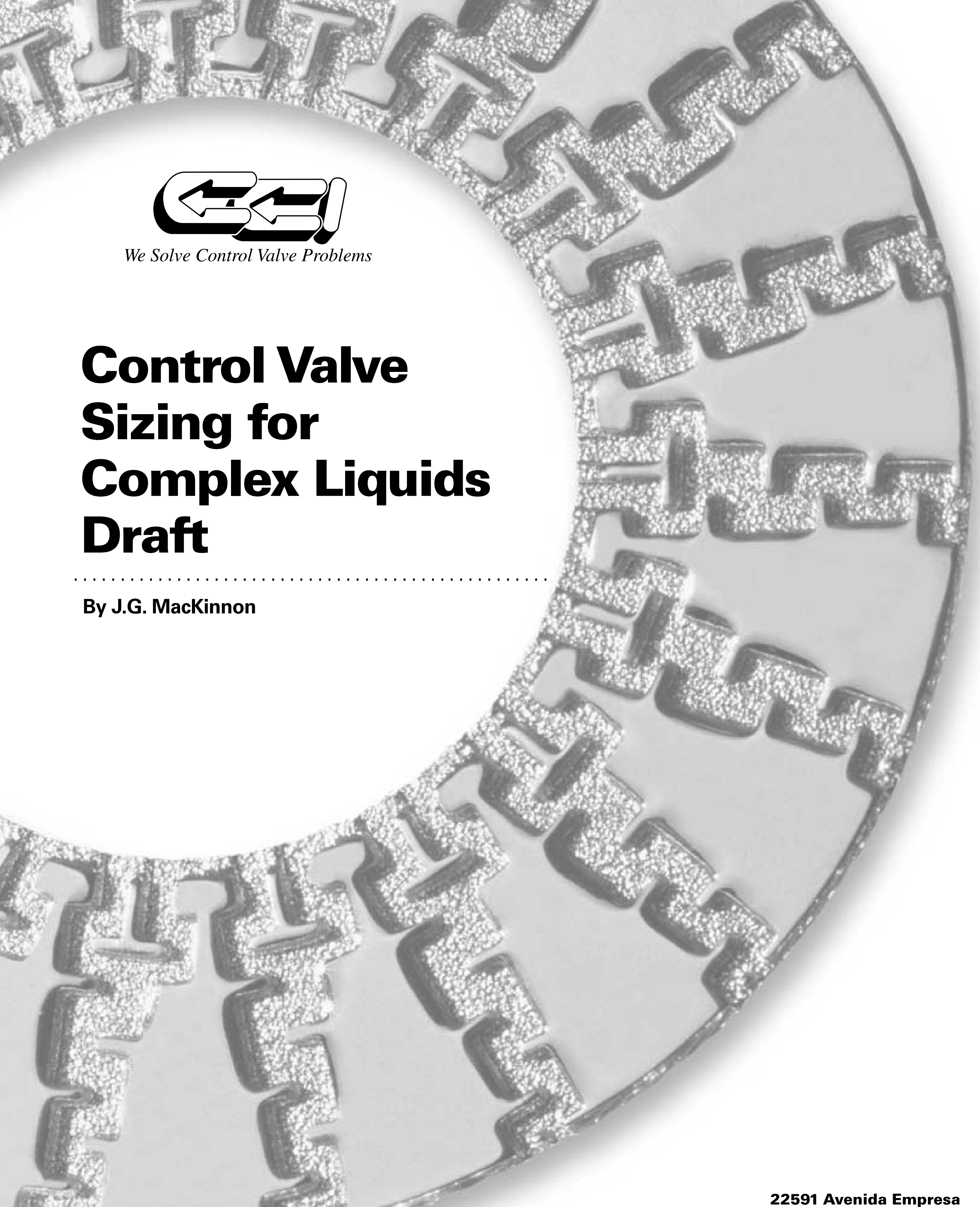

We Solve Control Valve Problems

Control Valve Sizing for Complex Liquids Draft

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Control Valve Sizing for Complex Liquids Draft

■ **By J. Gary MacKinnon,** Manager of Engineering Standards

Abstract

A method is derived for determining the required control valve capacity useful for complex fluids including gas-liquid mixtures and multiconstituent flashing liquids. The method agrees well enough with existing ISA sizing standards for the simple fluids such as non-flashing liquids, flashing liquids and gases to provide confidence in its use with the more complex fluids.

