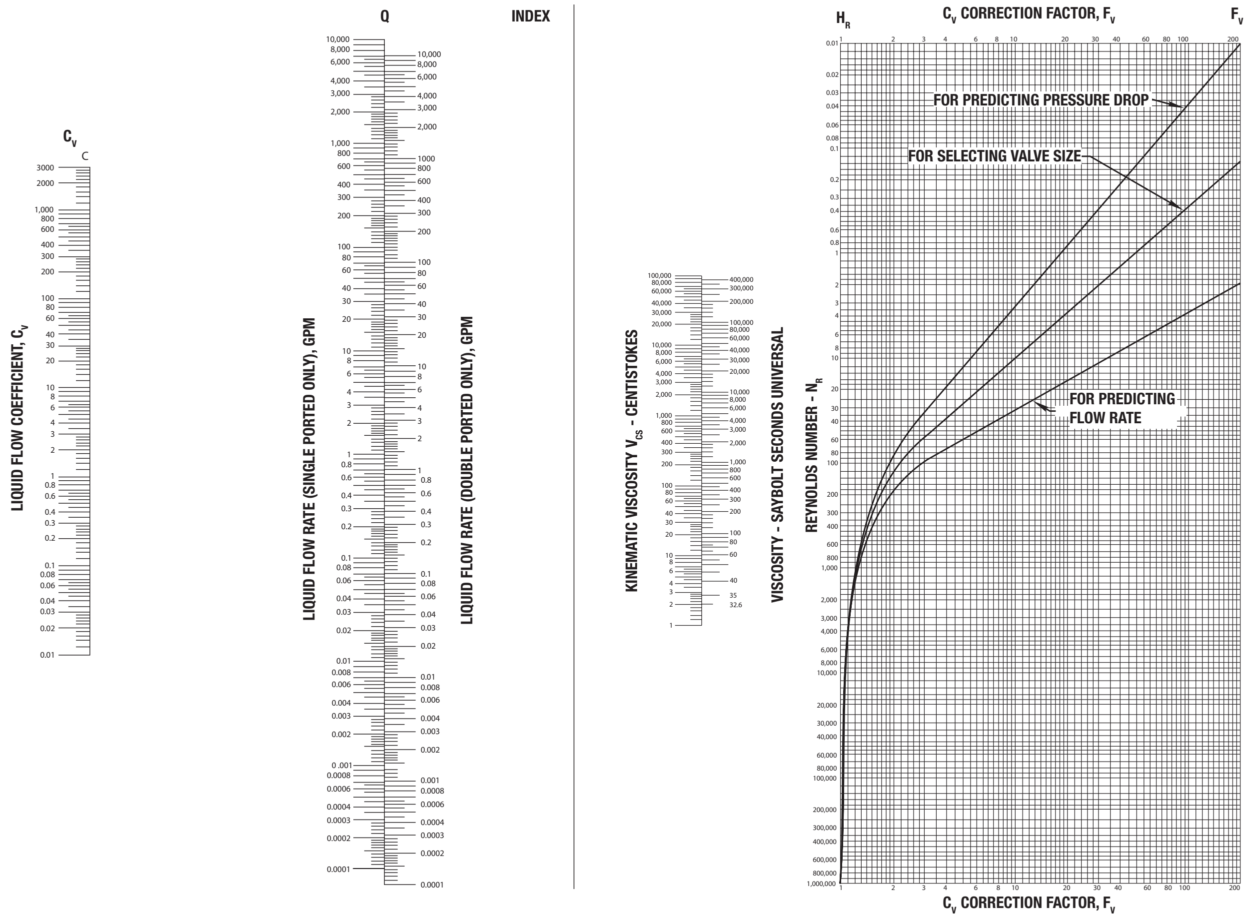

Figure 2. *Nomograph for Determining Viscosity Correction*

Nomograph Instructions

Use this nomograph to correct for the effects of viscosity. When assembling data, all units must correspond to those shown on the nomograph. For high-recovery, ball-type valves, use the liquid flow rate Q scale designated for single-ported valves. For butterfly and eccentric disk rotary valves, use the liquid flow rate Q scale designated for double-ported valves.

Nomograph Equations

1. Single-Ported Valves: $N_R = 17250 \dfrac{Q}{\sqrt{C_V \nu_{CS}}}$

2. Double-Ported Valves: $N_R = 12200 \dfrac{Q}{\sqrt{C_V \nu_{CS}}}$

Nomograph Procedure

1. Lay a straight edge on the liquid sizing coefficient on C_v scale and flow rate on Q scale. Mark intersection on index line. Procedure A uses value of C_{vc}; Procedures B and C use value of C_{vr}.

2. Pivot the straight edge from this point of intersection with index line to liquid viscosity on proper n scale. Read Reynolds number on N_R scale.

3. Proceed horizontally from intersection on N_R scale to proper curve, and then vertically upward or downward to F_v scale. Read C_v correction factor on F_v scale.

Valve Sizing Calculations (Traditional Method)

Predicting Flow Rate

Select the required liquid sizing coefficient (C_{vr}) from the manufacturer's published liquid sizing coefficients (C_v) for the style and size valve being considered. Calculate the maximum flow rate (Q_{max}) in gallons per minute (assuming no viscosity correction required) using the following adaptation of the basic liquid sizing equation:

$$Q_{max} = C_{vr}\sqrt{\Delta P / G} \qquad (4)$$

Then incorporate viscosity correction by determining the fluid Reynolds number and correction factor F_v from the viscosity correction nomograph and the procedure included on it.

Calculate the predicted flow rate (Q_{pred}) using the formula:

$$Q_{pred} = \frac{Q_{max}}{F_V} \qquad (5)$$

Predicting Pressure Drop

Select the required liquid sizing coefficient (C_{vr}) from the published liquid sizing coefficients (C_v) for the valve style and size being considered. Determine the Reynolds number and correct factor F_v from the nomograph and the procedure on it. Calculate the sizing coefficient (C_{vc}) using the formula:

$$C_{VC} = \frac{C_{vr}}{F_v} \qquad (6)$$

Calculate the predicted pressure drop (ΔP_{pred}) using the formula:

$$\Delta P_{pred} = G\,(Q/C_{vc})^2 \qquad (7)$$

Flashing and Cavitation

The occurrence of flashing or cavitation within a valve can have a significant effect on the valve sizing procedure. These two related physical phenomena can limit flow through the valve in many applications and must be taken into account in order to accurately size a valve. Structural damage to the valve and adjacent piping may also result. Knowledge of what is actually happening within the valve might permit selection of a size or style of valve which can reduce, or compensate for, the undesirable effects of flashing or cavitation.

