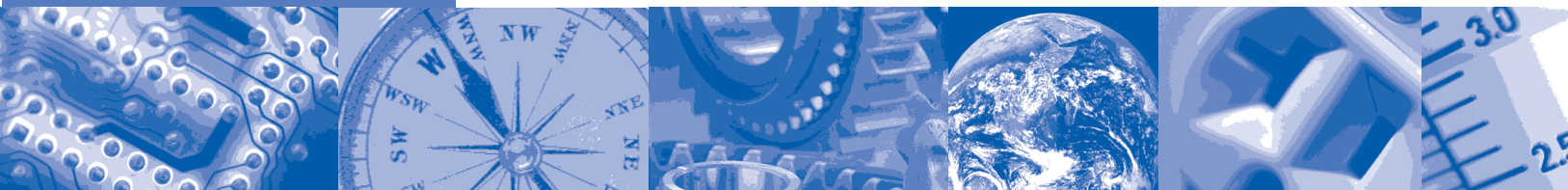


ANSI/ISA-75.01-1985 (R1995)

Formerly ANSI/ISA-S75.01-1985 (R1995)



Flow Equations for Sizing Control Valves



ISA—The Instrumentation,
Systems, and
Automation Society

Reaffirmed 18 October 1995



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ANSI/ISA-75.01-1985 (R1995), Flow Equations for Sizing Control Valves

ISBN 0-87664-899-5

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1 Scope

This standard presents equations for predicting the flow of compressible and incompressible fluids through control valves. The equations are not intended for use when mixed-phase fluids, dense slurries, dry solids, or non-Newtonian liquids are encountered. In addition, the prediction of cavitation, noise, or other effects is not a part of this standard.

2 Introduction

The equations of this standard are based on the use of experimentally determined capacity factors obtained by testing control valve specimens according to the procedures of ANSI/ISA S75.02, "Control Valve Capacity Test Procedure" ([see Annex J—References](#)).

The equations are used to predict the flow rate of a fluid through a valve when all the factors, including those related to the fluid and its flowing condition, are known. When the equations are used to select a valve size, it is often necessary to use capacity factors associated with the fully open or rated condition to predict an approximate required valve flow coefficient (C_v). This procedure is further explained in [Annex A](#).

2.1 Flow variable and fluid properties

The flow rate of a fluid through a control valve is a function of the following (where applicable):

- a) Inlet and outlet conditions
 - 1) Pressure
 - 2) Temperature
 - 3) Piping geometry
- b) Liquid properties
 - 1) Composition
 - 2) Density
 - 3) Vapor pressure
 - 4) Viscosity
 - 5) Surface tension
 - 6) Thermodynamic critical pressure
- c) Gas and vapor properties
 - 1) Composition
 - 2) Density
 - 3) Ratio of specific heats
- d) Control valve properties
 - 1) Size
 - 2) Valve travel
 - 3) Flow path geometry

3 Nomenclature

Symbol	Description
C_v	Valve flow coefficient
d	Valve inlet diameter
D	Internal diameter of the pipe
F_d	Valve style modifier
F_F	Liquid critical pressure ratio factor, dimensionless
F_k	Ratio of specific heats factor, dimensionless
F_L	Liquid pressure recovery factor of a valve without attached fittings, dimensionless
F_{LP}	Product of the liquid pressure recovery factor of a valve with attached fittings (no symbol has been identified) and the piping geometry factor, dimensionless
F_P	Piping geometry factor, dimensionless
F_R	Reynolds number factor, dimensionless
F_s	Laminar, or streamline, flow factor, dimensionless
g	Local acceleration of gravity
G_f	Liquid specific gravity at upstream conditions [ratio of density of liquid at flowing temperature to density of water at 60°F (15.6°C)], dimensionless
G_g	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions, which is equal to the ratio of the molecular weight of gas to the molecular weight of air), dimensionless
k	Ratio of specific heats, dimensionless
K	Head loss coefficient of a device, dimensionless
K_B	Bernoulli coefficient, dimensionless
K_i	Velocity head factors for an inlet fitting, dimensionless
M	Molecular weight, atomic mass units
$N_1, N_2, \text{etc.}$	Numerical constants for units of measurement used
p_1	Upstream absolute static pressure, measured two nominal pipe diameters upstream of valve-fitting assembly
p_2	Downstream absolute static pressure, measured six nominal pipe diameters downstream of valve-fitting assembly
Δp	Pressure differential, $p_1 - p_2$
p_c	Absolute thermodynamic critical pressure
p_r	Reduced pressure, dimensionless
p_v	Absolute vapor pressure of liquid at inlet temperature
p_{vc}	Apparent absolute pressure at vena contracta
q	Volumetric flow rate
q_{max}	Maximum flow rate (choked flow conditions) at a given upstream condition