Introduction

The Instrument Society of America publishes standard S75.01 entitled "Control Valve Sizing Equations". This standard outlines the method of sizing control valves for flashing liquids, non-flashing liquids and gases which account for the vast majority of fluids encountered in industrial applications. Occasionally, valve sizing is required for fluids that differ from those covered by the standard such as a gas liquid mixture and multiconstituent liquids whose constituents flash at various pressures. The Standard is not applicable to these fluids because the behavior of the fluid density as the pressure drops through the valve does not fit the fluid models which form the basis of the standard. For liquids, the density is assumed constant and for gases the density is assumed to vary according to the laws governing ideal gases. But for complex fluids the relation between pressure and density forms no pattern and can vary widely from fluid to fluid. In addition, the problem is complicated by slip between the phases and thermal non-equilibrium. It is not surprising that a general solution has not been found.

This paper outlines a method of sizing control valves handling complex fluids using a set of apparently overly restrictive assumptions. Yet, when the results are compared to the present ISA equations where these assumptions are not present, good agreement is found.

The ISA equation for Liquid Sizing is

$$w = N_{10} F_p F_y C_v \sqrt{(P_1 - P_2)\gamma_f} \quad (1)$$

The liquid is assumed to be non-choking and that Reynolds number effects and piping geometry effects are neglibible. Finally for the sake of later comparisons to the ISA gas and liquid equations, the specific gravity term is converted to density which results in equation 2.

$$w = NC_v \sqrt{(P_1 - P_2)\ \gamma 1} \quad (2)$$

The sizing equation we seek is of the form of equation 3.

$$w = NYC_v \sqrt{(P_1 - P_2)\gamma 1} \quad (3)$$

Where Y is an expansion factor which accounts for the density change through the valve.

Squaring equation 2 and taking the limit as P2 approaches P1 results in equation 4.

$$dw^2 = N^2 C_v^2 \gamma 1\, dP \quad (4)$$

Allowing γ to vary with P and integrating leads to eqution 5.

$$w = NC_v \left[\int_{P_2}^{P_1} \gamma dP\right]^{1/2} \quad (5)$$

Equating equations 3 and 5 yield equation 6.

$$Y = \left[1/(P_1 - P_2) \int_{P_2}^{P_1} (\gamma / \gamma_1) dP\right]^{1/2} \quad (6)$$

Generally, γ is not available as an analytical function of pressure so this integral format is not very useful. Of more use is a conversion of this expression to a summation based on knowing several (n) discrete values of density and pressure. Equation 7 is the solution of equation 6 assuming the pressure-density relationship is linear between selected points.

$$Y = \left[\sum_{i=1}^{n-1} \frac{\gamma_i + \gamma_{i+1}}{2\gamma_1} \frac{P_i - P_{i+1}}{P_1 - P_n}\right]^{1/2} \quad (7)$$

Comparison To Standard S75.01

For example, if only the starting and ending density are known, it is reasonable to assume without any other information that the change in density is linear with pressure from inlet to outlet. In that case, equation 7 reduces to equation 8.

$$Y = \sqrt{\frac{\gamma_1 + \gamma_2}{2\gamma 1}} \quad (8)$$

If the fluid is a liquid, then the density does not change and equation 8 reduces to the expression

$$Y = 1 \quad (9)$$

As would be expected.

