

# Control Valve Sizing

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### 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:

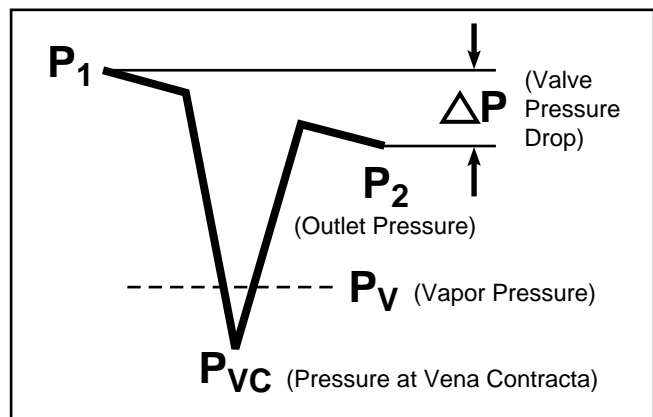
$$C_v = \text{flow} \sqrt{\frac{\text{specific gravity at flowing temperature}}{\text{pressure drop}}}$$

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.

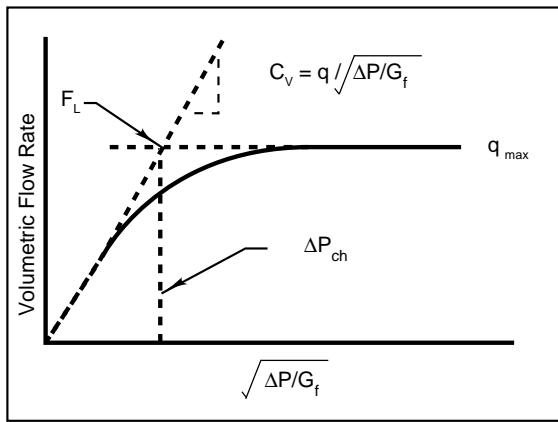
### Pressure Profile

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  $\Delta P_{ch}$  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,  $\Delta P_a$ .

### 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  $\Delta P$  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:

$$C_v = \frac{q}{F_p} \sqrt{\frac{G_f}{\Delta P_a}} \quad (3.1)$$

Where:

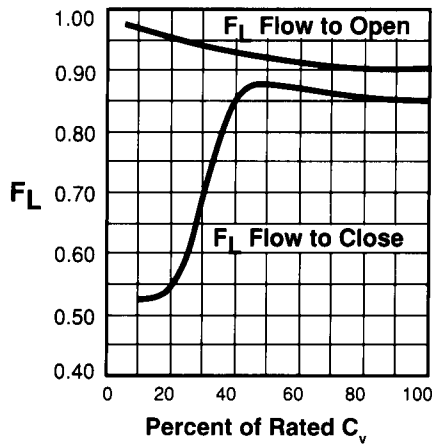
- $C_v$  = Valve sizing coefficient
- $F_p$  = Piping geometry factor
- $q$  = Flow rate, gpm
- $\Delta P_a$  = Allowable pressure drop across the valve for sizing, psi
- $G_f$  = Specific gravity at flowing temperature

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

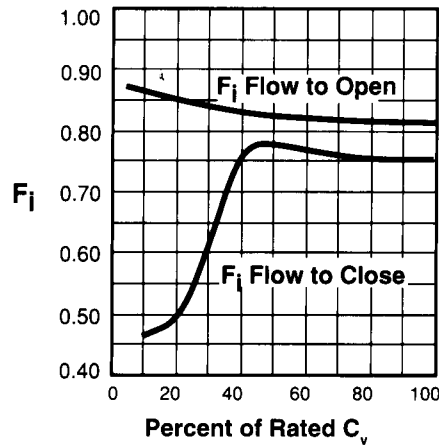
NOTE: Values are given for full-open valves. See charts below for part-stroke values

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	60° Open	Full	0.76	0.65	.36	.71
Rotary Disc	90° Open	Full	0.56	0.49	.26	.71
ShearStream	60° Open	Full	0.78	0.65	.51	1.0
Rotary Ball	90° 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*