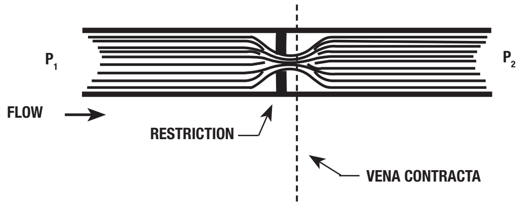

Figure 3. *Vena Contracta*

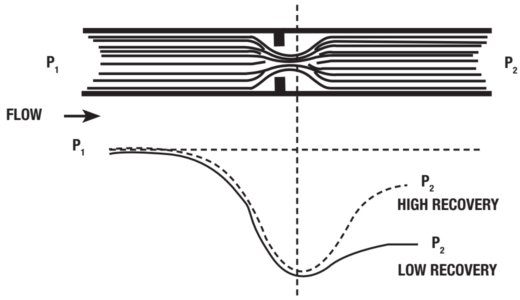

Figure 4. *Comparison of Pressure Profiles for High and Low Recovery Valves*

The "physical phenomena" label is used to describe flashing and cavitation because these conditions represent actual changes in the form of the fluid media. The change is from the liquid state to the vapor state and results from the increase in fluid velocity at or just downstream of the greatest flow restriction, normally the valve port. As liquid flow passes through the restriction, there is a necking down, or contraction, of the flow stream. The minimum cross-sectional area of the flow stream occurs just downstream of the actual physical restriction at a point called the vena contracta, as shown in Figure 3.

To maintain a steady flow of liquid through the valve, the velocity must be greatest at the vena contracta, where cross sectional area is the least. The increase in velocity (or kinetic energy) is accompanied by a substantial decrease in pressure (or potential energy) at the vena contracta. Farther downstream, as the fluid stream expands into a larger area, velocity decreases and pressure increases. But, of course, downstream pressure never recovers completely to equal the pressure that existed upstream of the valve. The pressure differential (ΔP) that exists across the valve

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is a measure of the amount of energy that was dissipated in the valve. Figure 4 provides a pressure profile explaining the differing performance of a streamlined high recovery valve, such as a ball valve and a valve with lower recovery capabilities due to greater internal turbulence and dissipation of energy.

Regardless of the recovery characteristics of the valve, the pressure differential of interest pertaining to flashing and cavitation is the differential between the valve inlet and the vena contracta. If pressure at the vena contracta should drop below the vapor pressure of the fluid (due to increased fluid velocity at this point) bubbles will form in the flow stream. Formation of bubbles will increase greatly as vena contracta pressure drops further below the vapor pressure of the liquid. At this stage, there is no difference between flashing and cavitation, but the potential for structural damage to the valve definitely exists.

If pressure at the valve outlet remains below the vapor pressure of the liquid, the bubbles will remain in the downstream system and the process is said to have "flashed." Flashing can produce serious erosion damage to the valve trim parts and is characterized by a smooth, polished appearance of the eroded surface. Flashing damage is normally greatest at the point of highest velocity, which is usually at or near the seat line of the valve plug and seat ring.

However, if downstream pressure recovery is sufficient to raise the outlet pressure above the vapor pressure of the liquid, the bubbles will collapse, or implode, producing cavitation. Collapsing of the vapor bubbles releases energy and produces a noise similar to what one would expect if gravel were flowing through the valve. If the bubbles collapse in close proximity to solid surfaces, the energy released gradually wears the material leaving a rough, cylinder like surface. Cavitation damage might extend to the downstream pipeline, if that is where pressure recovery occurs and the bubbles collapse. Obviously, "high recovery" valves tend to be more subject to cavitation, since the downstream pressure is more likely to rise above the vapor pressure of the liquid.

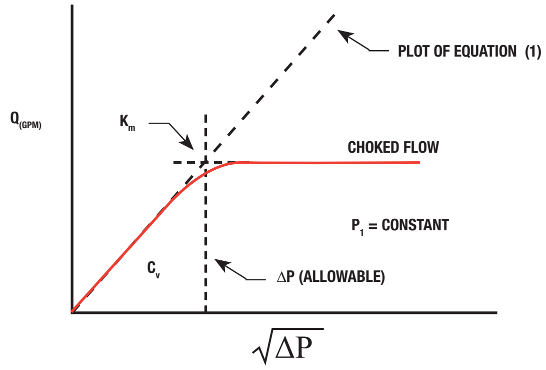


Figure 5. *Flow Curve Showing C_v and K_m*

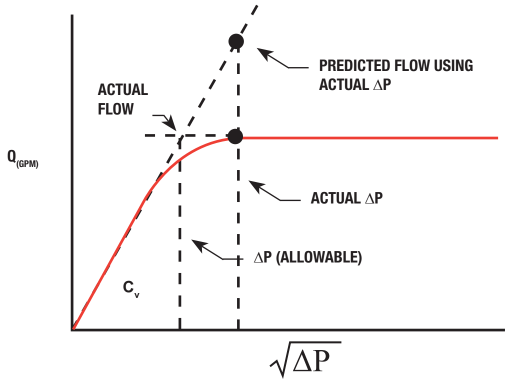


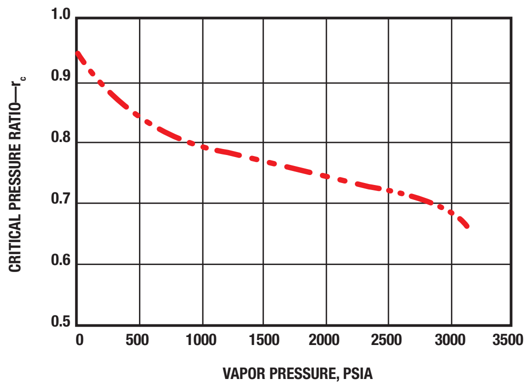
Figure 6. *Relationship Between Actual ΔP and ΔP Allowable*

Choked Flow

Aside from the possibility of physical equipment damage due to flashing or cavitation, formation of vapor bubbles in the liquid flow stream causes a crowding condition at the vena contracta which tends to limit flow through the valve. So, while the basic liquid sizing equation implies that there is no limit to the amount of flow through a valve as long as the differential pressure across the valve increases, the realities of flashing and cavitation prove otherwise.

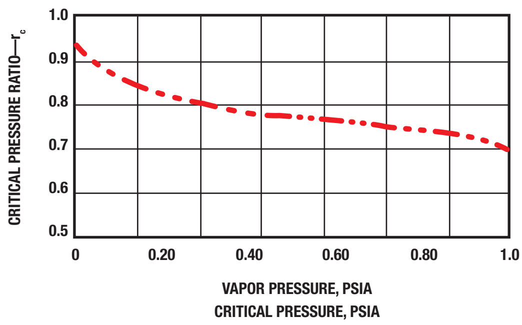
If valve pressure drop is increased slightly beyond the point where bubbles begin to form, a choked flow condition is reached. With constant upstream pressure, further increases in pressure drop (by reducing downstream pressure) will not produce increased flow. The limiting pressure differential is designated ΔP_{allow} and the valve recovery coefficient (K_m) is experimentally determined for each valve, in order to relate choked flow for that particular valve to the basic liquid sizing equation. K_m is normally published with other valve capacity coefficients. Figures 5 and 6 show these flow vs. pressure drop relationships.

Valve Sizing Calculations (Traditional Method)



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 7. *Critical Pressure Ratios for 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.