For ideal gases, the density is proportional to pressure which agrees with the linearity assumption in deriving equation 8. In addition, this proportionality allows the following alternate of equation 8 which applies to ideal gases.

$$Y = \sqrt{\frac{(P_1 + P_2)}{2P_1}} \quad (10)$$

Introducing the pressure drop ratio, x, defined as

$$x = \sqrt{\frac{(P_1 - P_2)}{2P_1}} \quad (11)$$

And substituting this into equaiton 10 yields

$$Y = \sqrt{1 - x/2} \qquad (12)$$

This equation can be directly compared with the ISA equation for gas expansion factor, repeated here.

$$Y = 1 - (x/3x_t)(1.4/k) \quad [ISAMethod] \qquad (13)$$

The two methods of calculating Y are compared in Figure 1 for value of X_t of .75 which is typcial for many plug valves and a value of 1.0 which is typical for controlled velocity valves.

Note that the present formula agrees very well with a controlled velocity type valve. This is to be expected since flow through a controlled velocity valve is nearly isenthalpic.

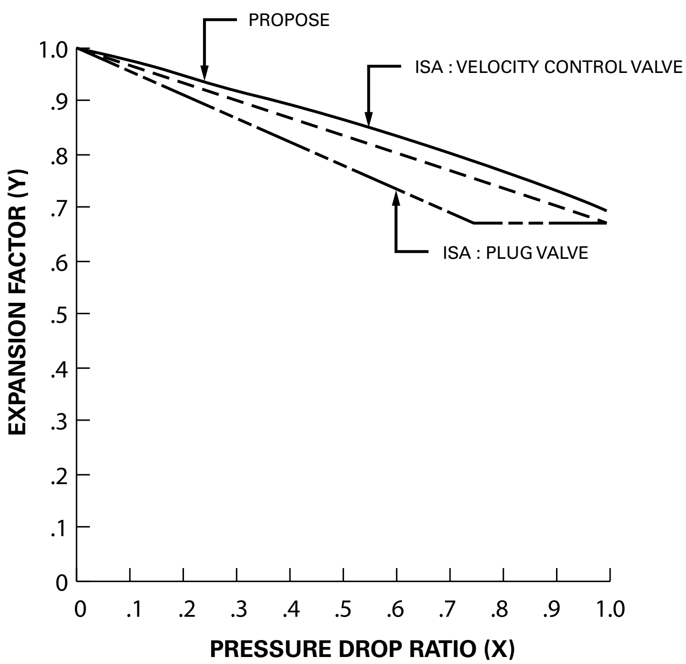

Figure 1—Proposed Sizing Method vs. ISA Methods for Gases

Finally, equation 6 is compared to the ISA equations for sizing of flashing liquids. Flashing liquids, especially those of low vapor pressures represent the opposite end of the spectrum from liquids. These fluids have the greateset variation in density from the inlet to outlet of the valve. To make the comparison, an expression for the expansion factor Y must be derived for the flashing liquids using the ISA equations. Recognizing that Y is simply the ratio of the flow rate of an expanding fluid to that of a non-flashing liquid under the same pressure and inlet density conditions equation, 14 is derived.

$$Y = \sqrt{(P_1 - P_0)/(P_1 - P_2)} \qquad (14)$$

Where:

$$P_O = F_f P_V \text{ if } P_2 < F_f P_V$$

$$P_O = P_2 \quad \text{if } P_2 \geq F_f P_V$$

Values for equation 14 were calculated for water assuming a saturated inlet condition. Two sets of comparisons were made, one with inlet pressure chosen at 30% of the critical pressure and one at 3%. These are illustrated in Figures 2 and 3 respectively.

Note that there is fairly good agreement between the curves except under the conditions that the outlet pressure is close to the vapor pressure. However, this discrepancy is perhaps due more to the ISA sizing rules which do not recognize a flow reduction due to incipient choking and instead identify a discrete choking point at $F_f P_V$.