Symbol	Description
Re_v	Valve Reynolds number, dimensionless
T_r	Reduced temperature, dimensionless
T_c	Absolute thermodynamic critical temperature
T_1	Absolute upstream temperature (in degrees K or R)
U_1	Velocity at valve inlet
w	Weight or mass flow rate
x	Ratio of pressure drop to absolute inlet pressure ($\Delta p/p_1$), dimensionless
x_T	Pressure drop ratio factor, dimensionless
x_{TP}	Value of x_T for valve-fitting assembly, dimensionless
Y	Expansion factor, ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number, dimensionless
Z	Compressibility factor, dimensionless
γ_1 (gamma)	Specific weight, upstream conditions
μ (mu)	Viscosity, absolute
ν (nu)	Kinematic viscosity, centistokes
ρ (rho)	Density
Subscripts	
1	Upstream conditions
2	Downstream conditions
s	Nonturbulent
t	Turbulent

4 Incompressible fluid — flow of nonvaporizing liquid

The flow rate of a liquid through a given control valve at a given travel is a function of the differential pressure ($p_1 - p_2$) when the liquid does not partially vaporize between the inlet and outlet of the valve. If vapor bubbles form either temporarily (cavitation) or permanently (flashing), this relationship may no longer hold. (Refer to [Section 5](#) for choked flow equations that apply when extensive vaporization occurs.) In the transitional region between nonvaporizing liquid flow and fully choked flow, the actual flow rate is less than that predicted by either the equations in this section or those in [Section 5](#). Cavitation that occurs in this transitional region can produce physical damage to the valve and/or to the downstream piping and equipment.

4.1 Equations for turbulent flow

The equations for determining the flow rate of a liquid through a valve under turbulent, nonvaporizing flow conditions are:

$$\begin{aligned}
 & q = N_1 F_p C_v \sqrt{\frac{p_1 - p_2}{G_f}} \\
 \text{or} \quad & C_v = \frac{q}{N_1 F_p \sqrt{p_1 - p_2}}
 \end{aligned}
 \quad \left. \vphantom{\begin{aligned} q = N_1 F_p C_v \sqrt{\frac{p_1 - p_2}{G_f}} \\ C_v = \frac{q}{N_1 F_p \sqrt{p_1 - p_2}} \end{aligned}} \right\} \text{(Eq. 1)}$$

$$\begin{aligned}
 & w = N_6 F_p C_v \sqrt{(p_1 - p_2) \gamma_1} \\
 \text{or} \quad & C_v = \frac{w}{N_6 F_p \sqrt{(p_1 - p_2) \gamma_1}}
 \end{aligned}
 \quad \left. \vphantom{\begin{aligned} w = N_6 F_p C_v \sqrt{(p_1 - p_2) \gamma_1} \\ C_v = \frac{w}{N_6 F_p \sqrt{(p_1 - p_2) \gamma_1}} \end{aligned}} \right\} \text{(Eq. 2)}$$

4.2 Numerical constants N

The numerical constants N are chosen to suit the measurement units used in the equations. Values for N are listed in [Table 1](#).

Table 1 — Numerical constants for liquid flow equations

Constant		Units Used in Equations					
N		w	q	$p, \Delta p$	d, D	γ_1	v
N_1	0.0865	—	m ³ /h	kPa	—	—	—
	0.865	—	m ³ /h	bar	—	—	—
	1.00	—	gpm	psia	—	—	—
N_2	0.00214	—	—	—	mm	—	—
	890	—	—	—	in	—	—
N_4	76 000	—	m ³ /h	—	mm	—	centistokes*
	17 300	—	gpm	—	in	—	centistokes*
N_6	2.73	kg/h	—	kPa	—	kg/m ³	—
	27.3	kg/h	—	bar	—	kg/m ³	—
	63.3	lb/h	—	psia	—	lb/ft ³	—

*To convert m²/s to centistokes, multiply m²/s by 10⁶. To convert centipoises to centistokes, divide centipoises by G_f .

4.3 Piping geometry factor F_p

The piping geometry factor F_p accounts for fittings attached to either the valve inlet or the outlet that disturb the flow to the extent that valve capacity is affected. F_p is actually the ratio of the flow coefficient of a valve with attached fittings to the flow coefficient (C_v) of a valve installed in a straight pipe of the same size as the valve.

For maximum accuracy, F_p must be determined by the test procedures specified in ANSI/ISA S75.02 (see [Annex J—References](#)). Where estimated values are permissible (see Baumann reference, *Effect of Pipe Reducers on Control Valve Capacity*), F_p may be determined by using the following equation:

$$F_p = \left(\frac{\Sigma K C_v^2}{N_2 d^4} + 1 \right)^{-1/2} \quad (\text{Eq. 3})$$

(See [Annex B](#) for the mathematical derivation of F_p .)

