Control Valve Sizing

CONTENTS

INTRODUCTION

Valtek uses a systematic method for selecting body types, sizes, materials, pressure ratings and trim sizes based on flow characteristics.

Valtek control valve flow capacity (C_v) is based upon the industry standard, ANSI/ISA S75.01. This standard and the corresponding measuring standards contain Equations used to predict the flow of compressible and incompressible fluids in control valves. Slightly different forms of the basic Equation are used for liquids and gases.

Basic steps for sizing and selecting the correct valve include calculating the required C_v. Equations for calculating C_v for both gases and liquids are found in this section.

Valtek has programmed the ANSI/ISA sizing Equations and procedures, making computer-aided sizing available on IBM-PC or compatible computers. These programs permit rapid control valve flow capacity calculations and valve selection with minimal effort. The programs also include exit velocity, noise prediction and actuator sizing calculations. See Section 22 for more details on computer-aided valve selection.

These instructions are designed to expose the user to the different aspects of valve sizing. The step-by-step method outlined in this section is the most common method of sizing.

NOMENCLATURE

Flow Capacity

The valve sizing coefficient most commonly used as a measure of the capacity of the body and trim of a control valve is C_v. One C_v is defined as one U.S. gallon per minute of 60 degree Fahrenheit water that flows through a valve with a one psi pressure drop. The general Equation for C_v is as follows:

$$C_v = \text{flow}\sqrt{\frac{\text{specific gravity at flowing temperature}}{\text{pressure drop}}}$$

When selecting a control valve for an application, the calculated C_v is used to determine the valve size and the trim size that will allow the valve to pass the desired flow rate and provide stable control of the process fluid.

Pressure Profile

Fluid flowing through a control valve obeys the basic laws of conservation of mass and energy, and the continuity Equation. The control valve acts as a restriction in the flow stream. As the fluid stream approaches this restriction, its velocity increases in order for the full flow to pass through the restriction. Energy for this increase in velocity comes from a corresponding decrease in pressure.

Maximum velocity and minimum pressure occur immediately downstream from the throttling point at the narrowest constriction of the fluid stream, known as the vena contracta. Downstream from the vena contracta, the fluid slows and part of the energy (in the form of velocity) is converted back to pressure. A simplified profile of the fluid pressure is shown in Figure 3-1. The slight pressure losses in the inlet and outlet passages are due to frictional effects. The major excursions of pressure are due to the velocity changes in the region of the vena contracta.

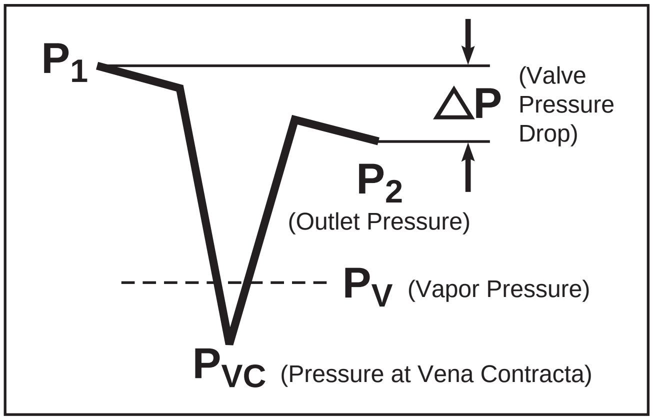


Figure 3-1: Pressure Profile of Fluid Passing Through a Valve

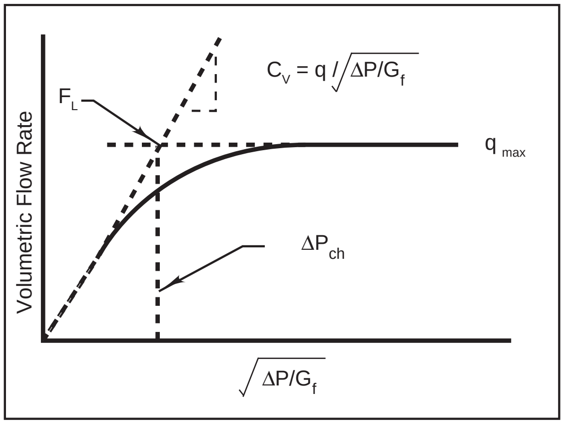


Figure 3–2: Choked Pressure Drop

Allowable Pressure Drop

The capacity curve shown in Figure 3-2 shows that, with constant upstream pressure, flow rate, q, is related to the square root of pressure drop through the proportionality constant C_v. The curve departs from a linear relationship at the onset of "choking" described using the F_i factor. The flow rate reaches a maximum, q_{max}, at the fully choked condition due to effects of cavitation for liquids or sonic velocity for compressible fluids. The transition to choked flow may be gradual or abrupt, depending on valve design. ANSI/ISA liquid sizing Equations use a pressure recovery factor, F_L, to calculate the ΔP_{ch} at which choked flow is assumed for sizing purposes. For compressible fluids, a terminal pressure drop ratio, x_T, similarly describes the choked pressure drop for a specific valve.

When sizing a control valve, the *smaller* of the actual pressure drop or the choked pressure drop is always used to determine the correct C_v. This pressure drop is known as the allowable pressure drop, ΔP_a.

Cavitation

In liquids, when the pressure anywhere in the liquid drops below the vapor pressure of the fluid, vapor bubbles begin to form in the fluid stream. As the fluid decelerates there is a resultant increase in pressure. If this pressure is higher than the vapor pressure, the bubbles collapse (or implode) as the vapor returns to the liquid phase. This two-step mechanism – called cavitation – produces noise, vibration, and causes erosion damage to the valve and downstream piping.

The onset of cavitation – known as incipient cavitation – is the point when the bubbles first begin to form and collapse. Advanced cavitation can affect capacity and valve performance, which begins at a ΔP determined from the factor, F_i. The point at which full or choked cavitation occurs (severe damage, vibration, and noise) can be determined from Equation 3.3. Under choked conditions, “allowable pressure drop,” is the choked pressure drop.

Liquid Pressure Recovery Factor, F_L

The liquid pressure recovery factor, F_L, predicts the amount of pressure recovery that will occur between the vena contracta and the valve outlet. F_L is an experimentally determined coefficient that accounts for the influence of the valve’s internal geometry on the maximum capacity of the valve. It is determined from capacity test data like that shown in Figure 3-2.

F_L also varies according to the valve type. High recovery valves – such as butterfly and ball valves – have significantly lower pressures at the vena contracta and hence recover much farther for the same pressure drop than a globe valve. Thus they tend to choke (or cavitate) at smaller pressure drops than globe valves.

Liquid Critical Pressure Ratio Factor, F_F

The liquid critical pressure ratio factor, F_F, multiplied by the vapor pressure, predicts the theoretical vena contracta pressure at the maximum effective (choked) pressure drop across the valve.

Flashing

If the downstream pressure is equal to or less than the vapor pressure, the vapor bubbles created at the vena contracta do not collapse, resulting in a liquid-gas mixture downstream of the valve. This is commonly called flashing. When flashing of a liquid occurs, the inlet fluid is 100 percent liquid which experiences pressures in and downstream of the control valve which are at or below vapor pressure. The result is a two phase mixture (vapor and liquid) at the valve outlet and in the downstream piping. Velocity of this two phase flow is usually very high and results in the possibility for erosion of the valve and piping components.

Choked Flow

Choked flow occurs in gases and vapors when the fluid velocity reaches sonic values at any point in the valve body, trim, or pipe. As the pressure in the valve or pipe is lowered, the specific volume increases to the point where sonic velocity is reached. In liquids, vapor formed as the result of cavitation or flashing increases the specific volume of the fluid at a faster rate than the increase in flow due to pressure differential. Lowering the downstream pressure beyond this point in either case will not increase the flow rate for a constant upstream pressure. The velocity at any point in the valve or downstream piping is limited to sonic (Mach = 1). As a result, the flow rate will be limited to an amount which yields a sonic velocity in the valve trim or the pipe under the specified pressure conditions.