Figure 8. *Critical Pressure Ratios for Liquid Other than Water*

Use the following equation to determine maximum allowable pressure drop that is effective in producing flow. Keep in mind, however, that the limitation on the sizing pressure drop, ΔP_{allow}, does not imply a maximum pressure drop that may be controlled y the valve.

$$\Delta P_{allow} = K_m (P_1 - r_c P_v) \qquad (8)$$

where:

- ΔP_{allow} = maximum allowable differential pressure for sizing purposes, psi
- K_m = valve recovery coefficient from manufacturer's literature
- P_1 = body inlet pressure, psia
- r_c = critical pressure ratio determined from Figures 7 and 8
- P_v = vapor pressure of the liquid at body inlet temperature, psia (vapor pressures and critical pressures for many common liquids are provided in the Physical Constants of Hydrocarbons and Physical Constants of Fluids tables; refer to the Table of Contents for the page number).

After calculating ΔP_{allow}, substitute it into the basic liquid sizing equation $Q = C_V \sqrt{\Delta P / G}$ to determine either Q or C_v. If the actual ΔP is less the ΔP_{allow}, then the actual ΔP should be used in the equation.

The equation used to determine ΔP_{allow} should also be used to calculate the valve body differential pressure at which significant cavitation can occur. Minor cavitation will occur at a slightly lower pressure differential than that predicted by the equation, but should produce negligible damage in most globe-style control valves.

Consequently, initial cavitation and choked flow occur nearly simultaneously in globe-style or low-recovery valves.

However, in high-recovery valves such as ball or butterfly valves, significant cavitation can occur at pressure drops below that which produces choked flow. So although ΔP_{allow} and K_m are useful in predicting choked flow capacity, a separate cavitation index (K_c) is needed to determine the pressure drop at which cavitation damage will begin (ΔP_c) in high-recovery valves.

The equation can e expressed:

$$\Delta P_C = K_C (P_1 - P_V) \qquad (9)$$

This equation can be used anytime outlet pressure is greater than the vapor pressure of the liquid.

Addition of anti-cavitation trim tends to increase the value of K_m. In other words, choked flow and incipient cavitation will occur at substantially higher pressure drops than was the case without the anti-cavitation accessory.

Valve Sizing Calculations (Traditional Method)

Liquid Sizing Equation Application		
EQUATION		**APPLICATION**
1	$Q = C_v \sqrt{\Delta P / G}$	Basic liquid sizing equation. Use to determine proper valve size for a given set of service conditions. (Remember that viscosity effects and valve recovery capabilities are not considered in this basic equation.)
2	$C_V = Q \sqrt{\frac{G}{\Delta P}}$	Use to calculate expected C_v for valve controlling water or other liquids that behave like water.
3	$C_{vr} = F_V C_V$	Use to find actual required C_v for equation (2) after including viscosity correction factor.
4	$Q_{max} = C_{vr} \sqrt{\Delta P / G}$	Use to find maximum flow rate assuming no viscosity correction is necessary.
5	$Q_{pred} = \frac{Q_{max}}{F_V}$	Use to predict actual flow rate based on equation (4) and viscosity factor correction.
6	$C_{VC} = \frac{C_{vr}}{F_v}$	Use to calculate corrected sizing coefficient for use in equation (7).
7	$\Delta P_{pred} = G\,(Q/C_{vc})^2$	Use to predict pressure drop for viscous liquids.
8	$\Delta P_{allow} = K_m\,(P_1 - r_c P_v)$	Use to determine maximum allowable pressure drop that is effective in producing flow.
9	$\Delta P_C = K_C\,(P_1 - P_V)$	Use to predict pressure drop at which cavitation will begin in a valve with high recovery characteristics.

Liquid Sizing Summary

The most common use of the basic liquid sizing equation is to determine the proper valve size for a given set of service conditions. The first step is to calculate the required C_v by using the sizing equation. The ΔP used in the equation must be the actual valve pressure drop or ΔP_{allow}, whichever is smaller. The second step is to select a valve, from the manufacturer's literature, with a C_v equal to or greater than the calculated value.

Accurate valve sizing for liquids requires use of the dual coefficients of C_v and K_m. A single coefficient is not sufficient to describe both the capacity and the recovery characteristics of the valve. Also, use of the additional cavitation index factor K_c is appropriate in sizing high recovery valves, which may develop damaging cavitation at pressure drops well below the level of the choked flow.

Liquid Sizing Nomenclature

C_v = valve sizing coefficient for liquid determined experimentally for each size and style of valve, using water at standard conditions as the test fluid

C_{vc} = calculated C_v coefficient including correction for viscosity

C_{vr} = corrected sizing coefficient required for viscous applications

ΔP = differential pressure, psi

ΔP_{allow} = maximum allowable differential pressure for sizing purposes, psi

ΔP_c = pressure differential at which cavitation damage begins, psi

F_v = viscosity correction factor

G = specific gravity of fluid (water at 60°F = 1.0000)

K_c = dimensionless cavitation index used in determining ΔP_c

K_m = valve recovery coefficient from manufacturer's literature

P_1 = body inlet pressure, psia

P_v = vapor pressure of liquid at body inlet temperature, psia

Q = flow rate capacity, gallons per minute

Q_{max} = designation for maximum flow rate, assuming no viscosity correction required, gallons per minute

Q_{pred} = predicted flow rate after incorporating viscosity correction, gallons per minute

r_c = critical pressure ratio

Valve Sizing Calculations (Traditional Method)

Sizing for Gas or Steam Service

A sizing procedure for gases can be established based on adaptions of the basic liquid sizing equation. By introducing conversion factors to change flow units from gallons per minute to cubic feet per hour and to relate specific gravity in meaningful terms of pressure, an equation can be derived for the flow of air at 60°F. Because 60°F corresponds to 520° on the Rankine absolute temperature scale, and because the specific gravity of air at 60°F is 1.0, an additional factor can be included to compare air at 60°F with specific gravity (G) and absolute temperature (T) of any other gas. The resulting equation an be written:

$$Q_{SCFH} = 59.64\, C_V P_1 \sqrt{\frac{\Delta P}{P_1}} \sqrt{\frac{520}{GT}} \qquad \text{(A)}$$

The equation shown above, while valid at very low pressure drop ratios, has been found to be very misleading when the ratio of pressure drop (ΔP) to inlet pressure (P_1) exceeds 0.02. The deviation of actual flow capacity from the calculated flow capacity is indicated in Figure 8 and results from compressibility effects and critical flow limitations at increased pressure drops.

Critical flow limitation is the more significant of the two problems mentioned. Critical flow is a choked flow condition caused by increased gas velocity at the vena contracta. When velocity at the vena contracta reaches sonic velocity, additional increases in ΔP by reducing downstream pressure produce no increase in flow. So, after critical flow condition is reached (whether at a pressure drop/inlet pressure ratio of about 0.5 for glove valves or at much lower ratios for high recovery valves) the equation above becomes completely useless. If applied, the C_v equation gives a much higher indicated capacity than actually will exist. And in the case of a high recovery valve which reaches critical flow at a low pressure drop ratio (as indicated in Figure 8), the critical flow capacity of the valve may be over-estimated by as much as 300 percent.

