

Valve Sizing

Technical Bulletin

Scope

Valve size often is described by the nominal size of the end connections, but a more important measure is the flow that the valve can provide. And determining flow through a valve can be simple.

This technical bulletin shows how flow can be estimated well enough to select a valve size—easily, and without complicated calculations. Included are the principles of flow calculations, some basic formulas, and the effects of specific gravity and temperature. Also given are six simple graphs for estimating the flow of water or air through valves and other components and examples of how to use them.

Sizing Valves

The graphs cover most ordinary industrial applications—from the smallest metering valves to large ball valves, at system pressures up to 10 000 psig and 1000 bar.

The water formulas and graphs apply to ordinary liquids—and not to liquids that are boiling or flashing into vapors, to slurries (mixtures of solids and liquids), or to very viscous liquids.

The air formulas and graphs apply to gases that closely follow the ideal gas laws, in which pressure, temperature, and volume are proportional. They do not apply to gases or vapors that are near the pressure and temperature at which they liquefy, such as a cryogenic nitrogen or oxygen.

For convenience, the air flow graphs show gauge pressures, whereas the formulas use absolute pressure (gauge pressure plus one atmosphere). All the graphs are based on formulas adapted from ISA S75.01, Flow Equations for Sizing Control Valves.¹

Safe Product Selection

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Flow Calculation Principles

The principles of flow calculations are illustrated by the common orifice flow meter (Fig. 1). We need to know only the size and shape of the orifice, the diameter of the pipe, and the fluid density. With that information, we can calculate the flow rate for any value of pressure drop across the orifice (the difference between inlet and outlet pressures).

For a valve, we also need to know the pressure drop and the fluid density. But in addition to the dimensions of pipe diameter and orifice size, we need to know all the valve passage dimensions and all the changes in size and direction of flow through the valve.

However, rather than doing complex calculations, we use the valve flow coefficient, which combines the effects of all the flow restrictions in the valve into a single number (Fig. 2).

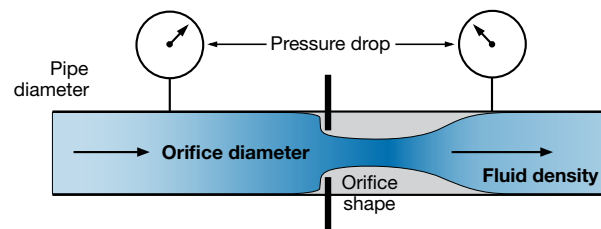


Fig. 1. The flow rate through a fixed orifice can be calculated from the meter dimensions of pipe diameter and orifice size and shape.

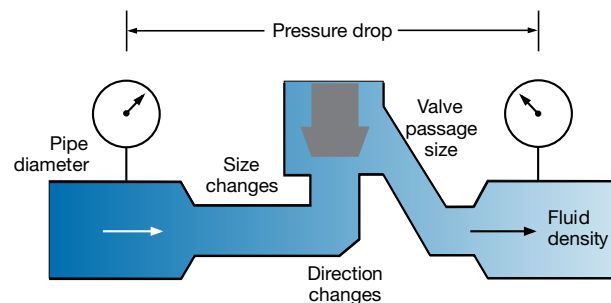
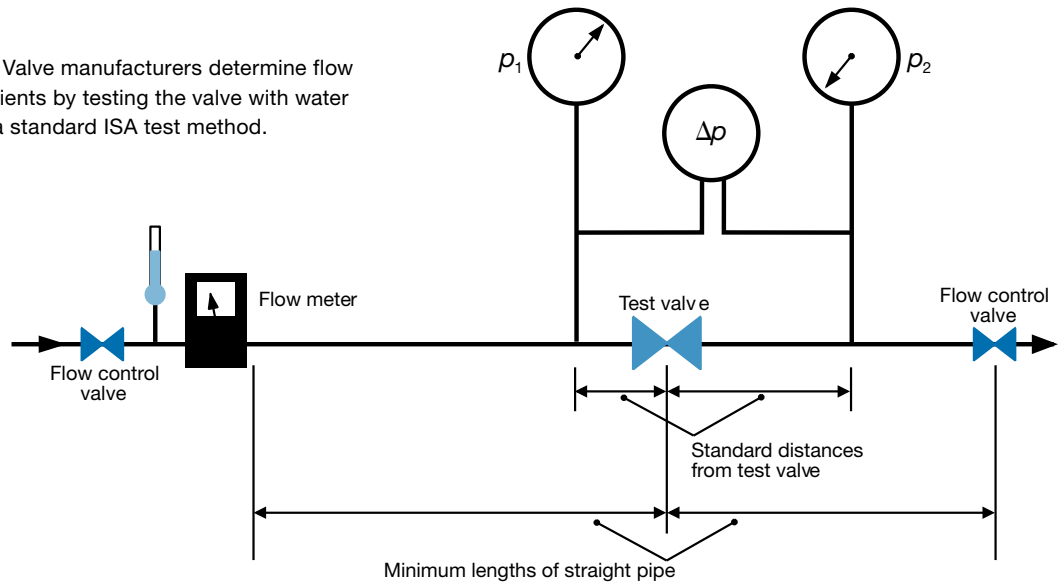


Fig. 2. Calculating the flow rate through a valve is much more complex. The valve flow coefficient (C_v) takes into account all the dimensions and other factors—including size and direction changes—that affect fluid flow.