Reynolds Number Factor, F_R

The Reynolds Number Factor, F_R, is used to correct the calculated C_v for non-turbulent flow conditions due to high viscosity fluids, very low velocities, or very small valve C_v.

Piping Geometry Factor, F_P

Valve sizing coefficients are determined from tests run with the valve mounted in a straight run of pipe which is the same diameter as the valve body. If the process piping configurations are different from the standard test manifold, the apparent valve capacity is changed. The effect of reducers and increasers can be approximated by the use of the piping geometry factor, F_P.

Velocity

As a general rule, valve outlet velocities should be limited to the following maximum values:

Liquids	50 feet per second
Gases	Approaching Mach 1.0
Mixed Gases and Liquids	500 feet per second

The above figures are guidelines for typical applications. In general, smaller sized valves handle slightly higher velocities and large valves handle lower velocities. Special applications have particular velocity requirements; a few of which are provided below.

Liquid applications – where the fluid temperature is close to the saturation point – should be limited to 30 feet per second to avoid reducing the fluid pressure below the vapor pressure. This is also an appropriate limit for applications designed to pass the full flow rate with a minimum pressure drop across the valve.

Valves in cavitating service should also be limited to 30 feet per second to minimize damage to the downstream piping. This will also localize the pressure recovery which causes cavitation immediately downstream from the vena contracta.

In flashing services, velocities become much higher due to the increase in volume resulting from vapor formation. For most applications, it is important to keep velocities below 500 feet per second. Expanded outlet style valves – such as the Mark One-X – help to control outlet velocities on such applications. Erosion damage can be limited by using chrome-moly body material and hardened trim. On smaller valve applications which remain closed for most of the time – such as heater drain valves – higher velocities of 800 to 1500 feet per second may be acceptable with appropriate materials.

Gas applications where special noise attenuation trim are used should be limited to approximately 0.33 Mach. In addition, pipe velocities downstream from the valve are critical to the overall noise level. Experimentation has shown that velocities around 0.5 Mach can create substantial noise even in a straight pipe. The addition of a control valve to the line will increase the turbulence downstream, resulting in even higher noise levels.

Expansion Factor, Y

The expansion factor, Y, accounts for the variation of specific weight as the gas passes from the valve inlet to the vena contracta. It also accounts for the change in cross-sectional area of the vena contracta as the pressure drop is varied.

Ratio of Specific Heats Factor, F_k

The ratio of specific heats factor, F_k, adjusts the Equation to account for different behavior of gases other than air.

Terminal Pressure Drop Ratio, x_T

The terminal pressure drop ratio for gases, x_T, is used to predict the choking point where additional pressure drop (by lowering the downstream pressure) will not produce additional flow due to the sonic velocity limitation across the vena contracta. This factor is a function of the valve geometry and varies similarly to F_L, depending on the valve type.

Compressibility Factor, Z

The compressibility factor, Z, is a function of the temperature and the pressure of a gas. It is used to determine the density of a gas in relationship to its actual temperature and pressure conditions.

CALCULATING C_V FOR LIQUIDS

Introduction

The Equation for the flow coefficient (C_v) in non-laminar liquid flow is:

$$C_v = \frac{q}{F_P}\sqrt{\frac{G_f}{\Delta P_a}} \qquad (3.1)$$

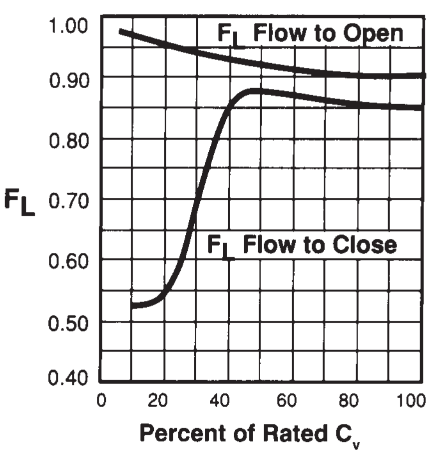
Where:
- C_v = Valve sizing coefficient
- F_P = Piping geometry factor
- q = Flow rate, gpm
- ΔP_a = Allowable pressure drop across the valve for sizing, psi
- G_f = Specific gravity at flowing temperature

Table 3-I: Typical Valve Recovery Coefficient and Incipient Cavitation Factors

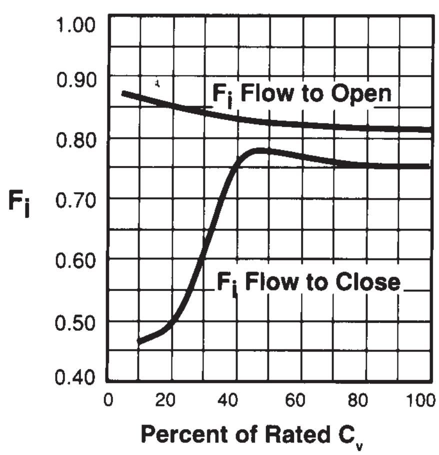
NOTE: *Values are given for full-open valves. See charts below for part-stroke values*

Valve Type	Flow Direction	Trim Size	F_L	F_i	x_T	F_d
Globe	Over Seat	Full Area	0.85	0.75	.70	1.0
	Over Seat	Reduced Area	0.80	0.72	.70	1.0
	Under Seat	Full Area	0.90	0.81	.75	1.0
	Under Seat	Reduced Area	0.90	0.81	.75	1.0
Valdisk	60º Open	Full	0.76	0.65	.36	.71
Rotary Disc	90º Open	Full	0.56	0.49	.26	.71
ShearStream	60º Open	Full	0.78	0.65	.51	1.0
Rotary Ball	90º Open	Full	0.66	0.44	.30	1.0
CavControl	Over Seat	All	0.92	0.90	N/A	$.2/\sqrt{d}$
MegaStream	Under Seat	All	~1.0	N/A	~1.0	$(n_s/25d)^{2/3}$**
ChannelStream	Over Seat	All	~1.0	0.87 to 0.999	N/A	.040*
Tiger-Tooth	Under Seat	All	~1.0	0.84 to 0.999	~1.0	.035*

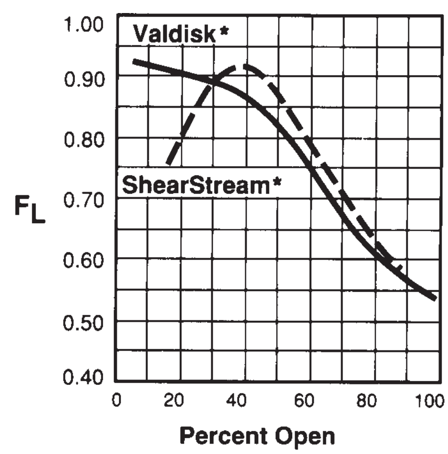
** Typical* *** n_s = number of stages*



Globe Valve F_L Values



Globe Valve F_i Values



Rotary Disc Valve F_L Values

The following steps should be used to compute the correct C_v, body size and trim number:

Step 1: Calculate Actual Pressure Drop

The allowable pressure drop, ΔP_a, across the valve for calculating C_v, is the smaller of the actual ΔP from Equation 3.2 and choked ΔP_{ch} from Equation 3.3.

$$\Delta P = P_1 - P_2 \qquad (3.2)$$

Step 2: Check for Choked Flow, Cavitation and Flashing

Use Equation 3.3 to check for choked flow:

$$\Delta P_{ch} = F_L^2 (P_1 - F_F P_V) \qquad (3.3)$$

Where:
- F_L = Liquid pressure recovery factor
- F_F = Liquid critical pressure ratio factor
- P_V = Vapor pressure of the liquid at inlet temperature, psia
- P_1 = Upstream pressure, psia

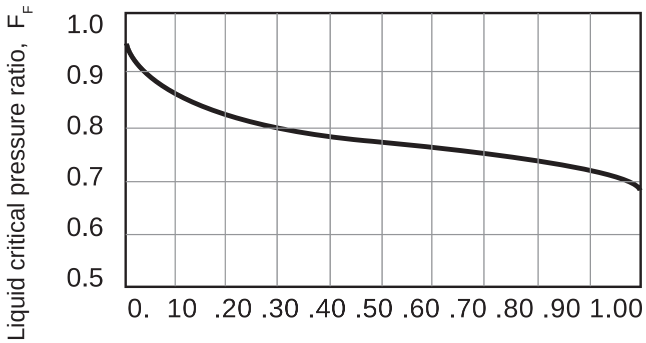
See Table 3-I for F_L factors for both full-open and part-stroke values.