The problems in predicting critical flow with a C_v-based equation led to a separate gas sizing coefficient based on air flow tests. The coefficient (C_g) was developed experimentally for each type and size of valve to relate critical flow to absolute inlet pressure. By including the correction factor used in the previous equation to compare air at 60°F with other gases at other absolute temperatures, the critical flow equation an be written:

$$Q_{critical} = C_g P_1 \sqrt{520 / GT} \qquad \text{(B)}$$

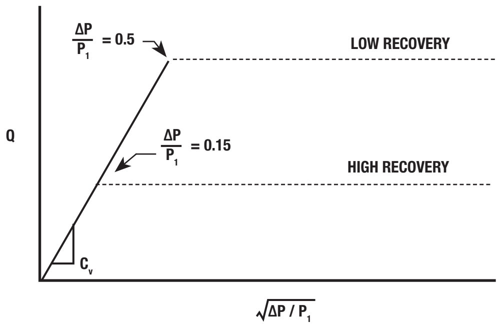


Figure 9. *Critical Flow for High and Low Recovery Valves with Equal C_v*

Universal Gas Sizing Equation

To account for differences in flow geometry among valves, equations (A) and (B) were consolidated by the introduction of an additional factor (C_1). C_1 is defined as the ratio of the gas sizing coefficient and the liquid sizing coefficient and provides a numerical indicator of the valve's recovery capabilities. In general, C_1 values can range from about 16 to 37, based on the individual valve's recovery characteristics. As shown in the example, two valves with identical flow areas and identical critical flow (C_g) capacities can have widely differing C_1 values dependent on the effect internal flow geometry has on liquid flow capacity through each valve. Example:

High Recovery Valve

C_g = 4680
C_v = 254
C_1 = C_g/C_v
= 4680/254
= 18.4

Low Recovery Valve

C_g = 4680
C_v = 135
C_1 = C_g/C_v
= 4680/135
= 34.7

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Valve Sizing Calculations (Traditional Method)

So we see that two sizing coefficients are needed to accurately size valves for gas flow—C_g to predict flow based on physical size or flow area, and C_1 to account for differences in valve recovery characteristics. A blending equation, called the Universal Gas Sizing Equation, combines equations (A) and (B) by means of a sinusoidal function, and is based on the "perfect gas" laws. It can be expressed in either of the following manners:

$$Q_{SCFH} = \sqrt{\frac{520}{GT}}\ C_g P_1 \text{ SIN}\left[\left(\frac{59.64}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{rad} \qquad \text{(C)}$$

OR

$$Q_{SCFH} = \sqrt{\frac{520}{GT}}\ C_g P_1 \text{ SIN}\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{Deg} \qquad \text{(D)}$$

In either form, the equation indicates critical flow when the sine function of the angle designated within the brackets equals unity. The pressure drop ratio at which critical flow occurs is known as the critical pressure drop ratio. It occurs when the sine angle reaches $\pi/2$ radians in equation (C) or 90 degrees in equation (D). As pressure drop across the valve increases, the sine angle increases from zero up to $\pi/2$ radians (90°). If the angle were allowed to increase further, the equations would predict a decrease in flow. Because this is not a realistic situation, the angle must be limited to 90 degrees maximum.

Although "perfect gases," as such, do not exist in nature, there are a great many applications where the Universal Gas Sizing Equation, (C) or (D), provides a very useful and usable approximation.

General Adaptation for Steam and Vapors

The density form of the Universal Gas Sizing Equation is the most general form and can be used for both perfect and non-perfect gas applications. Applying the equation requires knowledge of one additional condition not included in previous equations, that being the inlet gas, steam, or vapor density (d_1) in pounds per cubic foot. (Steam density can be determined from tables.)

Then the following adaptation of the Universal Gas Sizing Equation can be applied:

$$Q_{lb/hr} = 1.06\sqrt{d_1 P_1}\ C_g \text{ SIN}\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right) \text{Deg} \qquad \text{(E)}$$

Special Equation Form for Steam Below 1000 psig

If steam applications do not exceed 1000 psig, density changes can be compensated for by using a special adaptation of the Universal Gas Sizing Equation. It incorporates a factor for amount of superheat in degrees Fahrenheit (T_{sh}) and also a sizing coefficient (C_s) for steam. Equation (F) eliminates the need for finding the density of superheated steam, which was required in Equation (E). At pressures below 1000 psig, a constant relationship exists between the gas sizing coefficient (C_g) and the steam coefficient (C_s). This relationship can be expressed: $C_s = C_g/20$. For higher steam pressure application, use Equation (E).

$$Q_{lb/hr} = \left[\left(\frac{C_S P_1}{1 + 0.00065T_{sh}}\right)\right] \text{ SIN}\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] \text{Deg} \qquad \text{(F)}$$

Gas and Steam Sizing Summary

The Universal Gas Sizing Equation can be used to determine the flow of gas through any style of valve. Absolute units of temperature and pressure must be used in the equation. When the critical pressure drop ratio causes the sine angle to be 90 degrees, the equation will predict the value of the critical flow. For service conditions that would result in an angle of greater than 90 degrees, the equation must be limited to 90 degrees in order to accurately determine the critical flow.

Most commonly, the Universal Gas Sizing Equation is used to determine proper valve size for a given set of service conditions. The first step is to calculate the required C_g by using the Universal Gas Sizing Equation. The second step is to select a valve from the manufacturer's literature. The valve selected should have a C_g which equals or exceeds the calculated value. Be certain that the assumed C_1 value for the valve is selected from the literature.

It is apparent that accurate valve sizing for gases that requires use of the dual coefficient is not sufficient to describe both the capacity and the recovery characteristics of the valve.

Proper selection of a control valve for gas service is a highly technical problem with many factors to be considered. Leading valve manufacturers provide technical information, test data, sizing catalogs, nomographs, sizing slide rules, and computer or calculator programs that make valve sizing a simple and accurate procedure.

Valve Sizing Calculations (Traditional Method)

Gas and Steam Sizing Equation Application

	EQUATION	APPLICATION
A	$Q_{SCFH} = 59.64\, C_V P_1 \sqrt{\frac{\Delta P}{P_1}} \sqrt{\frac{520}{GT}}$	Use only at very low pressure drop (DP/P_1) ratios of 0.02 or less.
B	$Q_{critical} = C_g P_1 \sqrt{520 / GT}$	Use only to determine critical flow capacity at a given inlet pressure.
C	$Q_{SCFH} = \sqrt{\frac{520}{GT}}\; C_g P_1 \, SIN\left[\left(\frac{59.64}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] rad$ OR	Universal Gas Sizing Equation. Use to predict flow for either high or low recovery valves, for any gas adhering to the perfect gas laws, and under any service conditions.
D	$Q_{SCFH} = \sqrt{\frac{520}{GT}}\; C_g P_1 \, SIN\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] Deg$	
E	$Q_{lb/hr} = 1.06 \sqrt{d_1 P_1}\; C_g \, SIN\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right) Deg$	Use to predict flow for perfect or non-perfect gas sizing applications, for any vapor including steam, at any service condition when fluid density is known.
F	$Q_{lb/hr} = \left[\left(\frac{C_S P_1}{1 + 0.00065 T_{sh}}\right)\right] SIN\left[\left(\frac{3417}{C_1}\right)\left(\sqrt{\frac{\Delta P}{P_1}}\right)\right] Deg$	Use only to determine steam flow when inlet pressure is 1000 psig or less.