Fig. 3. Valve manufacturers determine flow coefficients by testing the valve with water using a standard ISA test method.



Valve manufacturers determine the valve flow coefficient by testing the valve with water at several flow rates, using a standard test method² developed by the Instrument Society of America for control valves and now used widely for all valves.

Flow tests are done in a straight piping system of the same size as the valve, so that the effects of fittings and piping size changes are not included (Fig. 3).

Symbols Used in Flow Equations

C_v = flow coefficient

q = flow rate

p_1 = inlet pressure

p_2 = outlet pressure

Δp = pressure drop ($p_1 - p_2$)

G_f = liquid specific gravity (water = 1.0)

G_g = gas specific gravity (air = 1.0)

N_1, N_2 = constants for units

T_1 = absolute upstream temperature:

K = °C + 273

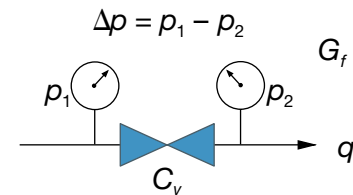
°R = °F + 460

Note: p_1 and p_2 are absolute pressures for gas flow.

Liquid Flow

Because liquids are incompressible fluids, their flow rate depends only on the difference between the inlet and outlet pressures (Δp , pressure drop). The flow is the same whether the system pressure is low or high, so long as the difference between the inlet and outlet pressures is the same. This equation shows the relationship:

$$q = N_1 C_v \sqrt{\frac{\Delta p}{G_f}}$$



The water flow graphs (pages 6 and 7) show water flow as a function of pressure drop for a range of C_v values.

Gas Flow

Gas flow calculations are slightly more complex, because gases are compressible fluids whose density changes with pressure. In addition, there are two conditions that must be considered—low pressure drop flow and high pressure drop flow.

Low and High Pressure Drop Gas Flow

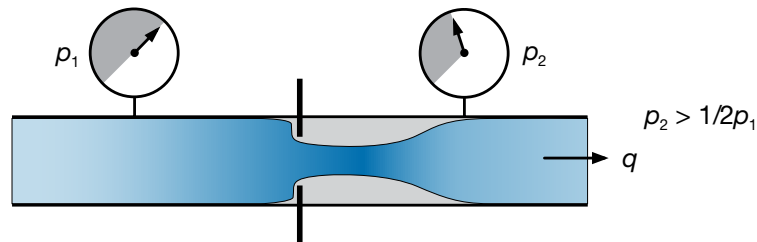
The basic orifice meter illustrates the difference between high and low pressure drop flow conditions.

In low pressure drop flow—when outlet pressure (p_2) is greater than half of inlet pressure (p_1)—outlet pressure restricts flow through the orifice: as outlet pressure decreases, flow increases, and so does the velocity of the gas leaving the orifice.

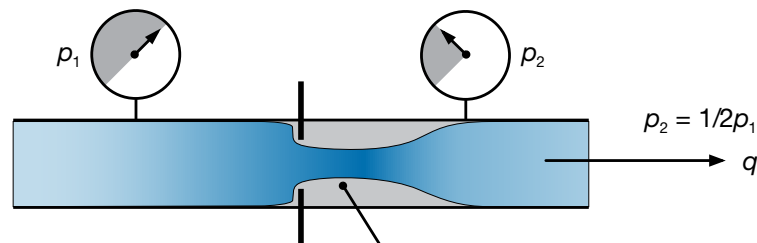
When outlet pressure decreases to half of inlet pressure, the gas leaves the orifice at the velocity of sound. The gas cannot exceed the velocity of sound and—therefore—this becomes the maximum flow rate. The maximum flow rate is also known as choked flow or critical flow.

Any further decrease in outlet pressure does not increase flow, even if the outlet pressure is reduced to zero. Consequently, high pressure drop flow only depends on inlet pressure and not outlet pressure.

