TABLE OF CONTENTS

METHOD OF SOLUTION

Introduction

In CON-FLO, a control valve is defined as a valve installed in a pipeline to control or regulate the flow of fluid. The sizing and selection of valves is based upon many piping system variables. CON-FLO analyzes the operation of the valve while taking into account the hydraulic characteristics of the system.

CON-FLO does not perform an analysis of the entire control loop. A control loop analysis includes the process piping system, control valve, actuator, and controlling mechanism under steady state and dynamic operation. Most control valve applications do not require a complete loop analysis. In practice, the hydraulic analysis of the system has the greatest effect on the proper selection and operation of the valve.

The CON-FLO program used in conjunction with the other programs in the FLO-SERIES provides a detailed hydraulic analysis of the system and the effect of the valve.

The source document for the sizing calculations used in CON-FLO is the American National Standard Institute, Instrument Society of America standard ANSI/ISA-S75.01-1985 (R 1995) *Flow Equations for Sizing Control Valves*.

The CON-FLO program is designed to provide a quick and effective means of evaluating various valves using the ANSI/ISA standard. Specific formulas from this standard used by CON-FLO are supplied in this section of the manual. When there is a discrepancy between the standard and the program documentation, the standard takes precedence.

The majority of valve manufacturers have adopted the ANSI/ISA standard for the sizing of their valves and they provide the necessary factors in their valve catalogs. When there is a discrepancy between a valve manufacturer's data and data presented in the supplied catalog disks, you should contact the valve manufacturer.

A few valve manufacturers have developed their own proprietary formulas and factors for sizing their valves. The CON-FLO program does not use any proprietary method for sizing valves. The calculation method used conforms with the ANSI/ ISA-S75.01-1985 (R 1995) *Flow Equations for Sizing Control Valves.* This approach allows valves from various manufacturers to be compared using the same approach, thus insuring that the best valve is selected for the application.

CON-FLO is not intended to be used to design or test valves.

Sizing Valves For Liquid Service

The equations for the flow of non-compressible fluids through a valve as described by the standard and used in CON-FLO, are as follows:

$$w = N_6 F_P F_R C_v (dP / \rho)^{1/2} \qquad \textit{equation 1}$$

N_6 = conversion coefficient
C_v = valve flow coefficient, dimensionless
F_P = piping geometry factor, dimensionless
F_R = Reynolds number factor, dimensionless (F_R = 1 for turbulent flow)
dP = pressure drop across the valve (P_1-P_2), pressure units
ρ = fluid density, mass/unit volume

C_V Valve Flow Coefficient

The flow coefficient (C_v) describes the flow vs pressure relationship through a valve. By definition, C_v is the number of gallons per minute of 60°F water which will pass through a valve with a fixed pressure drop of 1 psi.

The valve manufacturer supplies the C_v value of the valve for various valve body types, sizes, trim characteristics, and valve positions. The C_v value stored in the valve catalog is a function of the valve travel at 5%, 10%, 20% and every subsequent 10% of rated travel up to and including 100%. CON-FLO performs a linear interpolation to determine the Cv values for positions between the increments found in the Valve Catalog.

F_P Piping Geometry Factor

The C_v values for valves are obtained experimentally by installing the valve in a straight run of pipe without any inlet or outlet reducers. Since many applications of valves do require reducers, the F_P factor takes into account the effects of the inlet and outlet reducers.

The F_P factor is defined as the ratio of the valve C_v installed with reducers to the rated C_v of the valve installed without reducers. The following equation can be used to determine F_P:

$$F_P = (((K_{SUM}\, C_v^2)/(N_2\, Dv^4))+1)^{-½}$$

equation 2

N_2 = conversion coefficient
Dv = nominal valve diameter

$$K_{SUM} = K_1 + K_2 + K_{B1} - K_{B2}$$

equation 3

K_1 = inlet reducer resistance coefficient
K_2 = outlet reducer resistance coefficient
K_{B1} = inlet Bernoulli coefficient
K_{B2} = outlet Bernoulli coefficient

CON-FLO calculates the values of the coefficients with the following equations as found in the standard:

$$K_1 = 0.5\,(1 - (D_V^2/D_1^2))^2$$

equation 4A

$$K_2 = 1.0\,(1 - (D_V^2/D_2^2))^2$$

equation 4B

$$K_{B1} = 1 - (D_V/D_1)^4$$

equation 4C

$K_{B2} = 1 - (D_V/D_2)^4$

equation 4D

D = nominal pipe diameter

D_V = nominal valve diameter

1 = inlet

2 = outlet

CON-FLO also performs the Fp calculations during valve selection. The Fp factor is incorporated into the search value of C_v. This insures that the valve is selected based upon the installed piping arrangement. If CON-FLO is evaluating a valve that requires reducers, the following compensation is made to the "search" value for C_v:

C_v (search) = C_v (full size)/ Fp

If the flow through the valve is in the laminar and transition range, the standard states that pipe reducers are not to be installed around the valve. The value of F_P is therefore not factored into the sizing equation for the laminar and transition ranges. During sizing calculations, CON-FLO performs a turbulent flow check. If the flow is found to be in the laminar or transitional range, the program does not consider reduced size valves as a valid option.