Gas and Steam Sizing Nomenclature

C_1 = C_g/C_v

C_g = gas sizing coefficient

C_s = steam sizing coefficient, $C_g/20$

C_v = liquid sizing coefficient

d_1 = density of steam or vapor at inlet, pounds/cu. foot

G = gas specific gravity (air = 1.0)

P_1 = valve inlet pressure, psia

ΔP = pressure drop across valve, psi

$Q_{critical}$ = critical flow rate, SCFH

Q_{SCFH} = gas flow rate, SCFH

$Q_{lb/hr}$ = steam or vapor flow rate, pounds per hour

T = absolute temperature of gas at inlet, degrees Rankine

T_{sh} = degrees of superheat, °F

Valve Sizing (Standardized Method)

Introduction

Fisher® regulators and valves have traditionally been sized using equations derived by the company. There are now standardized calculations that are becoming accepted world wide. Some product literature continues to demonstrate the traditional method, but the trend is to adopt the standardized method. Therefore, both methods are covered in this application guide.

Liquid Valve Sizing

Standardization activities for control valve sizing can be traced back to the early 1960s when a 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 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 ISA.) 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
   - Process fluid (water, oil, etc.), and
   - Appropriate service conditions q or w, P_1, P_2, or ΔP, T_1, G_f, P_v, P_c, and υ.

   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 Abbreviations and Terminology Table 3-1 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 the Equation Constants Table 3-2.

   Use N_1, if sizing the valve for a flow rate in volumetric units (GPM or Nm³/h).

   Use N_6, if sizing the valve for a flow rate in mass units (pound/hr or kg/hr).

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, page 637.

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 q_{max}, the Maximum Flow Rate, or ΔP_{max}, the Allowable Sizing Pressure Drop. If it can be recognized that choked flow conditions will not develop within the valve, ΔP_{max} need not be calculated.

5. *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:

   $K_v = (0.865)\,(C_v)$

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

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

Valve Sizing (Standardized Method)

Table 3-1. Abbreviations and Terminology

SYMBOL		SYMBOL	
C_v	Valve sizing coefficient	P_1	Upstream absolute static pressure
d	Nominal valve size	P_2	Downstream absolute static pressure
D	Internal diameter of the piping	P_c	Absolute thermodynamic critical pressure
F_d	Valve style modifier, dimensionless	P_v	Vapor pressure absolute of liquid at inlet temperature
F_F	Liquid critical pressure ratio factor, dimensionless	ΔP	Pressure drop (P_1-P_2) across the valve
F_k	Ratio of specific heats factor, dimensionless	$\Delta P_{max(L)}$	Maximum allowable liquid sizing pressure drop
F_L	Rated liquid pressure recovery factor, dimensionless	$\Delta P_{max(LP)}$	Maximum allowable sizing pressure drop with attached fittings
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	q	Volume rate of flow
F_P	Piping geometry factor, dimensionless	q_{max}	Maximum flow rate (choked flow conditions) at given upstream conditions
G_f	Liquid specific gravity (ratio of density of liquid at flowing temperature to density of water at 60°F), dimensionless	T_1	Absolute upstream temperature (deg Kelvin or deg Rankine)
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	w	Mass rate of flow
k	Ratio of specific heats, dimensionless	x	Ratio of pressure drop to upstream absolute static pressure ($\Delta P/P_1$), dimensionless
K	Head loss coefficient of a device, dimensionless	x_T	Rated pressure drop ratio factor, dimensionless
M	Molecular weight, dimensionless	Y	Expansion factor (ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number), dimensionless
N	Numerical constant	Z	Compressibility factor, dimensionless
		γ^1	Specific weight at inlet conditions
		υ	Kinematic viscosity, centistokes

1. Standard conditions are defined as 60°F and 14.7 psia.

Table 3-2. Equation Constants[1]

		N	w	q	p[2]	γ	T	d, D
N_1		0.0865 0.865 1.00	- - - - - - - - - - - -	Nm³/h Nm³/h GPM	kPa bar psia	- - - - - - - - - - - -	- - - - - - - - - - - -	- - - - - - - - - - - -
N_2		0.00214 890	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	mm inch
N_5		0.00241 1000	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -	mm inch
N_6		2.73 27.3 63.3	kg/hr kg/hr pound/hr	- - - - - - - - - - - -	kPa bar psia	kg/m³ kg/m³ pound/ft³	- - - - - - - - - - - -	- - - - - - - - - - - -
N_7[3]	Normal Conditions T_N = 0°C	3.94 394	- - - - - - - -	Nm³/h Nm³/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_s = 16°C	4.17 417	- - - - - - - -	Nm³/h Nm³/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_s = 60°F	1360	- - - -	SCFH	psia	- - - -	deg Rankine	- - - -
N_8		0.948 94.8 19.3	kg/hr kg/hr pound/hr	- - - - - - - - - - - -	kPa bar psia	- - - - - - - - - - - -	deg Kelvin deg Kelvin deg Rankine	- - - - - - - - - - - -
N_9[3]	Normal Conditions T_N = 0°C	21.2 2120	- - - - - - - -	Nm³/h Nm³/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_S = 16°C	22.4 2240	- - - - - - - -	Nm³/h Nm³/h	kPa bar	- - - - - - - -	deg Kelvin deg Kelvin	- - - - - - - -
	Standard Conditions T_S = 60°F	7320	- - - -	SCFH	psia	- - - -	deg Rankine	- - - -

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 Nm³/h and the pressures are kPa, the N_1 constant becomes 0.0865.
2. All pressures are absolute.
3. Pressure base is 101.3 kPa (1,01 bar) (14.7 psia).

Valve Sizing (Standardized Method)

Determining Piping Geometry Factor (F_p)

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:

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

where,

N_2 = Numerical constant found in the Equation Constants table
d = Assumed nominal valve size
C_v = Valve sizing coefficient at 100% travel for the assumed valve size

In the above equation, the $\sum K$ term is the algebraic sum of the velocity head loss coefficients of all of the fittings that are attached to the control valve.

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

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, whereby:

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

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.