F_F can be estimated by the following relationship:

$$F_F = 0.96 - 0.28 \sqrt{\frac{P_V}{P_C}} \qquad (3.4)$$

Where:
- F_F = Liquid critical pressure ratio
- P_V = Vapor pressure of the liquid, psia
- P_C = Critical pressure of the liquid, psia (see Table 3-II)

If ΔP_{ch} (Equation 3.3) is less than the actual ΔP (Equation 3.2) , use ΔP_{ch} for ΔP_a in Equation 3.1.



$$\frac{P_v = \text{Vapor Pressure}}{P_c = \text{Critical Pressure}}$$

Figure 3-3: Liquid Critical Pressure Ratio Factor Curve

Table 3-II: Critical Pressures

Liquid	Critical Press. (psia)	Liquid	Critical Press. (psia)
Ammonia	1636.1	Hydrogen Chloride	1205.4
Argon	707.0	Isobutane	529.2
Benzene	710.0	Isobutylene	529.2
Butane	551.2	Kerosene	350.0
Carbon Dioxide	1070.2	Methane	667.3
Carbon Monoxide	507.1	Nitrogen	492.4
		Nitrous Oxide	1051.1
Chlorine	1117.2	Oxygen	732.0
Dowtherm A	547.0	Phosgene	823.2
Ethane	708.5	Propane	615.9
Ethylene	730.5	Propylene	670.3
Fuel Oil	330.0	Refrigerant 11	639.4
Fluorine	757.0	Refrigerant 12	598.2
Gasoline	410.0	Refrigerant 22	749.7
Helium	32.9	Sea Water	3200.0
Hydrogen	188.1	Water	3208.2

It may also be useful to determine the point at which substantial cavitation begins. The following Equation defines the pressure drop at which substantial cavitation begins:

$$\Delta P\ (\text{cavitation}) = F_i^2\,(P_1 - P_V) \qquad (3.5)$$

In high pressure applications, alternate analysis may be required; verify analysis with factory if $\Delta P \geq \Delta P$ (cavitation) $\geq$ 300 psi (globe valves) or 100 psi (rotary valves).

Where:

F_i = Liquid cavitation factor (Typical values for F_i are given in Table 3-I)

P_1 = Upstream pressure, psia

P_V = Vapor pressure of the liquid, psia

The required C_v for flashing applications is determined by using the appropriate ΔP allowable [ΔP_{ch} calculated from Equation 3.3].

Step 3: Determine Specific Gravity

Specific gravity is generally available for the flowing fluid at the operating temperature. The appendix provides fluid property data for 268 chemical compounds, from which the specific gravity, G_f can be calculated.

Step 4: Calculate Approximate C_v

Generally the effects of nonturbulent flow can be ignored, provided the valve is not operating in a laminar or transitional flow region due to high viscosity, very low velocity, or small C_v. In the event there is some question, calculate the C_v, from Equation 3.1, assuming F_P=1,and then proceed to steps 5-7. If the Reynolds number calculated in Equation 3.6a is greater than 40,000, F_R can be ignored (proceed to step 8 after step 5.)

Step 5: Select Approximate Body Size Based on C_v

From the C_v tables in section 4, select the smallest body size that will handle the calculated C_v.

Step 6: Calculate Valve Reynolds Number Re_v and Reynolds Number Factor F_R

Use Equation 3.6a to calculate valve Reynolds Number Factor:

$$Re_v = \frac{N_4 F_d q}{\nu \sqrt{F_L C_v}} \left(\frac{F_L^2 C_v^2}{N_2 d^4} + 1 \right)^{1/4} \qquad (3.6a)$$

Use Equation 3.6b to calculate valve Reynolds Number Factor F_R if Re_v < 40,000, otherwise F_R = 1.0:

$$F_R = 1.044 - .358 \left(\frac{C_{vs}}{C_{vt}} \right)^{0.655} \qquad (3.6b)$$

Where: C_{vs} = Laminar flow C_v

$$C_{vs} = \frac{1}{F_s} \left(\frac{q\,\mu}{N_s\,\Delta P} \right)^{2/3} \qquad (3.6c)$$

C_{vt} = Turbulent flow C_v (Equation 3.1)

F_s = streamline flow factor

Table 3-III: Piping Geometry Factors for Valves with Reducer and Increaser, F_p versus C_v/d^2

C_v/d^2	d / D				
	0.50	0.60	0.70	0.80	0.90
4	0.99	0.99	1.00	1.00	1.00
6	0.98	0.99	0.99	1.00	1.00
8	0.97	0.98	0.99	0.99	1.00
10	0.96	0.97	0.98	0.99	1.00
12	0.94	0.95	0.97	0.98	1.00
14	0.92	0.94	0.96	0.98	0.99
16	0.90	0.92	0.95	0.97	0.99
18	0.87	0.90	0.94	0.97	0.99
20	0.85	0.89	0.92	0.96	0.99
25	0.79	0.84	0.89	0.94	0.98
30	0.73	0.79	0.85	0.91	0.97
35	0.68	0.74	0.81	0.89	0.96
40	0.63	0.69	0.77	0.86	0.95

NOTE: *The maximum effective pressure drop (ΔP choked) may be affected by the use of reducers and increasers. This is especially true of Valdisk valves. Contact factory for critical applications.*

Table 3-IV: Piping Geometry Factors for Increaser Only on Valve Outlet, F_p versus C_v/d^2

C_v/d^2	d / D				
	0.50	0.60	0.70	0.80	0.90
4	1.00	1.00	1.00	1.00	1.00
6	1.01	1.01	1.01	1.01	1.01
8	1.01	1.02	1.02	1.02	1.01
10	1.02	1.03	1.03	1.03	1.02
12	1.03	1.04	1.04	1.04	1.03
14	1.04	1.05	1.06	1.05	1.04
16	1.06	1.07	1.08	1.07	1.05
18	1.08	1.10	1.11	1.10	1.06
20	1.10	1.12	1.12	1.12	1.08
25	1.17	1.22	1.24	1.22	1.13
30	1.27	1.37	1.42	1.37	1.20
35	1.44	1.65	1.79	1.65	1.32
40	1.75	2.41	3.14	2.41	1.50

Where:

d = Valve port inside diameter in inches

D = Internal diameter of the piping in inches (See Tables 3-VII and 3-VIII)

$$F_s = \frac{F_d^{2/3}}{F_L^{1/3}}\left(\frac{F_L^2 C_v^2}{N_2 d^4}+1\right)^{1/6} \qquad (3.6d)$$

Where:
- d = Valve inlet diameter, inches
- F_d = Valve style modifier (Table 3-1)
- F_s = Laminar, or streamline, flow factor
- q = Flow rate, gpm
- N_2 = 890 when d is in inches
- N_4 = 17,300, when q is in gpm and d in inches
- N_s = 47 when q is in gpm and ΔP in psi
- μ = absolute Viscosity, centipoise
- ν = kinematic viscosity, centistokes = μ/G_f

Step 7: Recalculate C_v Using Reynolds Number Factor

If the calculated value of F_R is less than 0.48, the flow is considered laminar; and the C_v is equal to C_{vs} calculated from Equation 3.6c. If F_R is greater than 0.98, turbulent flow can be assumed (F_R = 1.0); and C_v is calculated from Equation 3.1. Do not use the piping geometry factor F_p if F_R is less than 0.98. For values of F_R between 0.48 and 0.98, the flow is considered transitional; and the C_v is calculated from Equation 3.6e:

$$C_v = \frac{q}{F_R}\sqrt{\frac{G_f}{P_1 - P_2}} \qquad (3.6e)$$

For laminar and transitional flow, note the ΔP is always taken as $P_1 - P_2$.