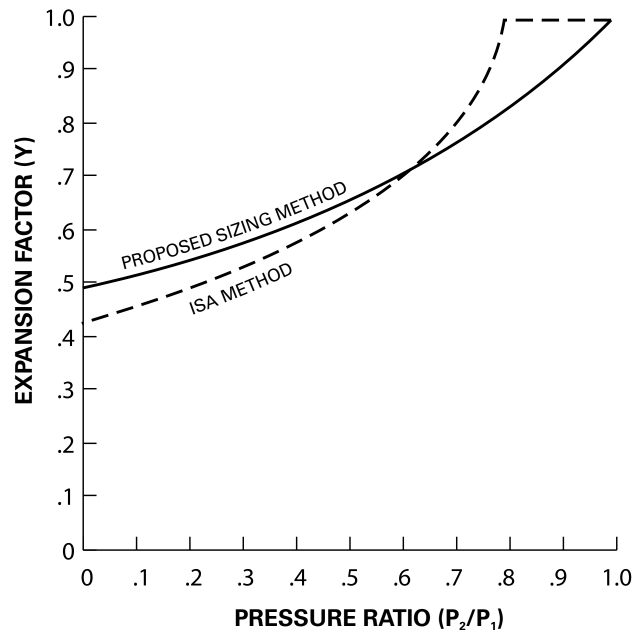

Figure 2—Proposed Sizing Method vs. ISA Method for Flashing Water (P_V/P_C = 0.3)

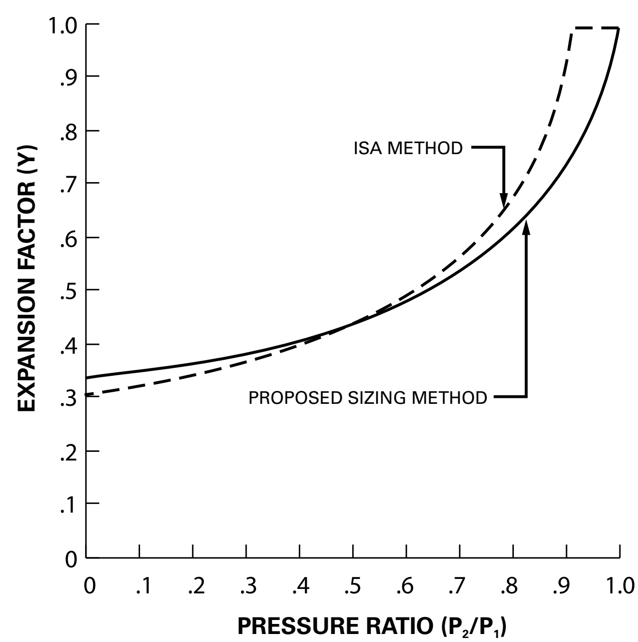

Figure 3—Proposed Sizing Method vs. ISA Method for Flashing Water (P_V/P_C = 0.03)