The most commonly used fitting in control valve installations is the short-length concentric reducer. The equations 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:

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

Determining Maximum Flow Rate (q_{max})

Determine either q_{max} or ΔP_{max} if it is 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.

$$q_{max} = N_1 F_L C_V \sqrt{\frac{P_1 - F_F P_V}{G_f}}$$

Values for F_F, the liquid critical pressure ratio factor, can be obtained from Figure 3-1, or from the following equation:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_V}{P_C}}$$

Values of F_L, the recovery factor for rotary valves installed without fittings attached, can be found in published 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 replaced 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.)

Valve Sizing (Standardized Method)

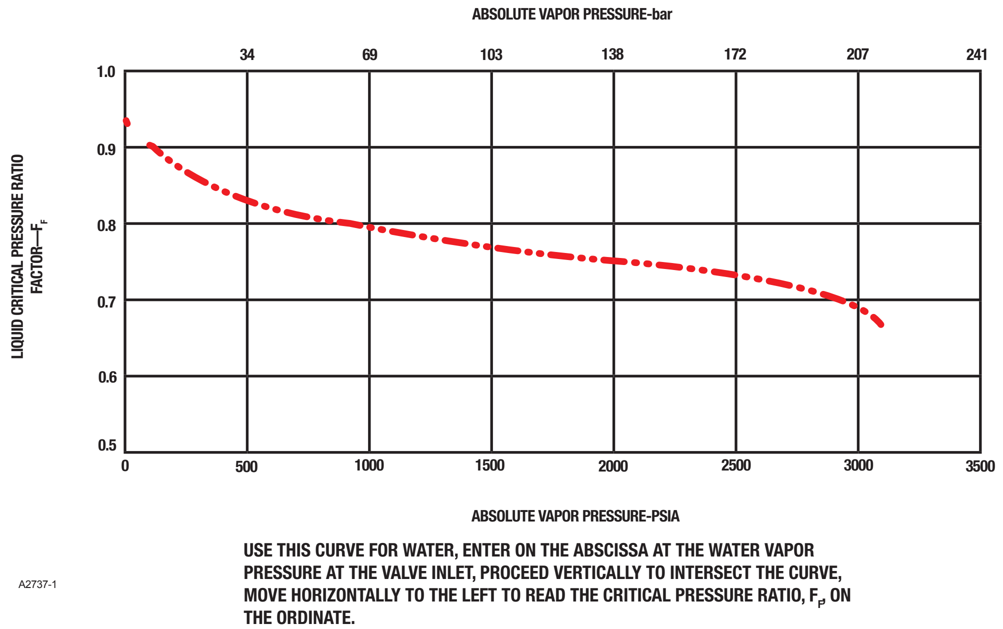


Figure 3-1. *Liquid Critical Pressure Ratio Factor for Water*

Determining Allowable Sizing Pressure Drop (ΔP_{max})

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 3-1 or from the following equation:

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

An explanation of how to calculate values of F_{LP}, the recovery factor for valves installed with fittings attached, is presented in the preceding procedure 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 ($\Delta P = P_1 - P_2$). 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 ($\Delta P_{max} < P_1 - P_2$), then step 5 of the procedure for Sizing Valves for Liquids must be modified by replacing the actual service pressure differential ($P_1 - P_2$) in the appropriate valve sizing equation with the calculated ΔP_{max} value.

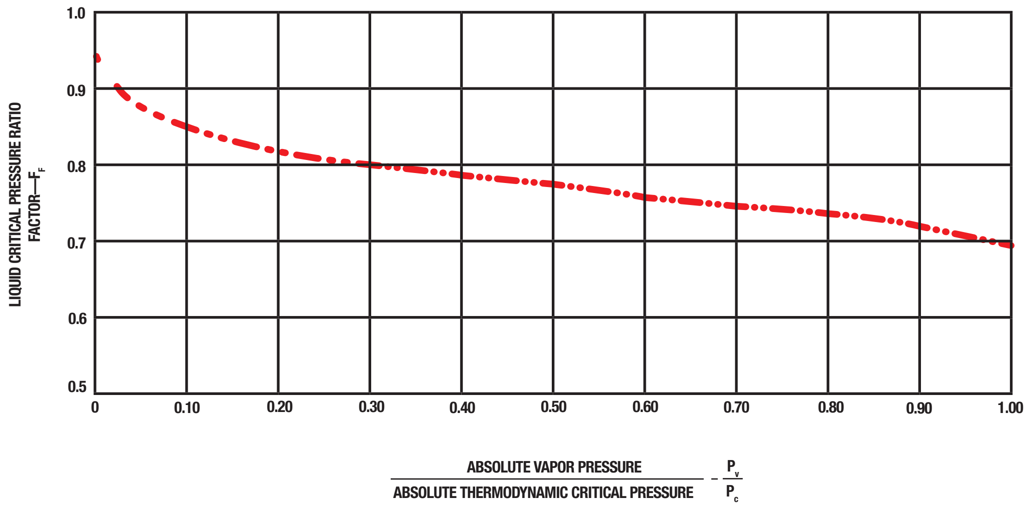
Note

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.

Liquid Sizing Sample Problem

Assume an installation that, at initial plant startup, 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 8-inch (DN 200) and an ASME CL300 globe 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.

Valve Sizing (Standardized Method)



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.

Figure 3-2. *Liquid Critical Pressure Ratio Factor for Liquids Other Than Water*

1. *Specify the necessary variables required to size the valve:*
   - Desired Valve Design—ASME CL300 globe valve with equal percentage cage and an assumed valve size of 3-inches.
   - Process Fluid—liquid propane
   - Service Conditions—q = 800 GPM (3028 l/min)

     P_1 = 300 psig (20,7 bar) = 314.7 psia (21,7 bar a)

     P_2 = 275 psig (19,0 bar) = 289.7 psia (20,0 bar a)

     ΔP = 25 psi (1,7 bar)

     T_1 = 70°F (21°C)

     G_f = 0.50

     P_v = 124.3 psia (8,6 bar a)

     P_c = 616.3 psia (42,5 bar a)
2. *Use an N_1 value of 1.0 from the Equation Constants table.*
3. *Determine F_p, the piping geometry factor.*

   Because it is proposed to install a 3-inch valve in an 8-inch (DN 200) line, it will be necessary to determine the piping geometry factor, F_p, which corrects for losses caused by fittings attached to the valve.

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

where,

N_2 = 890, from the Equation Constants table

d = 3-inch (76 mm), from step 1

C_v = 121, from the flow coefficient table for an ASME CL300, 3-inch globe valve with equal percentage cage

To compute $\sum K$ for a valve installed between identical concentric reducers:

$$\sum K = K_1 + K_2$$

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

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

$$= 1.11$$

Valve Sizing (Standardized Method)

where,

D = 8-inch (203 mm), 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 ($\Delta P_{max} > \Delta P$).

5. *Solve for C_v, using the appropriate equation.*

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

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

$$= 125.7$$

6. *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 (4-inch) would be the correct valve size, this may not always be true, and a repeat of the above procedure should be carried out.

   Assuming a 4-inches valve, $C_v = 203$. This value was determined from the flow coefficient table for an ASME CL300, 4-inch globe 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

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

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

$$= 121.7$$

This solution indicates only that the 4-inch 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 (116.2 versus 121.7), the valve sizing procedure is complete, and the conclusion is that a 4-inch valve opened to about 75% of total travel should be adequate for the required specifications.