Step 8: Calculate Piping Geometry Factor

If the pipe size is not given, use the approximate body size (from step 5) to choose the corresponding pipe size. The pipe diameter is used to calculate the piping geometry factor, F_P, which can be determined by Tables 3-III and 3-IV. If the pipe diameter is the same as the valve size, F_P is 1 and does not affect C_v.

Step 9: Calculate the Final C_v

Using the value of F_P, calculate the required C_v from Equation 3.1.

Step 10: Calculate Valve Exit Velocity

The following Equation is used to calculate entrance or exit velocities for liquids:

$$V = \frac{0.321\,q}{A_v} \qquad (3.7)$$

Where:

V = Velocity, ft/sec

q = Liquid flow rate, gpm

A_v = Applicable flow area, in^2 of body port (Table 3-VIII)

After calculating the exit velocity, compare that number to the acceptable velocity for that application. It may be necessary to go to a larger valve size.

Step 11: Recalculate C_v If Body Size Changed

Recalculate C_v if the F_P has been changed due to selection of a larger body size.

Step 12: Select Trim Number

First identify if the valve will be used for on/off or throttling service. Using the C_v tables in Section 4, select the appropriate trim number for the calculated C_v and body size selected. The trim number and flow characteristic (Section 9) may be affected by how the valve will be throttled. When cavitaiton is indicated, refer to Section 14 to evaluate special trims for cavitation protection.

LIQUID SIZING EXAMPLES

Example One

Given:

Liquid	Water
Critical Pressure (P_C)	3206.2 psia
Temperature	250° F
Upstream Pressure (P_1)	314.7 psia
Downstream Pressure (P_2)	104.7 psia
Specific Gravity	0.94
Valve Action	Flow-to-open
Line Size	4-inch (Class 600)
Flow Rate	500 gpm
Vapor Pressure (P_V)	30 psia
Kinematic Viscosity (ν)	0.014 centistokes
Flow Characteristic	Equal Percentage

Step 1: Calculate actual pressure drop using Equation (3.2).

$$\Delta P = 314.7 \text{ psia} - 104.7 \text{ psia} = 210 \text{ psi}$$

Step 2: Check for choked flow. Find F_L using Table 3-I. Looking under "globe, flow-under," find F_L as 0.90. Next, estimate F_F using Equation 3.4:

$$F_F = 0.96 - 0.28\sqrt{\frac{30}{3206.2}} = 0.93$$

Insert F_L and F_F into Equation 3.3:

$$\Delta P_{ch} = (0.90)^2\,[314.7 - (0.93)(30)] = 232.3 \text{ psi}$$

Since the actual ΔP is less than ΔP_{ch}, the flow is not choked; therefore, use the smaller (or actual ΔP) to size the valve.

At this point, also check for incipient cavitation using Equation 3.5 and Table 3-I:

$$\Delta P \text{ (cavitation)} = (0.81)^2\,(314.7-30) = 187 \text{ psi}$$

Since ΔP (actual) exceeds ΔP (cavitation), substantial cavitation is occurring, but flow is not choked. Special attention should be paid to material and trim selection.

Step 3: The specific gravity for water is given as 0.94

Step 4: Calculate the approximate C_vF_P using Equation 3.1 and assuming F_P is 1.0:

$$C_v = 500\sqrt{\frac{0.94}{210}} = 33.4$$

Step 5: From the C_v tables (Mark One, flow-under, equal percentage, Class 600) select the smallest body size for a C_v of 33.4, which is a 2-inch body.

Step 6: Calculate the Reynolds Number Factor, F_R, using Equations 3.6a and 3.6e as required.

$$Re_v = \frac{(17{,}300)\,(1)\,(500)}{(0.014)\sqrt{(0.90)(33.4)}}\left[\frac{(0.90)^2\,(33.4)^2}{(890)(2)^4} + 1\right]^{1/4} = 114 \times 10^6$$

Step 7: Since $R_{ev} > 40{,}000$, $F_R = 1.0$ and the recalculated C_vF_P remains as 33.4.

Step 8: Using the 2-inch body from step 5, determine the F_P using Table 3-III, where:

$$d/D = 2/4 = 0.5 \text{ and } C_v/d^2 = 33.4/2^2 = 8.35$$

Therefore according to Table 3-III, the F_P is 0.97.

Step 9: Recalculate the final C_v:

$$C_v = \frac{500}{0.97}\sqrt{\frac{0.94}{210}} = 34.5$$

Step 10: Using Equation 3.7, the velocity for a 2-inch body is found to be nearly 51 ft/sec. Since this application is cavitating, damage may result in a 2-inch valve. A 3-inch body reduces velocity to about 23 ft/sec which is a more acceptable value. However, special trim may be required to eliminate cavitation damage.

NOTE: *In this example, a 2 x 4-inch Mark One -X might also be chosen. It is less costly than a 3-inch valve and the larger outlets will lower the velocities. It will also be less costly to install in a 4-inch line.*

Step 11: Since the body size has changed, recalculate the C_v by following steps 8 and 9. The F_P for a 3-inch body is nearly 1.0, and the final C_v is 33.4.

Step 12: Referring to the C_v tables, a C_v 33, 3-inch valve would require at least a trim number of 1.25. Trim number 2.0 may also suffice and have no reduced trim price adder. Refer to Section 14 on special trims for cavitation protection.

Example Two

Given:

Liquid	Ammonia
Critical Pressure (P_C)	1638.2 psia
Temperature	20° F
Upstream Pressure (P_1)	149.7 psia
Downstream Pressure (P_2)	64.7 psia
Specific Gravity	0.65
Valve Action	Flow-to-close
Line Size	3-inch (Class 600)
Flow Rate	850 gpm
Vapor Pressure (P_V)	45.6 psia
Kinematic Viscosity (v)	0.02 centistokes
Flow Characteristic	Linear

Step 1: Calculate actual pressure drop using Equation 3.2.

$$\Delta P = 149.7 \text{ psia} - 64.7 \text{ psia} = 85 \text{ psid}$$

Step 2: Check for choked flow. Find F_L using Table 3-I. Looking under "globe, flow-over," find F_L as 0.85. Next, estimate F_F using Equation 3.4:

$$F_F = 0.96 - 0.28 \sqrt{\frac{45.6}{1638.2}} = 0.91$$

Insert F_L and F_F into Equation 3.3:

$$\Delta P_{ch} \text{ (choked)} = (0.85)^2 [149.7 - (0.91)(45.6)] = 78.2 \text{ ps}$$

Since the actual ΔP is more than ΔP_{ch}, the flow is choked and cavitating; therefore, use the ΔP_{ch} for ΔP_a to size the valve. Since the service is cavitating, special attention should be made to material and trim selection. CavControl or ChannelStream should be considered.