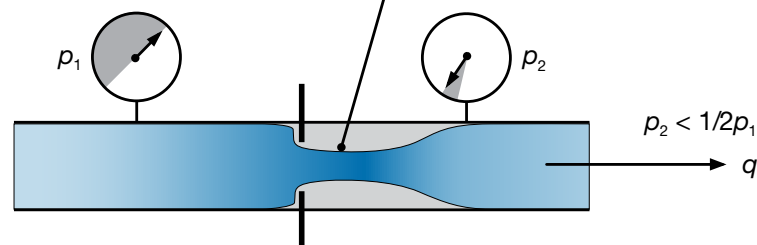
Low pressure drop



Maximum flow

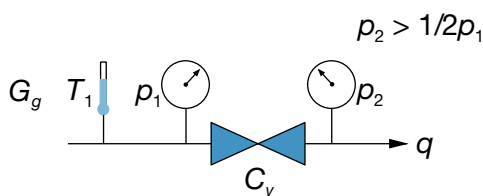


High pressure drop



This equation applies when there is low pressure drop flow—outlet pressure (p_2) is greater than one half of inlet pressure (p_1):

$$q = N_2 C_v p_1 \left(1 - \frac{2\Delta p}{3p_1}\right) \sqrt{\frac{\Delta p}{p_1 G_g T_1}}$$



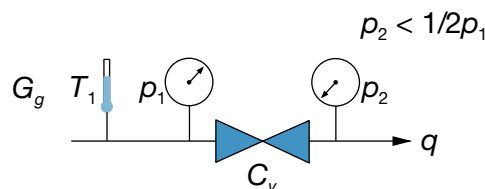
The low pressure drop air flow graphs (pages 8 and 9) show low pressure drop air flow for a valve with a C_v of 1.0, given as a function of inlet pressure (p_1) for a range of pressure drop (Δp) values.

When outlet pressure (p_2) is less than half of inlet pressure (p_1)—high pressure drop—any further decrease in outlet

pressure does not increase the flow because the gas has reached sonic velocity at the orifice, and it cannot break that “sound barrier.”

The equation for high pressure drop flow is simpler because it depends only on inlet pressure and temperature, valve flow coefficient, and specific gravity of the gas:

$$q = 0.471 N_2 C_v p_1 \sqrt{\frac{1}{G_g T_1}}$$



The high pressure drop air flow graphs (pages 10 and 11) show high pressure drop air flow as a function of inlet pressure for a range of flow coefficients.

Fig. 4. For most common liquids, the effect of specific gravity on flow is less than 10 %. Also, most high-density liquids such as concentrated acids and bases usually are diluted in water and—consequently—the specific gravity of the mixtures is much closer to that of water than to that of the pure liquid.

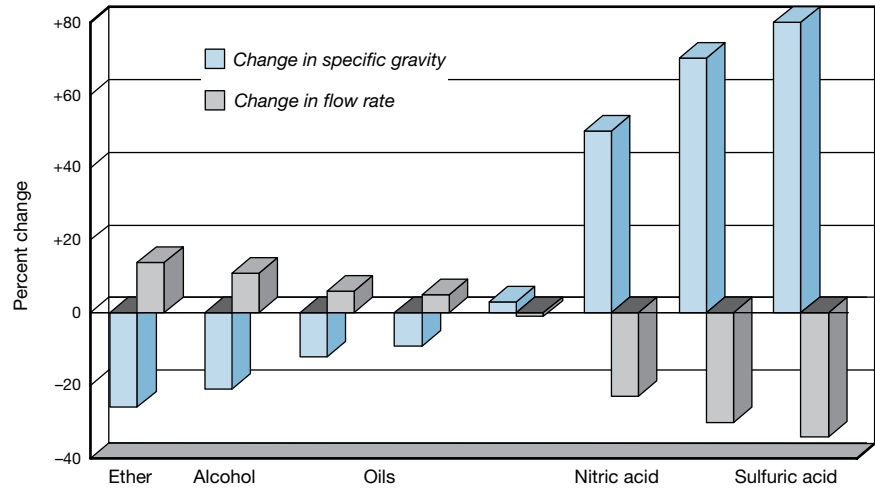
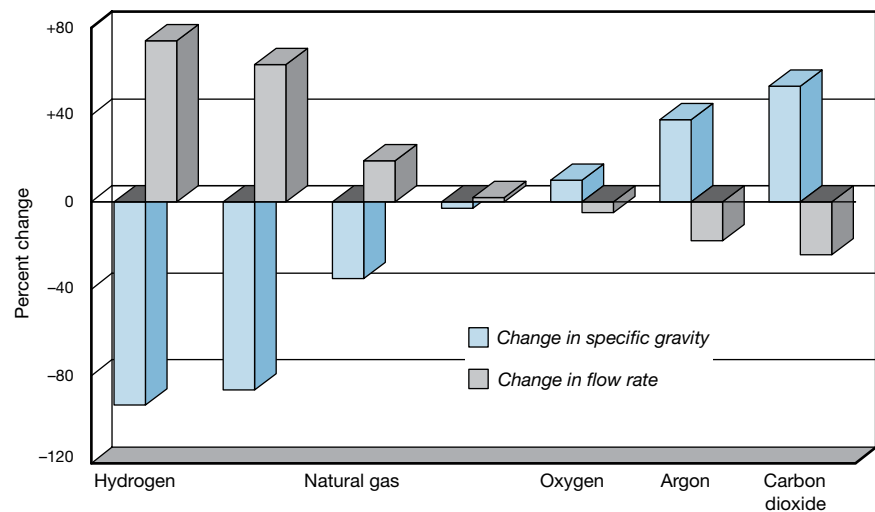


Fig. 5. For common gases, the specific gravity of the gas changes flow by less than 10% from that of air. And just as with liquids, gases with exceptionally high or low densities often are mixed with a carrier gas such as nitrogen, so that the specific gravity of the mixture is close to that of air.