Valve Sizing (Standardized Method)

Gas and Steam Valve Sizing

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 be 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. balanced globe with linear cage)
- Process fluid (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 the Abbreviations and Terminology Table 3-1 in Liquid Valve Sizing Section 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 the Equation Constants Table 3-2 in Liquid Valve Sizing Section.

Use either N_7 or N_9 if sizing the valve for a flow rate in volumetric units (SCFH or Nm^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 following 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 (pound/hr or kg/hr). 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 with reducers and 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 Liquid Valve Sizing Section.

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

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

where,

F_k = k/1.4, the ratio of specific heats factor

k = Ratio of specific heats

x = $\Delta P/P_1$, 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 following section for Determining x_{TP}, the Pressure Drop Ratio Factor.

Note

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

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

Although in actual service, pressure drop ratios can, and often will, exceed the indicated critical values, 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:

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

Valve Sizing (Standardized Method)

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

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\frac{x}{M T_1 Z}}}$$

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:

$K_v = (0.865)(C_v)$

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

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

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 the Equation Constants table

d = Assumed nominal valve size

C_v = Valve sizing coefficient from flow coefficient table at 100% 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 Problem No. 1

Determine the size and percent opening for a Fisher® Design V250 ball 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—Design V250 valve
- Process fluid—Natural gas
- Service conditions—

P_1 = 200 psig (13,8 bar) = 214.7 psia (14,8 bar)

P_2 = 50 psig (3,4 bar) = 64.7 psia (4,5 bar)

ΔP = 150 psi (10,3 bar)

$x = \Delta P/P_1 = 150/214.7 = 0.70$

T_1 = 60°F (16°C) = 520°R

M = 17.38

$G_g = 0.60$

k = 1.31

$q = 6.0 \times 10^6$ SCFH

2. *Determine the appropriate equation constant, N, from the Equation Constants Table 3-2 in Liquid Valve Sizing Section.*

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 8-inch Design V250 valve will be adequate for the specified service conditions. From the flow coefficient Table 4-2, x_T for an 8-inch Design V250 valve at 100% travel is 0.137.

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

Valve Sizing (Standardized Method)

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 = 0.667, and $x = F_k x_T = 0.129$.

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

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

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,

$$C_v = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\dfrac{0.129}{(0.6)(520)(1.0)}}} = 1515$$

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

The above result indicates that the valve is adequately sized (rated $C_v = 2190$). To determine the percent valve opening, note that the required C_v occurs at approximately 83 degrees for the 8-inch Design V250 valve. Note also that, at 83 degrees opening, the x_T value is 0.252, 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:

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\dfrac{x}{G_g T_1 Z}}} = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\dfrac{0.237}{(0.6)(520)(1.0)}}} = 1118$$

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,

$$C_v = \frac{q}{N_7 F_P P_1 Y \sqrt{\dfrac{x}{G_g T_1 Z}}} = \frac{6.0 \times 10^6}{(1360)(1.0)(214.7)(0.667)\sqrt{\dfrac{0.308}{(0.6)(520)(1.0)}}} = 980$$

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, for the service conditions given, an 8-inch Design V250 valve installed in an 8-inch (203 mm) 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 (17 bar). The supply source is a header maintained at 500 psig (34,5 bar) and 500°F (260°C). A 6-inch (DN 150) line from the steam main to the process is being planned. Also, make the assumption that if the required valve size is less than 6-inch (DN 150), it will be installed using concentric reducers. Determine the appropriate Design ED valve with a linear cage.

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

   a. Desired valve design—ASME CL300 Design ED valve with a linear cage. Assume valve size is 4 inches.

   b. Process fluid—superheated steam

   c. Service conditions—

   w = 125 000 pounds/hr (56 700 kg/hr)

   P_1 = 500 psig (34,5 bar) = 514.7 psia (35,5 bar)

   P_2 = 250 psig (17 bar) = 264.7 psia (18,3 bar)

   P = 250 psi (17 bar)

   $x = \Delta P/P_1 = 250/514.7 = 0.49$

   T_1 = 500°F (260°C)

   γ_1 = 1.0434 pound/ft^3 (16,71 kg/m^3)
   (from Properties of Saturated Steam Table)

   k = 1.28 (from Properties of Saturated Steam Table)

Valve Sizing (Standardized Method)

2. *Determine the appropriate equation constant, N, from the Equation Constants Table 3-2 in Liquid Valve Sizing Section.*

Because the specified flow rate is in mass units, (pound/hr), and the specific weight of the steam is also specified, the only sizing equation that can be used is 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,

$N_2 = 890$, determined from the Equation Constants Table

$d = 4$ inches

$C_v = 236$, which is the value listed in the flow coefficient Table 4-3 for a 4-inch Design ED valve at 100% total travel.

$$\Sigma K = K_1 + K_2$$

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

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

$$= 0.463$$

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.*

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

where,

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

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

$$= 0.91$$

$x = 0.49$ (As calculated in step 1.)

Because the 4-inch valve is to be installed in a 6-inch 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 the Equation Constants Table

$d = 4$ inches

$F_p = 0.95$, 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-inch

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.*

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

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

$$= 176$$

Valve Sizing (Standardized Method)

Table 4-1. Representative Sizing Coefficients for Type 1098-EGR Regulator

BODY SIZE, INCHES (DN)	LINEAR CAGE						
	Line Size Equals Body Size		2:1 Line Size to Body Size		X_T	F_D	F_L
	C_v		C_v				
	Regulating	Wide-Open	Regulating	Wide-Open			
1 (25)	16.8	17.7	17.2	18.1	0.806	0.43	0.84
2 (50)	63.3	66.7	59.6	62.8	0.820	0.35	
3 (80)	132	139	128	135	0.779	0.30	
4 (100)	202	213	198	209	0.829	0.28	
6 (150)	397	418	381	404	0.668	0.28	
BODY SIZE, INCHES (DN)	WHISPER TRIM™ CAGE						
	Line Size Equals Body Size Piping		2:1 Line Size to Body Size Piping		X_T	F_D	F_L
	C_v		C_v				
	Regulating	Wide-Open	Regulating	Wide-Open			
1 (25)	16.7	17.6	15.6	16.4	0.753	0.10	0.89
2 (50)	54	57	52	55	0.820	0.07	
3 (80)	107	113	106	110	0.775	0.05	
4 (100)	180	190	171	180	0.766	0.04	
6 (150)	295	310	291	306	0.648	0.03	