Step 3: The specific gravity for ammonia is given as 0.65

Step 4: Calculate the approximate C_v using Equation 3.1:

$$C_v = 850 \sqrt{\frac{0.65}{78.2}} = 77.5$$

Step 5: From the C_v tables (Mark One, flow-over, linear, Class 600) select the smallest body size for a C_v of 77.5, which is a 3-inch body.

Steps 6 and 7: Turbulent flow is assumed, so Reynolds Number Factor is ignored, $F_R = 1.0$.

Step 8: With the 3-inch body and 3-inch line, $F_P = 1$.

Step 9: Since $F_P = 1$, the final C_v remains as 77.5.

Step 10: Using Equation 3.7, the velocity for a 3-inch body is found to be over 38 ft/sec. Since this application is cavitating, this velocity may damage a 3-inch valve. However, since the size is restricted to a 3-inch line, a larger valve size cannot be chosen to lower the velocity. Damage problems may result from such a system. A cavitation control style trim should be suggested; see Section 14.

Step 11: If cavitation control trim is not selected, C_v recalculation is not necessary since the body size or trim style did not change.

Step 12: Referring to the C_v tables, a C_v 77.5, 3-inch valve would use a trim number of 2.00 or the full size trim number 2.62. Use of this trim, however, could result in cavitation damage to body and trim; see Section 14.

Flashing Liquids Velocity Calculations

When the valve outlet pressure is lower than or equal to the saturation pressure for the fluid temperature, part of the fluid flashes into vapor. When flashing exists, the following calculations must be used to determine velocity. Flashing requires special trim designs and/or hardened materials. Flashing velocity greater than 500 ft/sec requires special body designs. If flow rate is in lb/hr:

$$V = \frac{0.040}{A_v} w \left[\left(1 - \frac{x}{100\%}\right) v_{f2} + \frac{x}{100\%} v_{g2} \right] \quad (3.8)$$

if the flow rate is given in gpm, the following Equation can be used:

$$V = \frac{20}{A_v} q \left[\left(1 - \frac{x}{100\%} \right) v_{f2} + \frac{x}{100\%} v_{g2} \right] \qquad (3.9)$$

Where:

V = Velocity, ft/sec

w = Liquid flow rate, lb/hr

q = Liquid flow rate, gpm

A_v = Valve outlet flow area, in^2, see Table 3-VIII.

v_{f2} = Saturated liquid specific volume (ft^3/lb at outlet pressure)

v_{g2} = Saturated vapor specific volume (ft^3/lb at outlet pressure)

x = % of liquid mass flashed to vapor

Calculating Percentage Flash

The % flash (x) can be calculated as follows:

$$x = \left(\frac{h_{f1} - h_{f2}}{h_{fg2}} \right) x\ 100\% \qquad (3.10)$$

Where:

x = % of liquid mass flashed to vapor

h_{f1} = Enthalpy of saturated liquid at inlet temperature

h_{f2} = Enthalpy of saturated liquid at outlet pressure

h_{fg2} = Enthalpy of evaporation at outlet pressure

For water, the enthalpies (h_{f1}, h_{f2} and h_{fg2}) and specific volumes (v_{f2} and v_{g2}) can be found in the saturation temperature and pressure tables of any set of steam tables.

Flashing Liquid Example

Assume the same conditions exist as in Example One, except that the temperature is 350° F rather than 250° F. By referring to the saturated steam temperature tables, you find that the saturation pressure of water at 350° F is 134.5 psia, which is greater than the outlet pressure of 105 psia (90 psia). Therefore, the fluid is flashing. Since a portion of the liquid is flashing, Equations 3.9 and 3.10 must be used. x (% flashed) can be determined by using Equation 3.10:

h_{f1} = 321.8 Btu/lb at 350° F (from saturation temperature tables)

h_{f2} = 302.3 Btu/lb at 105 psia (from saturation pressure tables)

h_{fg2} = 886.4 Btu/lb at 105 psia (from saturation pressure tables)

$$x = \left(\frac{321.8 - 302.3}{886.4} \right) x\ 100\% = 2.2\%$$

Therefore, the velocity in a 3-inch valve can be determined by using Equation 3.9:

v_{f2} = 0.0178 ft^3/lb at 105 psia (from saturation pressure tables)

v_{g2} = 4.234 ft^3/lb at 105 psia (from saturation pressure tables)

$$V = \frac{(20)(500)}{7.07} \left[\left(1 - \frac{2.2\%}{100\%} \right) 0.0178 + \left(\frac{2.2\%}{100\%} \right) 4.234 \right]$$

V = 156 ft/sec

Flashing velocity is less than 500 ft/sec, which is acceptable for Mark One bodies. Hardened trim and CavControl should also be considered.

CALCULATING C_v FOR GASES

Introduction

Because of compressibility, gases and vapors expand as the pressure drops at the vena contracta, decreasing their specific weight. To account for the change in specific weight, an expansion factor, Y, is introduced into the valve sizing formula. The form of the Equation used is one of the following, depending on the process variables available:

$$w = 63.3\, F_P C_v Y \sqrt{x P_1 \gamma_1} \qquad (3.11)$$

$$Q = 1360\, F_P C_v P_1 Y \sqrt{\frac{x}{G_g T_1 Z}} \qquad (3.12)$$

$$w = 19.3\, F_P C_v P_1 Y \sqrt{\frac{x M_w}{T_1 Z}} \qquad (3.13)$$

$$Q = 7320\, F_P C_v P_1 Y \sqrt{\frac{x}{M_w T_1 Z}} \qquad (3.14)$$

Where:

- w = Gas flow rate, lb/hr
- F_P = Piping geometry factor
- C_v = Valve sizing coefficient
- Y = Expansion factor
- x = Pressure drop ratio
- γ_1 = Specific weight at inlet conditions, lb/ft^3
- Q = Gas flow in standard ft^3/hr (SCFH)
- G_g = Specific gravity of gas relative to air at standard conditions
- T_1 = Absolute upstream temperature $^oR = (^oF + 460^o)$
- Z = Compressibility factor
- M_w = Molecular weight
- P_1 = Upstream absolute pressure, psia

NOTE: *The numerical constants in Equations 3.11–3.14 are unit conversion factors.*

The following steps should be used to compute the correct C_v, body size and trim number:

Step 1: Select the Appropriate Equation

Based on the information available, select one of the four Equations: 3.11, 3.12, 3.13 or 3.14.

Step 2: Check for Choked Flow

Determine the terminal pressure drop ratio, x_T, for that particular valve by referring to Table 3-V.

Next, determine the ratio of specific heats factor, F_k, by using the Equation below:

$$F_k = \frac{k}{1.40} \qquad (3.15)$$

Where:

- F_k = Ratio of specific heats factor
- k = Ratio of specific heats (taken from Table 3-VI).