Effects of Specific Gravity

The flow equations include the variables G_f and G_g —liquid specific gravity and gas specific gravity—which are the density of the fluid compared to the density of water (for liquids) or air (for gases).

However, specific gravity is not accounted for in the graphs, so a correction factor must be applied, which includes the square root of G . Taking the square root reduces the effect and brings the value much closer to that of water or air, 1.0.

For example, the specific gravity of sulfuric acid is 80 % higher than that of water, yet it changes flow by just 34 %. The specific gravity of ether is 26 % lower than that of water, yet it changes flow by only 14 %.

Figure 4 shows how the significance of specific gravity on liquid flow is diminished by taking its square root. Only if the specific gravity of the liquid is very low or very high will the flow change by more than 10 % from that of water.

The effect of specific gravity on gases is similar. For example, the specific gravity of hydrogen is 93 % lower than that of air, but it changes flow by just 74 %. Carbon dioxide has a specific gravity 53 % higher than that of air, yet it changes flow by only 24 %. Only gases with very low or very high specific gravity change the flow by more than 10 % from that of air.

Figure 5 shows how the effect of specific gravity on gas flow is reduced by use of the square root.

Effects of Temperature

Temperature usually is ignored in liquid flow calculations because its effect is too small.

Temperature has a greater effect on gas flow calculations, because gas volume expands with higher temperature and

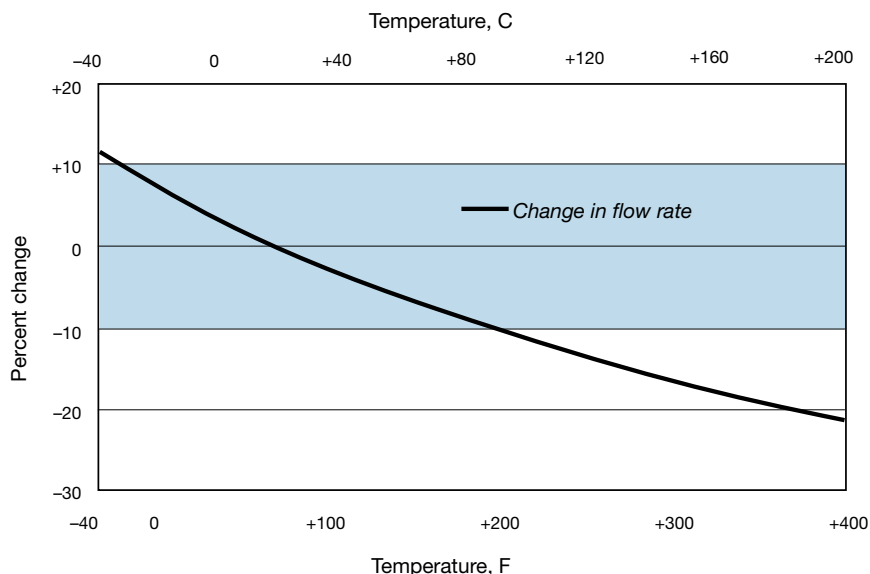


Fig. 6. Many systems operate in the range -40°F (-40°C) to $+212^{\circ}\text{F}$ ($+100^{\circ}\text{C}$). Within this range, temperature changes affect flow by little more than 10-%.

Numerical Constants for Flow Equations

Constant	Units Used in Equations			
	N	q	p	T_1
N_1	1.0	U.S. gal/min	psia	—
	0.833	Imperial gal/min	psia	—
	14.42	L/min	bar	—
	14.28	L/min	kg/cm ²	—
N_2	22.67	std ft ³ /min	psia	$^{\circ}\text{R}$
	6950	std L/min	bar	K
	6816	std L/min	kg/cm ²	K

contracts with lower temperature. But—similar to specific gravity—temperature affects flow by only a square-root factor. For systems that operate between -40°F (-40°C) and $+212^{\circ}\text{F}$ ($+100^{\circ}\text{C}$), the correction factor is only +12 to -11 %.

Figure 6 shows the effect of temperature on volumetric flow over a broad range of temperatures. The plus-or-minus 10 % range covers the usual operating temperatures of most common applications.

Other Services

As noted above, this technical bulletin covers valve sizing for many common applications and services. What about viscous liquids, slurries, or boiling and flashing liquids? Suppose vapors, steam, and liquefied gases are used? How are valves sized for these other services?

Such applications are beyond the scope of this document, but the ISA standards S75.01 and S75.02 contain a complete set of formulas for sizing valves that will be used in a variety of special services, along with a description of flow capacity test principles and procedures. These and other ISA publications are listed in the references. Also, most standard engineering handbooks have sections on fluid mechanics. Several of these are given in the references, as well.