Table 4-2. Representative Sizing Coefficients for Rotary Shaft Valves

VALVE SIZE, INCHES	VALVE STYLE	DEGREES OF VALVE OPENING	C_v	F_L	X_T	F_D
1	V-Notch Ball Valve	60	15.6	0.86	0.53	- - - -
		90	34.0	0.86	0.42	- - - -
1-1/2	V-Notch Ball Valve	60	28.5	0.85	0.50	- - - -
		90	77.3	0.74	0.27	- - - -
2	V-Notch Ball Valve	60	59.2	0.81	0.53	- - - -
		90	132	0.77	0.41	- - - -
	High Performance Butterfly Valve	60	58.9	0.76	0.50	0.49
		90	80.2	0.71	0.44	0.70
3	V-Notch Ball Valve	60	120	0.80	0.50	0.92
		90	321	0.74	0.30	0.99
	High Performance Butterfly Valve	60	115	0.81	0.46	0.49
		90	237	0.64	0.28	0.70
4	V-Notch Ball Valve	60	195	0.80	0.52	0.92
		90	596	0.62	0.22	0.99
	High Performance Butterfly Valve	60	270	0.69	0.32	0.49
		90	499	0.53	0.19	0.70
6	V-Notch Ball Valve	60	340	0.80	0.52	0.91
		90	1100	0.58	0.20	0.99
	High Performance Butterfly Valve	60	664	0.66	0.33	0.49
		90	1260	0.55	0.20	0.70
8	V-Notch Ball Valve	60	518	0.82	0.54	0.91
		90	1820	0.54	0.18	0.99
	High Performance Butterfly Valve	60	1160	0.66	0.31	0.49
		90	2180	0.48	0.19	0.70
10	V-Notch Ball Valve	60	1000	0.80	0.47	0.91
		90	3000	0.56	0.19	0.99
	High Performance Butterfly Valve	60	1670	0.66	0.38	0.49
		90	3600	0.48	0.17	0.70
12	V-Notch Ball Valve	60	1530	0.78	0.49	0.92
		90	3980	0.63	0.25	0.99
	High Performance Butterfly Valve	60	2500	- - - -	- - - -	0.49
		90	5400	- - - -	- - - -	0.70
16	V-Notch Ball Valve	60	2380	0.80	0.45	0.92
		90	8270	0.37	0.13	1.00
	High Performance Butterfly Valve	60	3870	0.69	0.40	- - - -
		90	8600	0.52	0.23	- - - -

Valve Sizing (Standardized Method)

Table 4-3. Representative Sizing Coefficients for Design ED Single-Ported Globe Style Valve Bodies

VALVE SIZE, INCHES	VALVE PLUG STYLE	FLOW CHARACTERISTICS	PORT DIAMETER, INCHES (mm)	RATED TRAVEL, INCHES (mm)	C_V	F_L	X_T	F_D
1/2	Post Guided	Equal Percentage	0.38 (9,7)	0.50 (12,7)	2.41	0.90	0.54	0.61
3/4	Post Guided	Equal Percentage	0.56 (14,2)	0.50 (12,7)	5.92	0.84	0.61	0.61
1	Micro-Form™	Equal Percentage	3/8 (9,5)	3/4 (19,1)	3.07	0.89	0.66	0.72
			1/2 (12,7)	3/4 (19,1)	4.91	0.93	0.80	0.67
			3/4 (19,1)	3/4 (19,1)	8.84	0.97	0.92	0.62
	Cage Guided	Linear	1-5/16 (33,3)	3/4 (19,1)	20.6	0.84	0.64	0.34
		Equal Percentage	1-5/16 (33,3)	3/4 (19,1)	17.2	0.88	0.67	0.38
1-1/2	Micro-Form™	Equal Percentage	3/8 (9,5)	3/4 (19,1)	3.20	0.84	0.65	0.72
			1/2 (12,7)	3/4 (19,1)	5.18	0.91	0.71	0.67
			3/4 (19,1)	3/4 (19,1)	10.2	0.92	0.80	0.62
	Cage Guided	Linear	1-7/8 (47,6)	3/4 (19,1)	39.2	0.82	0.66	0.34
		Equal Percentage	1-7/8 (47,6)	3/4 (19,1)	35.8	0.84	0.68	0.38
2	Cage Guided	Linear	2-5/16 (58,7)	1-1/8 (28,6)	72.9	0.77	0.64	0.33
		Equal Percentage	2-5/16 (58,7)	1-1/8 (28,6)	59.7	0.85	0.69	0.31
3	Cage Guided	Linear	3-7/16 (87,3)	1-1/2 (38,1)	148	0.82	0.62	0.30
		Equal Percentage	- - - -	- - - -	136	0.82	0.68	0.32
4	Cage Guided	Linear	4-3/8 (111)	2 (50,8)	236	0.82	0.69	0.28
		Equal Percentage	- - - -	- - - -	224	0.82	0.72	0.28
6	Cage Guided	Linear	7 (178)	2 (50,8)	433	0.84	0.74	0.28
		Equal Percentage	- - - -	- - - -	394	0.85	0.78	0.26
8	Cage Guided	Linear	8 (203)	3 (76,2)	846	0.87	0.81	0.31
		Equal Percentage	- - - -	- - - -	818	0.86	0.81	0.26

6. *Select the valve size using flow coefficient tables and the calculated C_v value.*

   Refer to the flow coefficient Table 4-3 for Design ED valves with linear cage. Because the assumed 4-inch valve has a C_v of 236 at 100% travel and the next smaller size (3-inch) 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 assumed size, it would have been necessary to rework the problem again using values for the new assumed size.

7. *Sizing equations for compressible fluids.*

   The equations listed below identify the relationships between flow rates, flow coefficients, related installation factors, and pertinent service conditions for control valves handling compressible fluids. Flow rates for compressible fluids may be encountered in either mass or volume units and thus equations are necessary to handle both situations. Flow coefficients may be calculated using the appropriate equations selected from the following. A sizing flow chart for compressible fluids is given in Annex B.

   The flow rate of a compressible fluid varies as a function of the ratio of the pressure differential to the absolute inlet pressure ($\Delta P/P_1$), designated by the symbol x. At values of x near zero, the equations in this section can be traced to the basic Bernoulli equation for Newtonian incompressible fluids. However, increasing values of x result in expansion and compressibility effects that require the use of appropriate factors (see Buresh, Schuder, and Driskell references).

7.1 Turbulent flow

7.1.1 Non-choked turbulent flow

7.1.1.1 Non-choked turbulent flow without attached fittings

[Applicable if $x < F_\gamma x_T$]

The flow coefficient shall be calculated using one of the following equations:

Eq. 6

$$C = \frac{W}{N_6 Y \sqrt{x P_1 \rho_1}}$$

Eq. 7

$$C = \frac{W}{N_8 P_1 Y}\sqrt{\frac{T_1 Z}{xM}}$$

Eq. 8a

$$C = \frac{Q}{N_9 P_1 Y}\sqrt{\frac{M T_1 Z}{x}}$$

Eq. 8b

$$C = \frac{Q}{N_7 P_1 Y}\sqrt{\frac{G_g T_1 Z}{x}}$$

NOTE 1 Refer to 8.5 for details of the expansion factor Y.

NOTE 2 See Annex C for values of M.

7.1.1.2 Non-choked turbulent flow with attached fittings

[Applicable if $x < F_\gamma x_{TP}$]