Calculate the ratio of actual pressure drop to absolute inlet pressure, x, by using Equation 3.16:

$$x = \frac{\Delta P}{P_1} \qquad (3.16)$$

Where:

- x = Ratio of pressure drop to absolute inlet pressure
- ΔP = Pressure drop ($P_1 - P_2$)
- P_1 = Inlet pressure, psia
- P_2 = Outlet pressure, psia

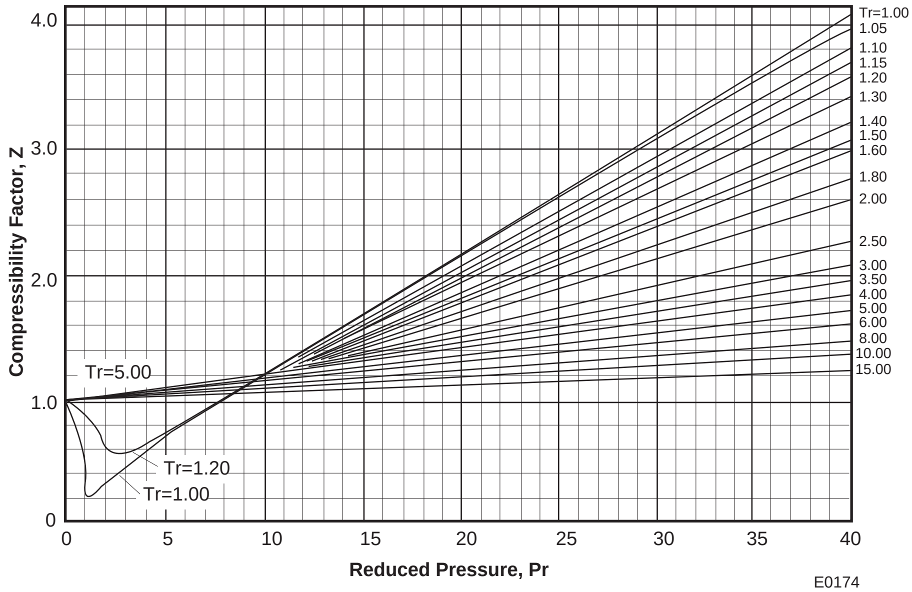
Choked flow occurs when x reaches the value of $F_k x_T$. Therefore, if x is less than $F_k x_T$, the flow is not choked. If x is greater, the flow is choked. If flow is choked, then $F_k x_T$ should be used in place of x (whenever it applies) in the gas sizing Equations.

Table 3-V: Pressure Drop Ratios, x_T

Valve Type	Flow Direction	Trim Size	x_T
Globe	Flow-to-close Flow-to-close Flow-to-open Flow-to-open	Full Area Reduced Area Full Area Reduced Area	0.70 0.70 0.75 0.75
High Performance Butterfly Multi-stage	60^o Open 90^o Open Under Seat	Full Full All	0.36 0.26 ~1.00
Ball	90^o Open	Full	0.30

Figure 3-4: Compressibility Factors for Gases with Reduced Pressures from 0 to 40.

(Reproduced from charts of L.C. Nelson and E.F. Obert, Northwestern Technological Institute)



Step 3: Calculate the Expansion Factor

The expansion factor, Y, may be expressed as:

$$Y = 1 - \frac{x}{3F_k x_T} \quad (3.17)$$

NOTE: *If the flow is choked, use $F_k x_T$ for x.*

Step 4: Determine the Compressibility Factor

To obtain the compressibility factor, Z, first calculate the reduced pressure, P_r, and the reduced temperature, T_r:

$$P_r = \frac{P_1}{P_C} \quad (3.18)$$

Where:

P_r = Reduced pressure

P_1 = Upstream pressure, psia

P_C = Critical Pressure, psia (from Table 3-VI)

$$T_r = \frac{T_1}{T_C} \quad (3.19)$$

Where:

T_r = Reduced temperature

T_1 = Absolute upstream temperature

T_C = Critical absolute temperature (from Table VI)

Using the factors P_r and T_r, find Z in Figures 3-4 or 3-5.

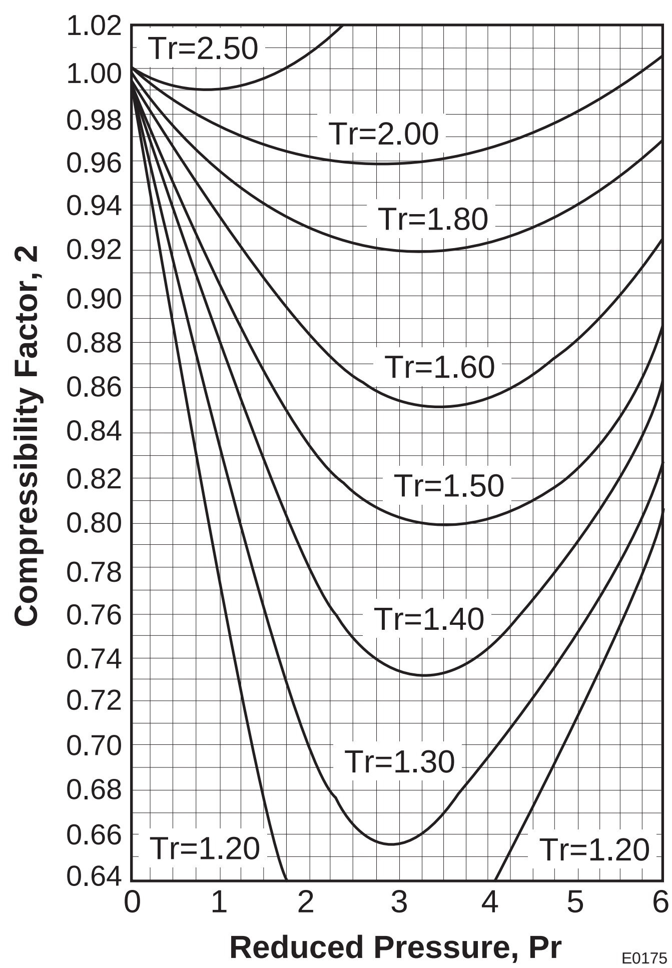


Figure 3-5: Compressibility Factors for Gases with Reduced Pressures from 0 to 6.

(Reproduced from charts of L.C. Nelson and E.F. Obert, Northwestern Technological Institute)

Table 3-VI: Gas Physical Data

Gas	Critical Pressure (psia)	Critical Temperature (^{o}R)	Molecular Weight (M_w)	Ratio of Specific Heats (k)
Air	492.4	227.1	28.97	1.40
Ammonia	1636.1	729.8	17.0	1.31
Argon	707.0	271.1	39.9	1.67
Carbon Dioxide	1070.2	547.2	44.0	1.29
Carbon Monoxide	507.1	238.9	28.0	1.40
Ethane	708.5	549.4	30.1	1.19
Ethylene	730.6	508.0	28.1	1.24
Helium	32.9	9.01	4.00	1.66
Hydrogen	188.2	59.4	2.02	1.40
Methane	667.4	342.8	16.04	1.31
Natural Gas	667.4	342.8	16.04	1.31
Nitrogen	492.4	226.8	28.0	1.40
Oxygen	732.0	278.0	32.0	1.40
Propane	615.9	665.3	44.1	1.13
Steam	3208.2	1165.1	18.02	1.33

Step 5: Calculate C_v

Using the above calculations, use one of the four gas sizing Equations to determine C_v (assuming F_P is 1).

Step 6: Select Approximate Body Size Based on C_v

From the C_v tables in the appendix, select the smallest body size that will handle the calculated C_v.

Step 7:Calculate Piping Geometry Factor

If the pipe size is not given, use the approximate body size (from step 6) to choose the corresponding pipe size. The pipe size is used to calculate the piping geometry factor, F_P, which can be determined by Tables 3-III or 3-IV. If the pipe diameter is the same as the valve size, F_P is 1 and is not a factor.

Step 8: Calculate the Final C_v

With the calculation of the F_P, figure the final C_v.