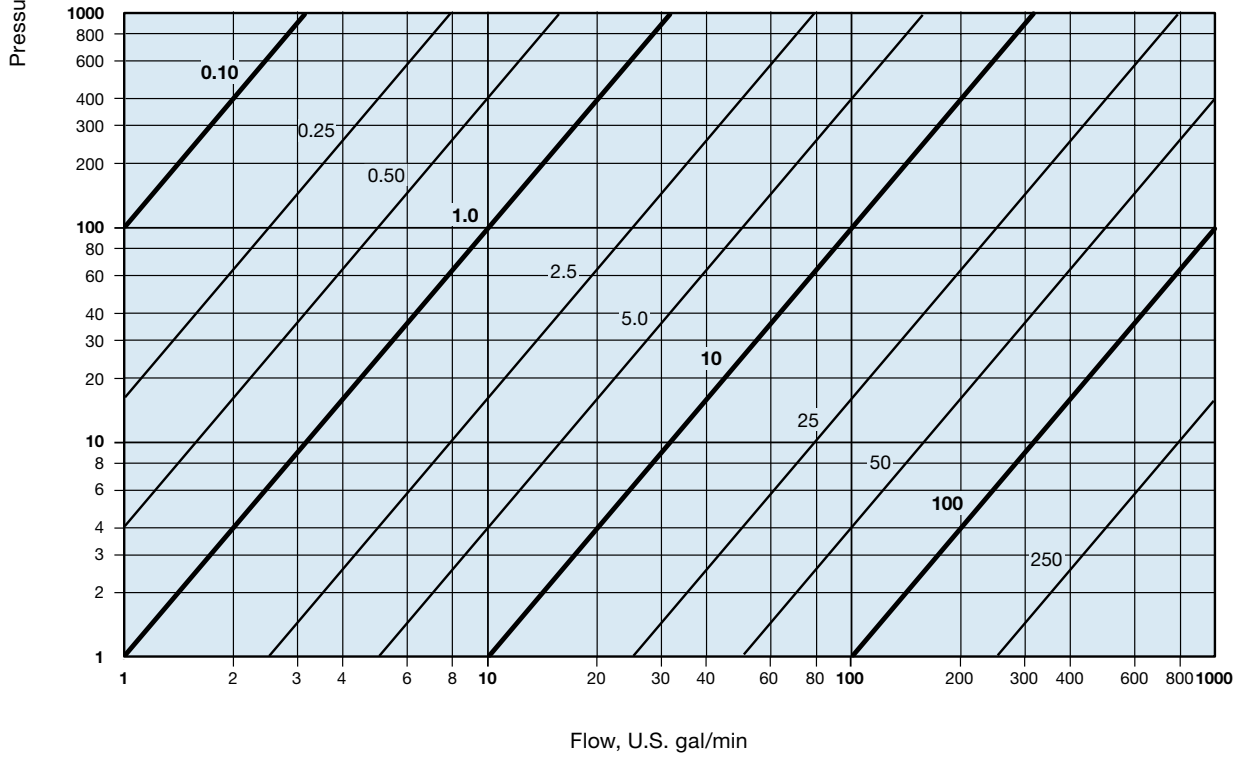
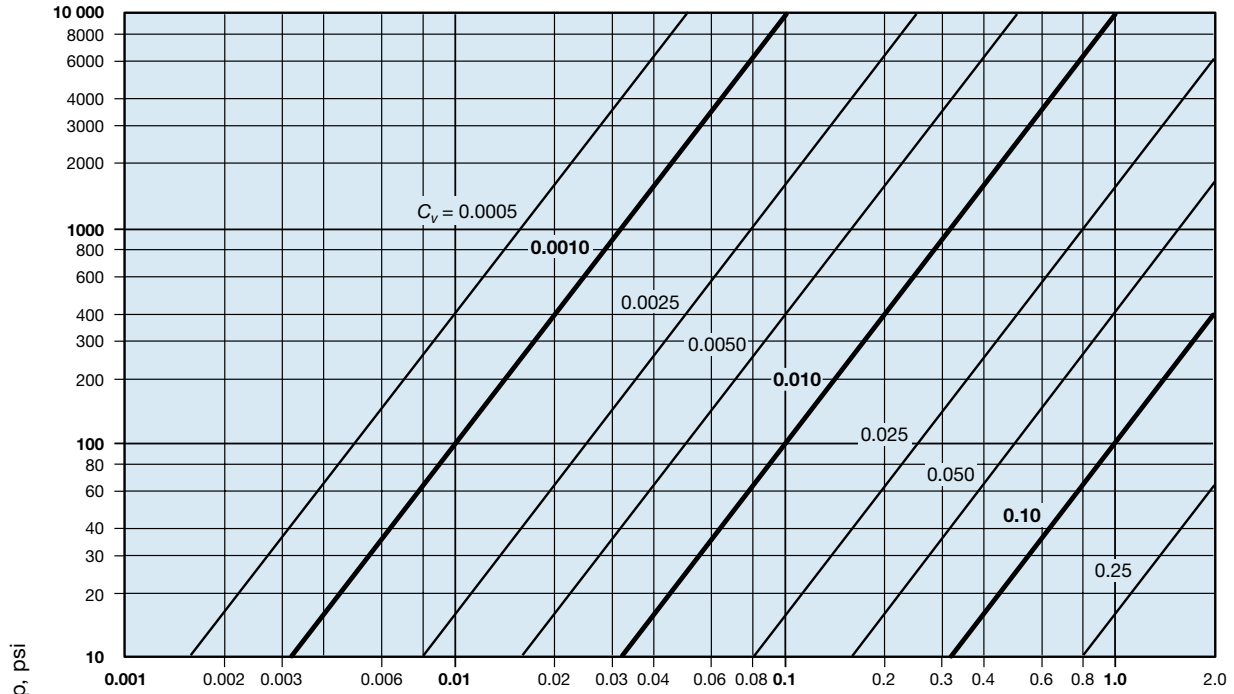
Cited References