In many instances, the nominal sizes for valve and pipe (d and D) may be used in Equations 3, 5, 6, and 7 without significant error.

The factor ΣK is the algebraic sum of the effective velocity head coefficients of all fittings attached to but not including the valve. For instance,

$$\Sigma K = K_1 + K_2 + K_{B1} - K_{B2} \quad (\text{Eq. 4})$$

where K_1 and K_2 are the resistance coefficients of the inlet and outlet fittings, respectively, and K_{B1} and K_{B2} are the Bernoulli coefficients for the inlet and outlet fittings, respectively. The Bernoulli coefficients compensate for the changes in pressure resulting from differences in stream area and velocity.

When the diameters of the inlet and outlet fittings are identical, $K_{B1} = K_{B2}$, both factors drop out of the equation. When the diameters of the inlet and outlet fittings are different, K_B is calculated as follows:

$$K_B = 1 - \left(\frac{d}{D} \right)^4 \quad (\text{Eq. 5})$$

The fittings most commonly encountered are standard, short-pattern concentric pipe reducers. These fittings have little taper, and their pressure loss will not exceed that of an abrupt contraction with a slightly rounded entrance. On that basis, if experimental values for the resistance coefficients K_1 and K_2 are unavailable, estimated values may be computed as follows:

Inlet reducer only:

$$K_1 = 0.5 \left(1 - \frac{d^2}{D_1^2} \right)^2 \quad (\text{Eq. 6})$$

Outlet increaser only:

$$K_2 = 1.0 \left(1 - \frac{d^2}{D_2^2} \right)^2 \quad (\text{Eq. 7})$$

When the reducer and increaser are the same size:

$$K_1 + K_2 = 1.5 \left(1 - \frac{d^2}{D^2} \right)^2 \quad (\text{Eq. 8})$$

(See Annex C for a graphic representation of system head changes around a valve with attached reducers.)

4.4 Equations for nonturbulent flow

Nonturbulent flow occurs at high fluid viscosities and/or low velocities. In these circumstances, the flow rate through a valve is less than for turbulent flow, and the Reynolds number factor F_R must be introduced. F_R is the ratio of nonturbulent flow rate to the turbulent flow rate predicted by Equations 1 or 2. The corresponding nonturbulent equations then become, respectively:

$$\begin{aligned} \text{or} \quad q &= N_1 F_R C_v \sqrt{\frac{p_1 - p_2}{G_f}} \\ C_v &= \frac{q}{N_1 F_R \sqrt{\frac{G_f}{p_1 - p_2}}} \end{aligned} \quad \left. \vphantom{\begin{aligned} q &= N_1 F_R C_v \sqrt{\frac{p_1 - p_2}{G_f}} \\ C_v &= \frac{q}{N_1 F_R \sqrt{\frac{G_f}{p_1 - p_2}}} \end{aligned}} \right\} \quad (\text{Eq. 9})$$

$$\begin{aligned} \text{or} \quad w &= N_6 F_R C_v \sqrt{(p_1 - p_2) \gamma_1} \\ C_v &= \frac{w}{N_6 F_R \sqrt{(p_1 - p_2) \gamma_1}} \end{aligned} \quad \left. \vphantom{\begin{aligned} w &= N_6 F_R C_v \sqrt{(p_1 - p_2) \gamma_1} \\ C_v &= \frac{w}{N_6 F_R \sqrt{(p_1 - p_2) \gamma_1}} \end{aligned}} \right\} \quad (\text{Eq. 10})$$

Note the absence of the piping geometry factor in the above equations. For nonturbulent flow, the effect of close-coupled reducers or other flow-disturbing fittings is unknown. Thus, Equation 3 applies to turbulent flow only.

Tests (see Stiles reference, *Liquid Viscosity Effects on Control Valve Sizing*, and McCutcheon reference, *A Reynolds Number for Control Valves*) show that F_R can be found by using the valve Reynolds number and Figure 1. The shading around the central curve indicates the scatter of test data and the range of uncertainty of flow rate prediction in the nonturbulent regimes.

The valve Reynolds number is defined as:

$$\text{Re}_v = \frac{N_4 F_d q}{v F_L^{1/2} C_v^{1/2} \left(\frac{F_L^2 C_v^2}{N_2 d^4} + 1 \right)^{1/4}} \quad (\text{Eq. 11})$$

The valve style modifier F_d in Equation 11 correlates data from tests of several valve styles with different hydraulic radii, so that a single curve represents all the styles tested. (See Annex D for representative values of F_d .) Caution must be used in applying the curve in Figure 1 to valve styles for which F_d has not been established.