Step 9: Calculate Valve Exit Mach Number

Equations 3.20, 3.21, 3.22 or 3.23 are used to calculate entrance or exit velocities (in terms of the approximate Mach number). Use Equations 3.20 or 3.21 for gases, Equation 3.22 for air and Equation 3.23 for steam. Use downstream temperature if it is known, otherwise use upstream temperature as an approximation.

$$M\text{ (gas)} = \frac{Q_a}{5574\, A_v \sqrt{\dfrac{kT}{M_w}}} \quad (3.20)$$

$$M\text{ (gas)} = \frac{Q_a}{1036\, A_v \sqrt{\dfrac{kT}{G_g}}} \quad (3.21)$$

$$M\text{ (air)} = \frac{Q_a}{1225\, A_v \sqrt{T}} \quad (3.22)$$

$$M\text{ (steam)} = \frac{w\,v}{1514\, A_v \sqrt{T}} \quad (3.23)$$

Where:

- M = Mach number
- Q_a = Actual flow rate, ft^3/hr (CFH, not SCFH; see page 3-13)
- A_v = Applicable flow area, in^2, of body port (Table 3-VIII)
- T_1 = Absolute temperature ^{o}R, ($^{o}F + 460^{o}$)
- w = Mass flow rate, lb/hr
- v = Specific volume at flow conditions, ft^3/lb
- G_g = Specific gravity at standard conditions relative to air
- M_w = Molecular weight
- k = Ratio of specific heats

NOTE: *To convert SCFH to CFH use the Equation:*

$$\frac{(P_a)(Q_a)}{T_a} = \frac{(P_S)(Q)}{T_S} \qquad (3.24)$$

Where:

- P_a = Actual operating pressure
- Q_a = Actual volume flow rate, CFH
- T_a = Actual temperature,° R (° F + 460°)
- P_S = Standard pressure (14.7 psi)
- Q = Standard volume flow rate, SCFH
- T_S = Standard temperature (520° Rankine)

After calculating the exit velocity, compare that number to the acceptable velocity for that application. Select a larger size valve if necessary. Refer to section 13 to predict noise level.

Caution: Noise levels in excess of 110 dBA may cause vibration in valves/piping resulting in equipment damage.

Step 10: Recalculate C_v if Body Size Changed

Recalculate C_v if F_P has changed due to the selection of a larger body size.

Step 11: Select Trim Number

Identify if the valve is for on/off or throttling service. Using the C_v tables in Section 4, select the appropriate trim number for the calculated C_v and body size selected. The trim number and flow characteristic (Section 9) may be affected by how the valve is throttled.

GAS SIZING EXAMPLES

Example One

Given:

Gas	Steam
Temperature	450° F
Upstream Pressure (P_1)	140 psia
Downstream Pressure (P_2)	50 psia
Flow Rate	10,000 lb/hr
Valve Action	Flow-to-open
Critical Pressure (P_C)	3206.2 psia
Critical Temperature (T_C)	705.5° F
Molecular Weight (M_w)	18.026
Ratio of Specific Heats (k)	1.33
Flow Characteristic	Equal percentage
Line Size	2-inch (Class 600)
Specific Volume	10.41

Step 1: Given the above information, Equation 3.13 can be used to solve for C_v.

Step 2: Referring to Table 3-V, the pressure drop ratio, x_T, is 0.75. Calculate F_k using Equation 3.15 and x using Equation 3.16:

$$F_k = \frac{1.33}{1.40} = 0.95$$

$$x = \frac{140 - 50}{140} = 0.64$$

Therefore, $F_k x_T$ is (0.95)(0.75) or 0.71. Since x is less than $F_k x_T$, flow is not choked. Use x in all Equations.

Step 3: Determine Y using Equation 3.17:

$$Y = 1 - \frac{0.64}{3\,(0.71)} = 0.70$$

Step 4: Determine Z by calculating P_r and T_r using Equations 3.18 and 3.19:

$$P_r = \frac{140}{3208.2} = 0.04$$

$$T_r = \frac{450 + 460}{705.5 + 460} = 0.78$$

Using Figure 3-4, Z is found to be 1.0

Step 5: Determine C_v using Equation 3.13 and assuming F_P is 1:

$$C_v = \frac{10{,}000}{(19.3)\,(140)\,(0.70)} \sqrt{\frac{(910)\,(1.0)}{(0.64)\,(18.02)}} = 47.0$$

Step 6: From the C_v tables (Mark One, flow-under, equal percentage, Class 600), select the smallest body size for a C_v of 47, which is a 2-inch body.

Steps 7 and 8: Since the pipe size is the same as the body, F_P is 1 and is not a factor. Therefore, the C_v is 47.

Step 9: The gas is steam, calculate the Mach number using Equation 3.23. Assume a constant enthalpy process to find specific volume at downstream conditions; from steam tables, v = 10.41 ft³/lb at T_2 = 414°F :

$$M = \frac{(10{,}000)\,(10.41)}{1515\,(3.14)\sqrt{414 + 460}} = 0.74$$

This is greater than Mach 0.5 and should be reviewed for excessive noise and use of noise reducing trim.

Step 10: If body size does not change, there is no impact on C_v calculation.

Step 11: Referring to the C_v tables, a C_v 47, 2-inch Mark One would use a trim number of 1.62. If noise is a consideration, see Sections 13 and 14.

Example Two

Given:

- Gas .... Natural Gas
- Temperature .... 65° F
- Upstream Pressure (P_1) .... 1314.7 psia
- Downstream Pressure (P_2) .... 99.7 psia
- Flow Rate .... 2,000,000 SCFH
- Valve Action .... Flow-to-open
- Critical Pressure (P_C) .... 672.92 psia
- Critical Temperature (T_C) .... 342.8°R
- Molecular Weight (M_w) 16.042
- Ratio of Specific Heats (k) 1.31
- Flow Characteristic .... Linear
- Line Size .... Unknown (Class 600)

Step 1: Given the above information, Equation 3.14 can be used to solve for C_V.

Step 2: Referring to Table 3-V, the pressure drop ratio, x_T, is 0.75 by assuming a Mark One flow-under. Calculate F_k using Equation 3.15 and x using Equation 3.16:

$$F_k = \frac{1.31}{1.40} = 0.936$$

$$x = \frac{1314.7 - 99.7}{1314.7} = 0.92$$

Therefore, $F_k x_T$ is (0.94)(0.75) or 0.70. Since x is greater than $F_k x_T$, flow is choked. Use $F_k x_T$ in place of x in all Equations.

Step 3: Determine Y using Equation 3.17:

$$Y = 1 - \frac{0.70}{3\,(0.70)} = 0.667$$

Step 4: Determine Z by calculating P_r and T_r using Equations 3.18 and 3.19:

$$P_r = \frac{1314.7}{667.4} = 1.97$$

$$T_r = \frac{65 + 460}{342.8} = 1.53$$

Using Figure 3-5, Z is found to be about 0.86.

Step 5: Determine C_V using Equation 3.14 and assuming F_P is 1:

$$C_V = \frac{(2{,}000{,}00)}{(7320)(1314.7)(.667)}\sqrt{\frac{(16.04)(525)(0.86)}{0.70}} = 31.7$$

Step 6: From the C_v tables (Mark One, flow-under, linear, Class 600), select the smallest body size for a C_v of 31.7, which is a 1 1/2-inch body.

Steps 7 and 8: Since the pipe size is unknown, use 1 as the F_P factor. Therefore, the C_V is 31.7.

Step 9: Since the gas is natural gas, calculate the Mach number using Equation 3.20:

$$M = \frac{(297{,}720^*)}{5574\,(1.77)\sqrt{\frac{(1.31)(65 + 460)}{16.04}}} = 6.61$$

****NOTE:*** *To convert SCFH to CFH, use Equation 3.24.*

Step 10: Mach numbers in excess of sonic velocity at the outlet of the valve are not possible. A larger valve size should be selected to bring the velocity below the sonic level. To properly size the valve, select a size to reduce the velocity to less than 1.0 Mach.

Step 11: Using Equation 3.20, solve for the recommended valve area required for 0.5 Mach velocity:

$$0.5\ M = \frac{297{,}720\ CFH}{5574\ A\sqrt{\frac{1.31\,(65 + 460)}{16.04}}} \quad A_v = 16.3\ in^2$$

Solve for the valve diameter from the area by:

$$A_v = \pi d^2 \ \text{ or } \ d = \sqrt{\frac{4A_v}{\pi}} = \sqrt{\frac{4\,(16.3)}{\pi}} = 4.6\ in.$$

Thus a 6-inch valve is required.