1. ISA S75.01, Flow Equations for Sizing Control Valves, Standards and Recommended Practices for Instrumentation and Control, 10th ed., Vol. 2, 1989.
2. ISA S75.02, Control Valve Capacity Test Procedure, Standards and Recommended Practices for Instrumentation and Control, 10th ed., Vol. 2, 1989.

Other References

- L. Driskell, *Control-Valve Selection and Sizing*, ISA, 1983.
- J.W. Hutchinson, *ISA Handbook of Control Valves*, 2nd ed., ISA, 1976.
- Chemical Engineers' Handbook*, 4th ed., Robert H. Perry, Cecil H. Chilton, and Sidney D. Kirkpatrick, Ed., McGraw-Hill, New York.
- Instrument Engineers' Handbook*, revised ed., Béla G. Lipták and Kriszta Venczel, Ed., Chilton, Radnor, PA.
- Piping Handbook*, 5th ed., Reno C. King, Ed., McGraw-Hill, New York.
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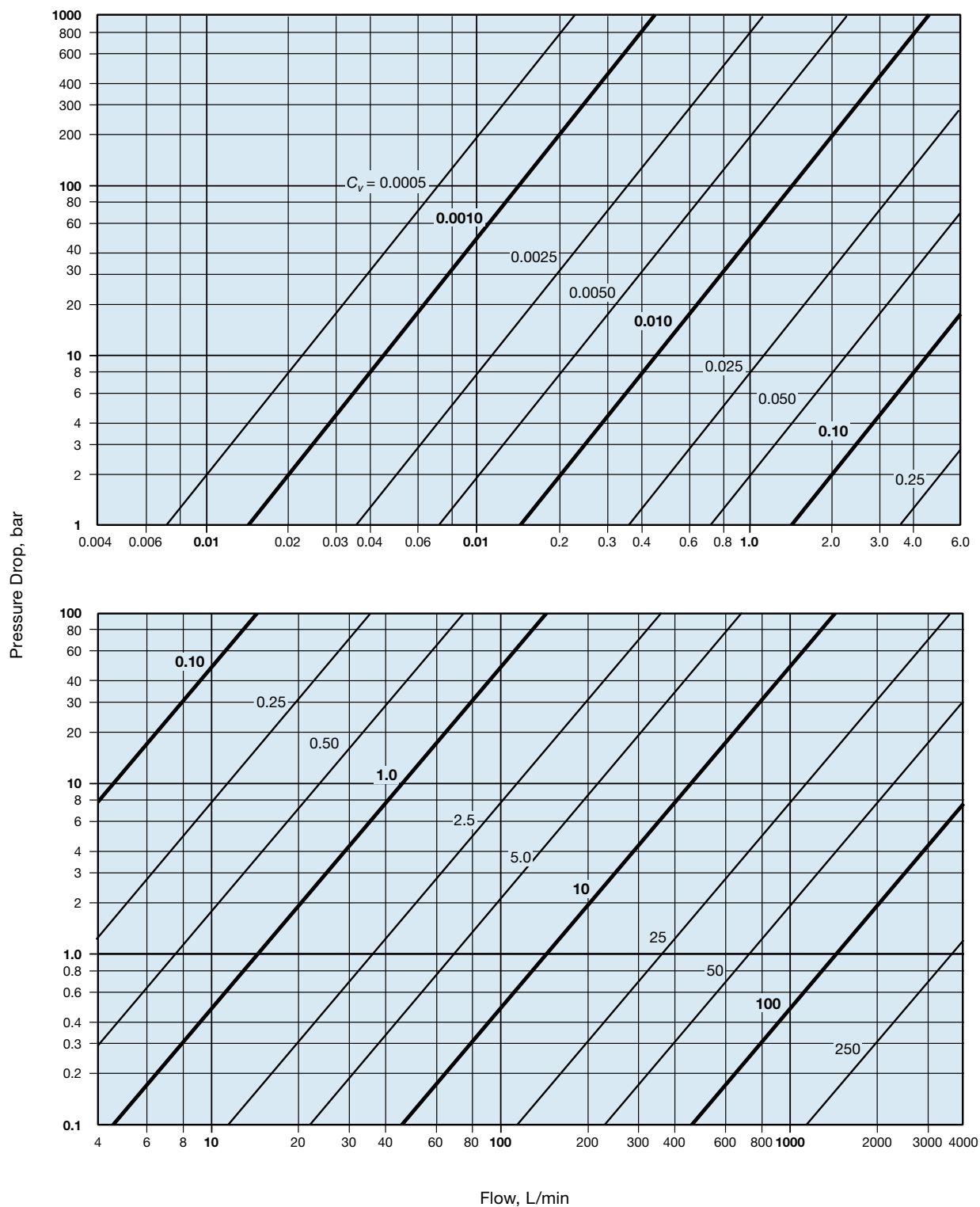
Water Flow—U.S. Units