Non-Turbulent Flow

If the flow through the valve is non-turbulent (due to a high fluid viscosity or low flow rate) a correction factor is added to the sizing equation to correct for the non-turbulent conditions. For fully turbulent flow, the correction factor (F_R) is assumed to be 1. For flow in the laminar range, the C_v value can be calculated directly, eliminating the need to calculate the value of F_R. When the flow is in the transition range, the F_R value is calculated and used in the general sizing equation (equation 1).

Non-turbulent Flow and Valves with Close-coupled Reducers

The standard used by CON-FLO, ANSI/ISA-S75.01-1985 (R 1995) *Flow Equations for Sizing Control Valves*, states that for non-turbulent flow conditions, the effect of close-coupled reducers is not known. Thus, when the specified design condition is in the non-turbulent region, CON-FLO does not allow the selection of valve sizes which are smaller than the pipeline size.

The correction factors for laminar and transitional flow are described below:

Laminar Flow

The C_v calculation for the laminar flow range is as follows:

$$C_v = (1/F_S)(w\mu / N_S \rho dP)^{2/3}$$

equation 5

N_S = conversion coefficient
F_S = laminar flow factor, dimensionless
w = mass flow rate
µ = fluid viscosity (absolute)
ρ = fluid density

The value of F_S is determined by manufacturer testing and is stored in the valve catalog. Note that for each valve body type, CON-FLO uses the same value of F_S for flow to open, flow to close, and full and reduced seated trims.

Transitional Flow

When the flow is in the transitional range, the value of F_R varies depending on what type of calculation is being done.

In valve sizing calculations, the following formula is used for F_R:

$$F_R = 1.044 - 0.358 (C_{vs}/C_{vt})^{0.655}$$

equation 6

C_{vs} = the C_v value for laminar flow (equation 5)
C_{vt} = the C_v value for fully developed turbulent flow (equation 1, without F_P)

When calculating the flow rate, the following formula is used for F_R:

$$F_R = 1.004 - 0.358\,(w_t/w_s)^{0.588}$$

equation 7

w_s = the mass flow rate for laminar flow (equation 5)
w_t = the mass flow for fully developed turbulent flow (equation 1)

Once F_R is calculated using either equation 6 or equation 7 above, it is inserted into the general sizing equation (equation 1). If the F_R value calculated is less than 0.48, the flow through the valve is laminar and equation 5 is used in all sizing calculations. When F_R is greater than 0.98, the flow is considered turbulent and equation 1 is used with F_R set equal to 1.

CON-FLO displays a laminar line on the Flow vs dP Graph Window whenever the flow through a valve is non-turbulent.

Choked Flow Conditions

As the inlet pressure to the valve is held constant and the outlet pressure is decreased, the flow rate through the valve will increase. This is true until the static pressure at the vena contracta (the point of lowest pressure in the valve) falls below the vapor pressure of the fluid. The maximum pressure drop and flow rate for the valve have been reached and choked flow occurs, resulting in either cavitation or flashing. If the outlet pressure is greater than the vapor pressure of the liquid, cavitation occurs. If the outlet pressure is equal to or less than the vapor pressure of the liquid, flashing occurs.

The calculation of the choked flow and pressure conditions are as follows:

$$Q_{MAX} = N_6\, F_{LP}\, C_v\, (\,(P_1 - P_{vc})\,\rho)^{1/2}$$

equation 8

N_6 = conversion coefficient
Q_{MAX} = maximum mass flow rate
P_{vc} = absolute pressure at vena contracta
F_{LP} = liquid pressure recovery factor with reducers installed, dimensionless

The value of Pvc can be calculated from the following formula:

$P_{vc} = F_F\, P_v$

equation 9

F_F = liquid critical pressure ratio factor, dimensionless
P_v = vapor pressure at inlet temperature

The value of Q_{MAX} is displayed on the Flow vs dP and %Open vs Flow Graph Windows when choked flow conditions occur in the specified flow rate range.

F_L Liquid Pressure Recovery Factor

The liquid pressure recovery factor, F_L, is a measure of the valve's ability to convert the kinetic energy of the fluid at the vena contracta back into pressure. The internal geometry of the valve determines the value of F_L. It is a function of the direction of flow through the valve, the valve position, and whether the valve has a full or reduced seated trim.

The values of F_L used in CON-FLO are supplied in the manufacturer's catalog. F_L values are stored for each valve at 10% or 10° increments of valve position. If a manufacturer does not provide F_L values for a valve, CON-FLO does not consider that valve when a non-compressible fluid is specified.