Step 12: Referring to the C_V tables, a C_V of 31.7, 6-inch Mark One would use a trim number of 1.62. Since the flow is choked, noise should be calculated from Section 13, and special trim may be selected from Section 14.

CALCULATING C_v FOR TWO PHASE FLOW

Introduction

The method of C_v calculation for two phase flow assumes that the gas and liquid pass through the valve orifice at the same velocity. The required C_v is determined by using an equivalent density for the liquid gas mixture. This method is intended for use with mixtures of a liquid and a non-condensable gas. To size valves with liquids and their own vapor at the valve inlet will require good engineering judgement.

Nomenclature:

A_v = flow area of body port (Table 3-VIII)

ΔP_a = allowable pressure drop

q_f = volumetric flow rate of liquid, ft^3/hr

q_g = volumetric flow rate of gas, ft^3/hr

w_f = liquid flow rate, lb/hr

w_g = gas flow rate, lb/hr

G_f = liquid specific gravity at upstream conditions

G_g = gas specific gravity at upstream conditions

T_1 = upstream temperature (^{o} R)

Step 1: Calculate the Limiting Pressure Drop

First it must be determined whether liquid or gas is the continuous phase at the vena contracta. This is done by comparing the volumetric flow rate of the liquid and gas. Whichever is greater will be the limiting factor:

If $q_f > q_g$, then $\Delta P_a = \Delta P_a$ for liquid
If $q_g > q_f$, then $\Delta P_a = \Delta P_a$ for gas

The ΔP_a for liquid or gas is either $P_1 - P_2$ or the choked pressure drop of the dominating phase if the valve is choked. (See the gas and liquid choked pressure Equations.)

Step 2: Calculate the Equivalent Specific Volume of the Liquid-gas Mixture

Where:

$$v_e = \frac{(f_g v_g)}{Y^2} + f_f v_f$$

$$f_g = \frac{w_g}{(w_g + w_f)}$$

$$f_f = \frac{w_f}{(w_g + w_f)}$$

$$v_g = \frac{T_1}{(2.7 P_1 G_g)}$$

$$v_f = \frac{1}{(62.4 G_f)}$$

Y = gas expansion factor (Equation 3.17)

Step 3: Calculate the Required C_v of the Valve

$$C_v F_p = \left(\frac{w_g + w_f}{63.3}\right)\sqrt{\frac{v_e}{\Delta P_a}}$$

Use the smaller of $P_1 - P_2$ and ΔP_{ch} for P_a.

Step 4: Select Body Size Based on C_v

From the C_v tables in the appendix, select the smallest body size that will handle the calculated C_v.

Step 5: Calculate Piping Geometry Factor

If the pipe size is not given, use the approximate body size (from step 6) to choose the corresponding pipe size. The pipe size is used to calculate the piping geometry factor, F_P, which can be determined by Tables 3-III or 3-IV. If the pipe diameter is the same as the valve size, F_P is 1.

Step 6: Calculate Final C_v

With the calculation of the F_P, figure the final C_v.

Step 7: Calculate the Valve Exit Velocity

Where:

$$\text{Velocity} = \frac{(q_f + q_g)}{A_v}$$

$$q_f = \frac{w_f}{62.4 G_f}$$

$$q_g = \frac{w_g T_1}{2.7 G_g P_2}$$

Area = applicable flow area

After calculating the exit velocity, compare that number to the acceptable velocity for that application. Select a larger valve size if necessary.

Recommended two phase flow velocity limits are similar to those for flashing when the gaseous phase is dominant. If liquid is the dominant phase, velocity of the mixture should be less than 50 ft/sec in the body.

Step 8: Recalculate C_v if Body Size Changed

Recalculate C_v if F_P has been changed due to the selection of a larger body size.

Step 9: Select Trim Number

Identify if the valve will be used for on/off or throttling service. Using the C_v tables in Section 4, select the appropriate trim number for the calculated C_v and body size selected. The trim number and flow characteristic (Section 9) may be affected by how the valve is throttled. Special trim and materials may be required if high noise levels or cavitation are indicated.

Table 3-VII: Pipe Flow Areas, A_p (Square Inches)

Nominal Pipe Diameter	Schedule												
	10	20	30	40	60	80	100	120	140	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				2.04		1.77				1.41	2.04	1.77	0.95
2				3.36		2.95				2.24	3.36	2.95	1.77
3				7.39		6.61				5.41	7.39	6.61	4.16
4				12.73		11.50		10.32		9.28	12.73	11.50	7.80
6				28.89		26.07		23.77		21.15	28.89	26.07	18.83
8		51.8	51.2	50.0	47.9	45.7	43.5	40.6	38.5	36.5	50.0	45.7	37.1
10		82.5	80.7	78.9	74.7	71.8	68.1	64.5	60.1	56.7	78.9	74.7	
12		117.9	114.8	111.9	106.2	101.6	96.1	90.8	86.6	80.5	113.1	108.4	
14	143.1	140.5	137.9	135.3	129.0	122.7	115.5	109.6	103.9	98.3	137.9	132.7	
16	188.7	185.7	182.6	176.7	169.4	160.9	152.6	144.5	135.3	129.0	182.6	176.7	
18	240.5	237.1	230.4	223.7	213.8	204.2	193.3	182.7	173.8	163.7	233.7	227.0	
20	298.6	291.0	283.5	278.0	265.2	252.7	238.8	227.0	213.8	202.7	298.0	283.5	
24	434	425	411	402	382	365	344	326	310	293	425	415	
30	678	661	649	663	602	574	542	513					
36	975	956	938	914	870	830	782						
42	1328	1302	1282	1255	1187	1132	1064						

Table 3-VIII: Valve Outlet Areas

Valve Size (inches)	Valve Outlet Area, A_v (Square Inches)						
	Class 150	Class 300	Class 600	Class 900	Class 1500	Class 2500	Class 4500
1/2	0.20	0.20	0.20	0.20	0.20	0.15	0.11
3/4	0.44	0.44	0.44	0.37	0.37	0.25	0.20
1	0.79	0.79	0.79	0.61	0.61	0.44	0.37
1 1/2	1.77	1.77	1.77	1.50	1.50	0.99	0.79
2	3.14	3.14	3.14	2.78	2.78	1.77	1.23
3	7.07	7.07	7.07	6.51	5.94	3.98	2.78
4	12.57	12.57	12.57	11.82	10.29	6.51	3.98
6	28.27	28.27	28.27	25.97	22.73	15.07	10.29
8	50.27	50.27	48.77	44.18	38.48	25.97	19.63
10	78.54	78.54	74.66	69.10	60.13	41.28	28.27
12	113.10	113.10	108.43	97.12	84.62	58.36	41.28
14	137.89	137.89	130.29	117.86	101.71	70.88	50.27
16	182.65	182.65	170.87	153.94	132.73	92.80	63.62
18	233.70	226.98	213.82	194.83	167.87	117.86	84.46
20	291.04	283.53	261.59	240.53	210.73	143.14	101.53
24	424.56	415.48	380.13	346.36	302.33	207.39	143.14
30	671.96	660.52	588.35	541.19	476.06	325.89	
36	962.11	907.92	855.30				
42	1320.25	1194.59					

NOTE: *To find approximate fluid velocity in the pipe, use the Equation* $V_P = V_v A_v / A_P$ *where:*

V_P = Velocity in pipe — A_v = Valve Outlet area from Table 3-VIII

V_v = Velocity in valve outlet — A_P = Pipe area from Table 3-VII

To find equivalent diameters of the valve or pipe inside diameter use: $d = \sqrt{4A_v/\pi}$, $D = \sqrt{4A_p/\pi}$