Example:

- Enter the vertical scale with the pressure drop across the valve ($\Delta p = 60$ psi).
- Read across to the desired flow rate ($q = 4$ U.S. gal/min).
- The diagonal line is the desired C_v value ($C_v = 0.50$).

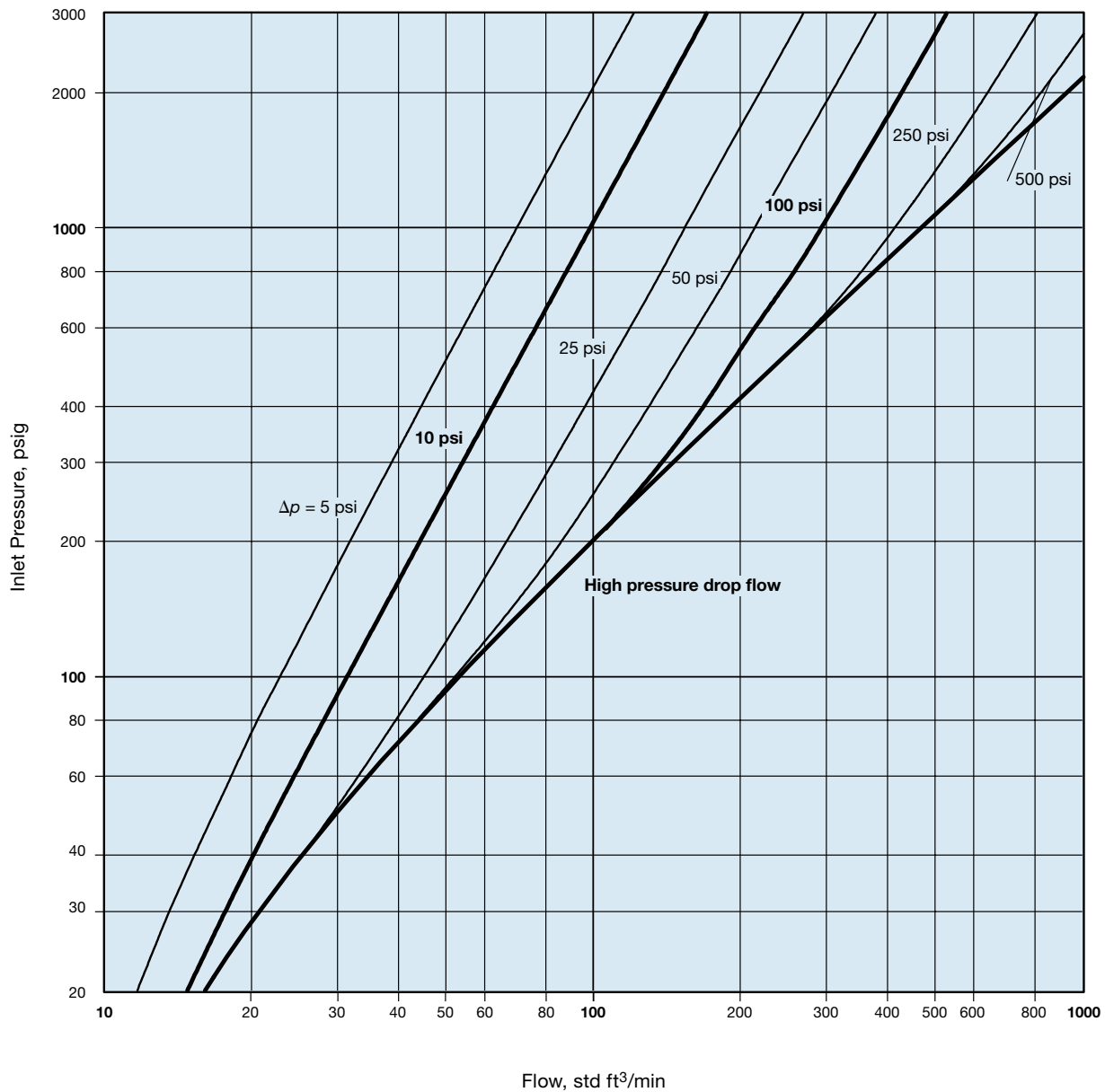
Water Flow—Metric Units



Example:

- Enter the vertical scale with the pressure drop across the valve ($\Delta p = 30$ bar).
- Read across to the desired flow rate ($q = 0.2$ L/min).
- The diagonal line is the desired C_v value ($C_v = 0.0025$).