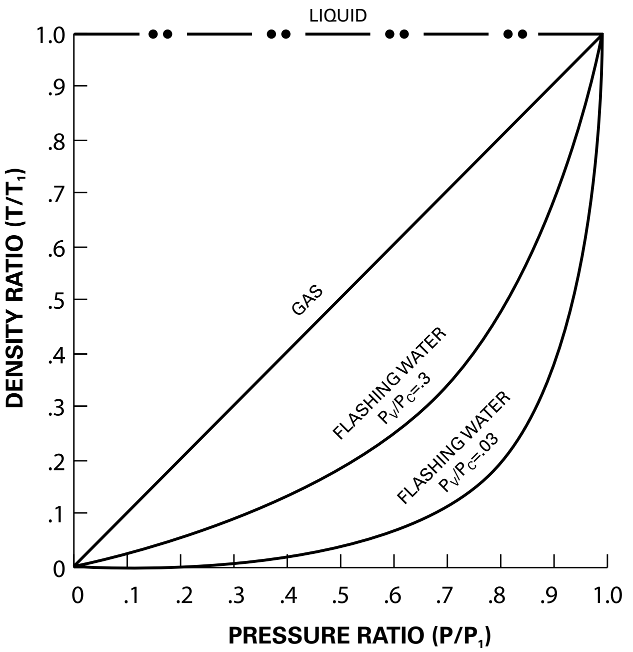

Figure 4—Density vs. Pressure For Fluid Curves

Figure 4 illustrates the normalized pressure density relationship for the four fluids which were used in the comparisons. Note the wide range of curves in which fairly good agreement between the proposed sizing method and the ISA method is achieved. Complex fluids involving gas-liquid mixtures, two phase inlet conditions and multiconsituent flashing fluids will in nearly all cases fall within the extremes of these fluids used in the comparisons.

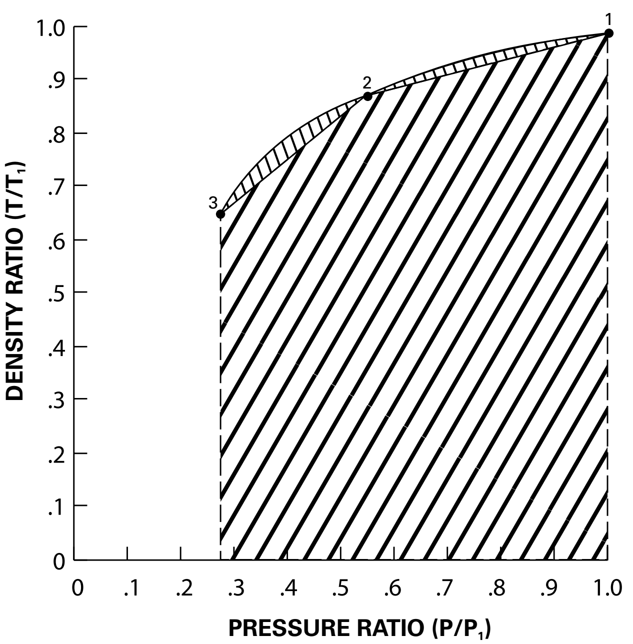

Figure 4—Error Caused by Using Discrete Pressure vs. Density Points

An intuitive feel for the value of the expansion factor Y can be achieved by recognizing that its value is equal to the square root of the area under the curves of Figure 4. This understanding helps indentify the number of discrete points along the pressure-density curve to use equation 7 with minimal error. The error is related to the proportion of the area that is added or subtracted from the exact pressure-density integral by connecting the chosen points with the straight lines. See Figure 5.

Conclusion

A simple method of sizing control valves, flowing complex liquids, utilizing the basic format of the ISA standard equations has been proposed. The method uses the expansion factor Y to account for the variation in density from inlet to outlet. Y can be calculated using a simple summation formula once a relationship between pressure and density is determined. Comparisons between the proposed sizing method and existing sizing methods for non-flashing and flashing liquids and for gases indicates that the assumptions used in driving the sizing method are not overly restrictive. These comparisions give reasonable assurance that the method will work for complex fluids with arbitrary density-pressure relationships.

References

(1) Control Valve Sizing Equations, ANSI/ISA –S75.01, 1977.

Nonmenclature

C_V	Valve sizing coefficient
F_f	Liquid critical pressure ratio factor
F_p	Piping geometry factor
F_y	Liquid choked flow factor
G_f	Specific gravity
k	Ratio of specific heats
N	Numerical constant
N_{10}	Numerical constant
n	Number of discrete points selected on the pressure-density curve
P_1	Inlet pressure
P_2	Outlet pressure
P_O	Effective outlet pressure
P_V	Vapor pressure
w	Mass flow rate
x	Pressure drop ratio
X_t	Rated pressure drop ratio
Y	Expansion factor
γ	Density
γ_1	Inlet density