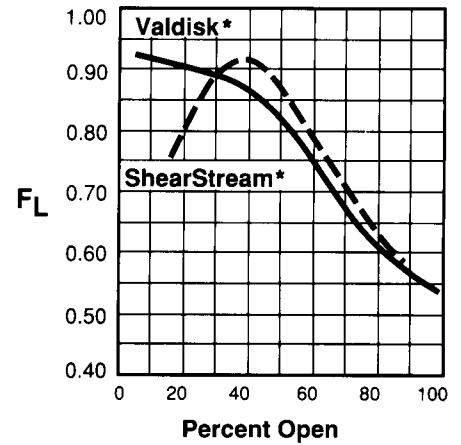
\* Typical    \*\*  $n_s$  = number of stages



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,  $\Delta P_a$ , across the valve for calculating  $C_v$ , is the smaller of the actual  $\Delta P$  from Equation 3.2 and choked  $\Delta P_{ch}$  from Equation 3.3.

$$\Delta P = P_1 - P_2 \tag{3.2}$$

**Step 2: Check for Choked Flow, Cavitation and Flashing**

Use Equation 3.3 to check for choked flow:

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

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

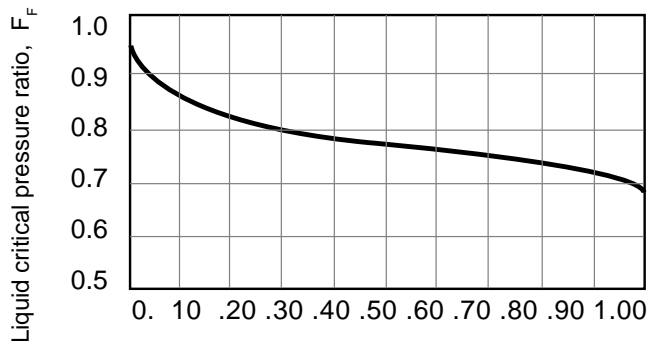
See Table 3-I for  $F_L$  factors for both full-open and part-stroke values.

$F_F$  can be estimated by the following relationship:

$$F_F = 0.96 - 0.28 \sqrt{\frac{P_V}{P_C}} \tag{3.4}$$

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  $\Delta P_{ch}$  (Equation 3.3) is less than the actual  $\Delta P$  (Equation 3.2), use  $\Delta P_{ch}$  for  $\Delta P_a$  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
Chlorine	1117.2	Nitrous Oxide	1051.1
Dowtherm A	547.0	Oxygen	732.0
Ethane	708.5	Phosgene	823.2
Ethylene	730.5	Propane	615.9
Fuel Oil	330.0	Propylene	670.3
Fluorine	757.0	Refrigerant 11	639.4
Gasoline	410.0	Refrigerant 12	598.2
Helium	32.9	Refrigerant 22	749.7
Hydrogen	188.1	Sea Water	3200.0
		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:

$$\Delta P (\text{cavitation}) = F_i^2 (P_1 - P_v) \quad (3.5)$$

In high pressure applications, alternate analysis may be required; verify analysis with factory if  $\Delta P \geq \Delta P (\text{cavitation}) \geq 300$  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  $\Delta P$  allowable [ $\Delta P_{ch}$  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:

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

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

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

Where:

$C_{vs}$  = Laminar flow  $C_v$

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

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

$F_s$  = streamline flow factor

**Table 3-III: Piping Geometry Factors for Valves with Reducer and In 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 ( $\Delta P$  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 In creaser 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)

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

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  $\Delta P$  in psi  
 $\mu$  = absolute Viscosity, centipoise  
 $\nu$  = kinematic viscosity, centistokes =  $\mu/G_f$

**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:

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

For laminar and transitional flow, note the  $\Delta P$  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:

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

Where:

- V = Velocity, ft/sec
- q = Liquid flow rate, gpm
- A<sub>v</sub> = Applicable flow area, in<sup>2</sup> 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<sub>v</sub> If Body Size Changed

Recalculate C<sub>v</sub> if the F<sub>p</sub> 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<sub>v</sub> tables in Section 4, select the appropriate trim number for the calculated C<sub>v</sub> and body size selected. The trim number and flow characteristic (Section 9) may be affected by how the valve will be throttled. When cavitation is indicated, refer to Section 14 to evaluate special trims for cavitation protection.