If reducers are installed around the valve, their effects are factored into the value of F_L. A new factor, called F_{LP}, is calculated and used in the valve sizing equation for non-compressible fluids with reducers. F_{LP} is calculated as follows:

$F_{LP} = F_L\, [(F_L{}^2\, (K_1 + K_{B1})/N_2)(C_v{}^2/\, Dv^2)^2 + 1]^{-½}$

equation 10

N_2 = conversion coefficient

F_F Liquid Critical Pressure Ratio Factor

The liquid critical pressure ratio factor, F_F, is the ratio of the apparent vena contracta pressure of the liquid under choked flow conditions to the vapor pressure of the liquid at the inlet temperature. CON-FLO uses the following equation (as found in the standard) to calculate the value of F_F used in the choked flow equations:

$$F_F = 0.96 - 0.28\,(P_v/P_c)^{1/2}$$

equation 11

P_c = critical pressure of the liquid
P_v = vapor pressure of the liquid

The above equation is based on the assumption that the fluid is always in thermodynamic equilibrium. Because this is usually not the case for a liquid as it flashes across a valve, the flow rate predicted using equation 11 will be less than the actual flow rate.

Sizing Valves for Compressible Service

The equations for the flow of a gas or vapor through a valve as described by the standard and used in CON-FLO are as follows:

$$w = N_6\, F_P\, C_v\, Y\, (X\, P_1\, \rho)^{1/2}$$

equation 12

N_6 = conversion coefficients
w = mass flow rate
X = ratio of pressure drop to absolute inlet static pressure dP/P_1, dimensionless
Y = expansion factor, dimensionless
ρ = density of the fluid, mass per unit volume

The piping geometry factor (F_P) is identical to the one used in the calculations for non-compressible fluids. The Reynolds factor (F_R) is not used in the gas sizing equation because for a gas it can be assumed that the flow through a valve is always turbulent. The values of Y and X are unique to the gas sizing equation and are explained below.

Y Expansion Factor

The expansion factor (Y) accounts for the change in the fluid density as it passes from the valve inlet to the vena contracta. The value of Y is affected by the following factors:

1 Ratio of the valve trim area to the inlet area

2 Shape of the flow path

3 Pressure drop ratio (X)

4 Ratio of specific heats (k) of the fluid.

The effect of items 1, 2, and 3 are accounted for in the pressure drop ratio factor, x_T. The value of x_T is determined experimentally for each valve. x_T factors are supplied in the manufacturer's catalog.

The effect of item 4 is accounted for by using the ratio of specific heat factor, F_k.

The calculated value of Y is determined by the following equation:

$$Y = 1 - X/(3\,F_k\,x_T)$$

equation 13

(limits $0.67 \leq Y \leq 1.0$)

F_k = ratio of specific heat factor, dimensionless
X = ratio of pressure drop to absolute inlet static pressure dP/P_1, dimensionless
x_T = pressure drop ratio factor, dimensionless

Ratio of Pressure Drop to Inlet Pressure (X)

The value of X is the ratio of the differential pressure to the inlet static pressure. X is defined in the standard as follows:

$$X = (P_1 - P_2)/P_1$$

equation 14

(limit $X = x_T F_k$)

As the differential pressure increases and the inlet pressure is held constant, the value of X increases. This results in a higher mass flow rate through the valve. The value of X continues to increase until it equals $x_T F_k$. This corresponds to a minimum value of 0.67 for Y. When this condition occurs, the flow through the valve is sonic. Once sonic flow is achieved, the reduction of outlet pressure has no further effect on the mass flow rate through the valve.

The CON-FLO program checks for sonic or choked flow and indicates when these conditions exist.

F_k Ratio of Specific Heats Factor

The flow rate through a valve is affected by the ratio of specific heats for the compressible fluid. The factor F_k accounts for this effect. The standard uses the following formula to determine F_k.

$$F_k = k / 1.40$$

equation 15

k = ratio of specific heats

The ratio of specific heats (k) can be found in fluid tables for most common gases.

Rated Pressure Drop Ratio Factor (x_T)

The value of x_T is determined experimentally and supplied by the valve manufacturer. x_T values are stored for each valve at 10% or 10° increments of valve position. If a manufacturer does not provide x_T values for a valve, CON-FLO does not consider that valve when a compressible fluid is specified.

If there is a reducer on the valve inlet, its effect must be factored into x_T, resulting in a new factor designated as x_{TP}. The value of x_{TP} is calculated in CON-FLO by the following equation:

$$x_{TP} = (x_T / F_P^2)[(x_T K_{IN} C_v^2/(N_5 Dv^4)) + 1]^{-1}$$

equation 16

N_5 = conversion coefficient
$K_{IN} = (K_1 + K_{B1})$

References

1 American National Standard Institute, Instrument Society of America Standard, Flow Equations for Sizing Control Valves, ANSI/ISA-75.01-1985 (R 1995), sponsor Instrument Society of America, Research Triangle, 1995.

2 Les Driskell, “Control-Valve Selection and Sizing,” first edition, Instrument Society of America, Research Triangle, 1983.

3 J.W. Hutchison, “ISA Handbook of Control Valves,” second edition, Instrument Society of America, 1976.

4 Crane, Crane Technical Paper 410, “Flow of Fluids through Valves, Fittings, and Pipe” twenty-fifth printing, Crane Company 1988.

5 Vennard, “Elementary Fluid Mechanics” fourth edition, John Wiley & Sons Inc., New York, 1961.