## LIQUID SIZING EXAMPLES

### Example One

Given:

- Liquid ..... Water
- Critical Pressure (P<sub>c</sub>) ..... 3206.2 psia
- Temperature ..... 250° F
- Upstream Pressure (P<sub>1</sub>) ..... 314.7 psia
- Downstream Pressure (P<sub>2</sub>) ..... 104.7 psia
- Specific Gravity ..... 0.94
- Valve Action ..... Flow-to-open
- Line Size ..... 4-inch (Class600)
- Flow Rate ..... 500 gpm
- Vapor Pressure (P<sub>v</sub>) ..... 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<sub>L</sub> using Table 3-I. Looking under "globe, flow-under," find F<sub>L</sub> as 0.90. Next, estimate F<sub>F</sub> using Equation 3.4:

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

Insert F<sub>L</sub> and F<sub>F</sub> 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<sub>ch</sub>, 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<sub>v</sub>F<sub>p</sub> using Equation 3.1 and assuming F<sub>p</sub> is 1.0:

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

**Step 5:** From the C<sub>v</sub> tables (Mark One, flow-under, equal percentage, Class 600) select the smallest body size for a C<sub>v</sub> of 33.4, which is a 2-inch body.

**Step 6:** Calculate the Reynolds Number Factor, F<sub>R</sub>, 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 Re<sub>ev</sub> > 40,000, F<sub>R</sub> = 1.0 and the recalculated C<sub>v</sub>F<sub>p</sub> remains as 33.4.

**Step 8:** Using the 2-inch body from step 5, determine the F<sub>p</sub> 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<sub>p</sub> is 0.97.

**Step 9:** Recalculate the final C<sub>v</sub>:

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

**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 ( $\nu$ ) .....	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 3-1. 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  $\Delta P$  is more than  $\Delta P_{ch}$ , the flow is choked and cavitating; therefore, use the  $\Delta P_{ch}$  for  $\Delta P_a$  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:

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

Where:

$V$  = Velocity, ft/sec

$w$  = Liquid flow rate, lb/hr

$q$  = Liquid flow rate, gpm

$A_v$  = Valve outlet flow area, in<sup>2</sup>, see Table 3-VIII.

$v_{f2}$  = Saturated liquid specific volume (ft<sup>3</sup>/lb at outlet pressure)

$v_{g2}$  = Saturated vapor specific volume (ft<sup>3</sup>/lb at outlet pressure)

$x$  = % of liquid mass flashed to vapor

### Calculating Percentage Flash

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

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

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:

$$h_{f1} = 321.8 \text{ Btu/lb at } 350^\circ \text{ F} \\ \text{(from saturation temperature tables)}$$

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

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

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

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

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

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

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

$$V = 156 \text{ ft/sec}$$

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:

$$w = 63.3 F_p C_v Y \sqrt{x P_1 \gamma_1} \quad (3.11)$$

$$Q = 1360 F_p C_v P_1 Y \sqrt{\frac{x}{G_g T_1 Z}} \quad (3.12)$$

$$w = 19.3 F_p C_v P_1 Y \sqrt{\frac{x M_w}{T_1 Z}} \quad (3.13)$$

$$Q = 7320 F_p C_v P_1 Y \sqrt{\frac{x}{M_w T_1 Z}} \quad (3.14)$$

Where:

$w$  = Gas flow rate, lb/hr

$F_p$  = Piping geometry factor

$C_v$  = Valve sizing coefficient

$Y$  = Expansion factor

$x$  = Pressure drop ratio

$\gamma_1$  = Specific weight at inlet conditions, lb/ft<sup>3</sup>

$Q$  = Gas flow in standard ft<sup>3</sup>/hr (SCFH)

$G_g$  = Specific gravity of gas relative to air at standard conditions

$T_1$  = Absolute upstream temperature  
°R = (°F + 460°)

$Z$  = 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:

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

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:

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

Where:

$x$  = Ratio of pressure drop to absolute inlet pressure

$\Delta P$  = Pressure drop ( $P_1 - P_2$ )

$P_1$  = Inlet pressure, psia

$P_2$  = Outlet pressure, psia

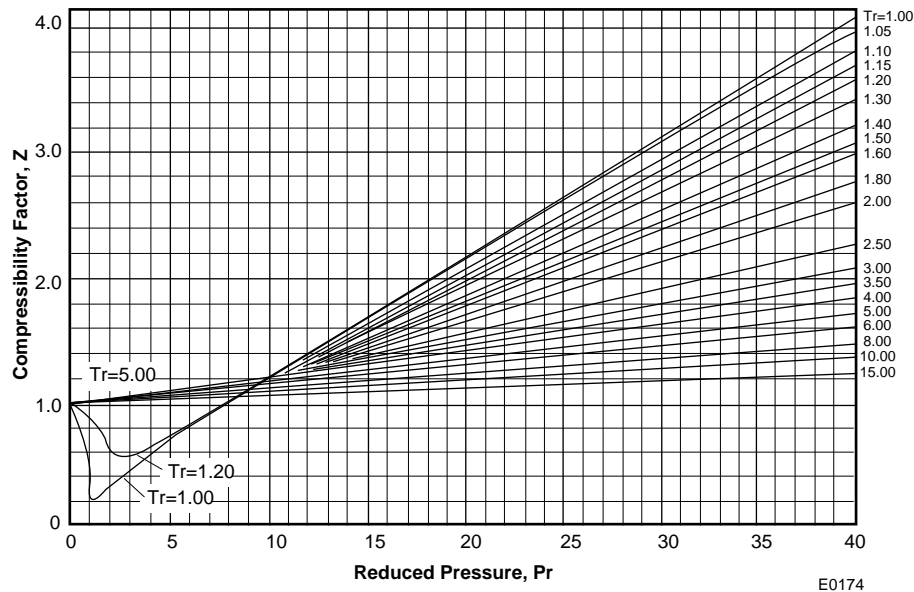
Choked flow occurs when  $x$  reaches the value of  $F_k x_T$ . Therefore, if  $x$  is less than  $F_k x_T$ , the flow is not choked. If  $x$  is greater, the flow is choked. If flow is choked, then  $F_k x_T$  should be used in place of  $x$  (whenever it applies) in the gas sizing Equations.

**Table 3-V: Pressure Drop Ratios,  $x_T$**

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

$$Y = 1 - \frac{x}{3F_k x_T} \tag{3.17}$$

**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,  $T_r$ :

$$P_r = \frac{P_1}{P_c} \tag{3.18}$$

Where:

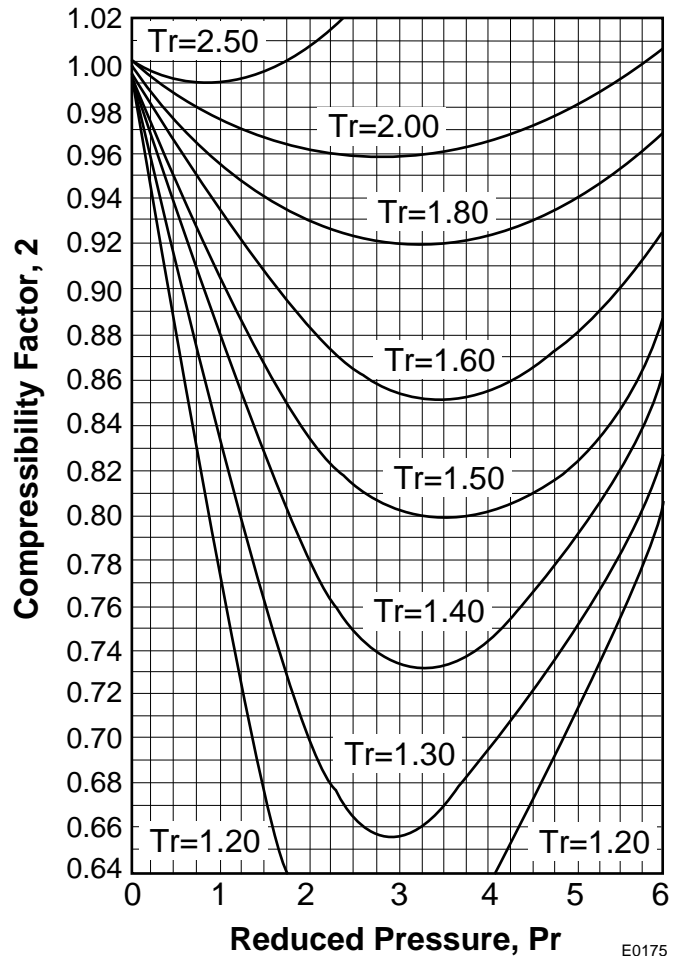
- $P_r$  = Reduced pressure
- $P_1$  = Upstream pressure, psia
- $P_c$  = Critical Pressure, psia (from Table 3-VI)

$$T_r = \frac{T_1}{T_c} \tag{3.19}$$

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 (°R)	Molecular Weight (M <sub>w</sub> )	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<sub>v</sub>**

Using the above calculations, use one of the four gas sizing Equations to determine C<sub>v</sub> (assuming F<sub>p</sub> is 1).

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

**Step 6: Select Approximate Body Size Based on C<sub>v</sub>**

From the C<sub>v</sub> tables in the appendix, select the smallest body size that will handle the calculated C<sub>v</sub>.

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

**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<sub>p</sub>, which can be determined by Tables 3-III or 3-IV. If the pipe diameter is the same as the valve size, F<sub>p</sub> is 1 and is not a factor.

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

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

Where:

- M = Mach number
- Q<sub>a</sub> = Actual flow rate, ft<sup>3</sup>/hr (CFH, not SCFH; see page 3-13)
- A<sub>v</sub> = Applicable flow area, in<sup>2</sup>, of body port (Table 3-VIII)
- T<sub>1</sub> = Absolute temperature° R, (° F + 460°)
- w = Mass flow rate, lb/hr
- v = Specific volume at flow conditions, ft<sup>3</sup>/lb
- G<sub>g</sub> = Specific gravity at standard conditions relative to air
- M<sub>w</sub> = Molecular weight
- k = Ratio of specific heats

**Step 8: Calculate the Final C<sub>v</sub>**

With the calculation of the F<sub>p</sub>, figure the final C<sub>v</sub>.

**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.

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

$$\frac{(P_a)(Q_a)}{T_a} = \frac{(P_s)(Q)}{T_s} \quad (3.24)$$

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,  $v = 10.41$  ft<sup>3</sup>/lb at  $T_2 = 414^\circ\text{F}$ :

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

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:

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

**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:

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

Solve for the valve diameter from the area by:

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

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)
- $\Delta P_a$  = allowable pressure drop
- $q_l$  = volumetric flow rate of liquid, ft<sup>3</sup>/hr
- $q_g$  = volumetric flow rate of gas, ft<sup>3</sup>/hr
- $w_l$  = liquid flow rate, lb/hr
- $w_g$  = gas flow rate, lb/hr
- $G_l$  = liquid specific gravity at upstream conditions
- $G_g$  = gas specific gravity at upstream conditions
- $T_1$  = upstream temperature ( $^{\circ}$  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  $q_l > q_g$ , then  $\Delta P_a = \Delta P_{a_l}$  for liquid
- If  $q_g > q_l$ , then  $\Delta P_a = \Delta P_{a_g}$  for gas

The  $\Delta P_a$  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:

$$v_e = \frac{(f_g v_g)}{Y^2} + f_l v_l$$

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

$$f_l = \frac{w_l}{(w_g + w_l)}$$

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

$$v_l = \frac{1}{(62.4 G_l)}$$

$Y$  = gas expansion factor (Equation 3.17)

### Step 3: Calculate the Required $C_v$ of the Valve

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

Use the smaller of  $P_1 - P_2$  and  $\Delta P_{ch}$  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:

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

$$q_l = \frac{w_l}{62.4 G_l}$$

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

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:  $d = \sqrt{4A_v/\pi}$ ,  $D = \sqrt{4A_p/\pi}$