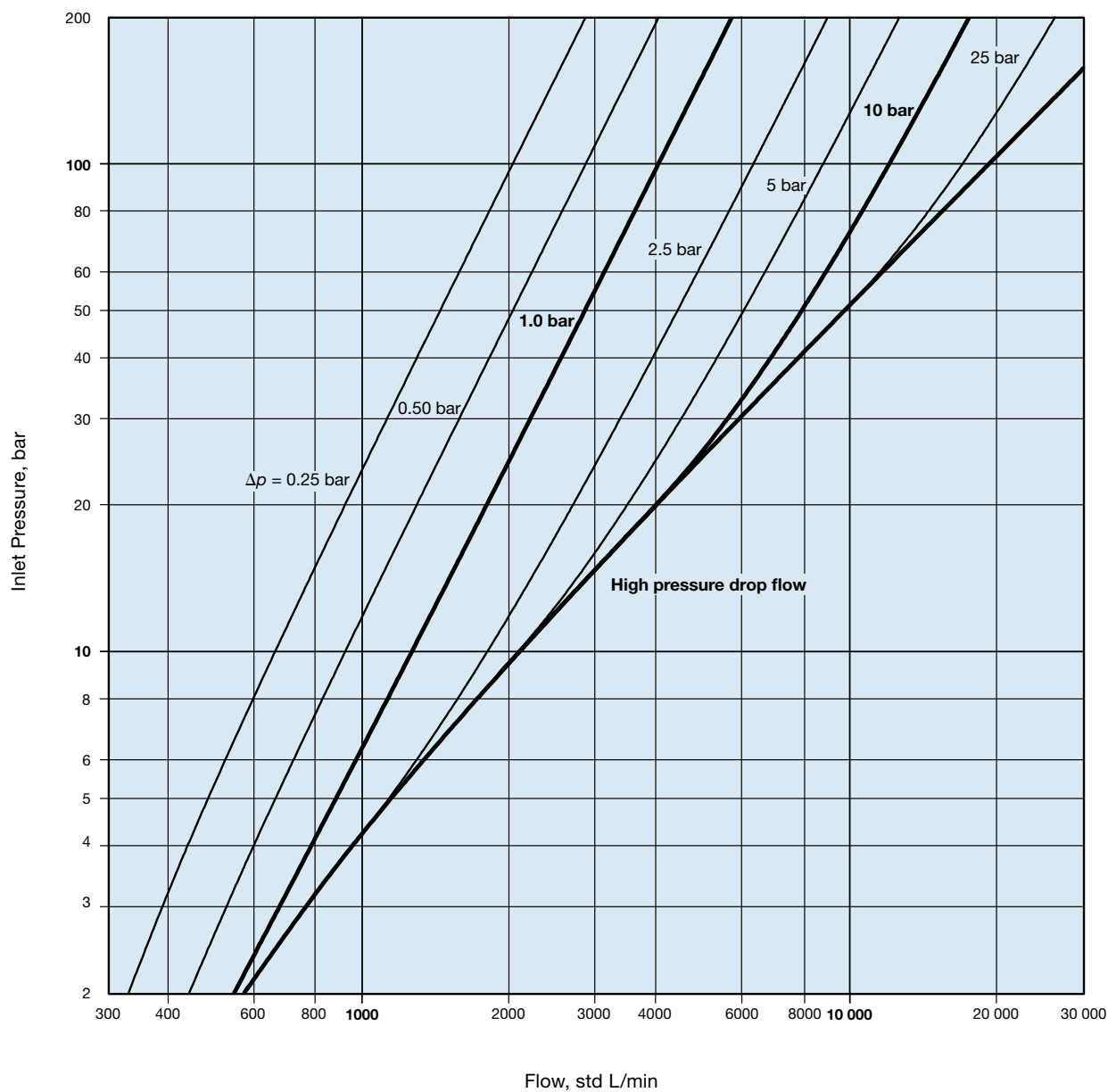
Low Pressure Drop Air Flow—U.S. Units



Example:

- Enter the vertical scale with the inlet pressure at the valve ($p_1 = 200$ psig).
- Read across to the diagonal line for the pressure drop across the valve ($\Delta p = 25$ psi).
- Read down to the horizontal scale for the flow rate through a valve with a C_v of 1.0 ($q = 65$ std ft³/min).
- Multiply that flow rate by the valve C_v to determine the actual flow rate.

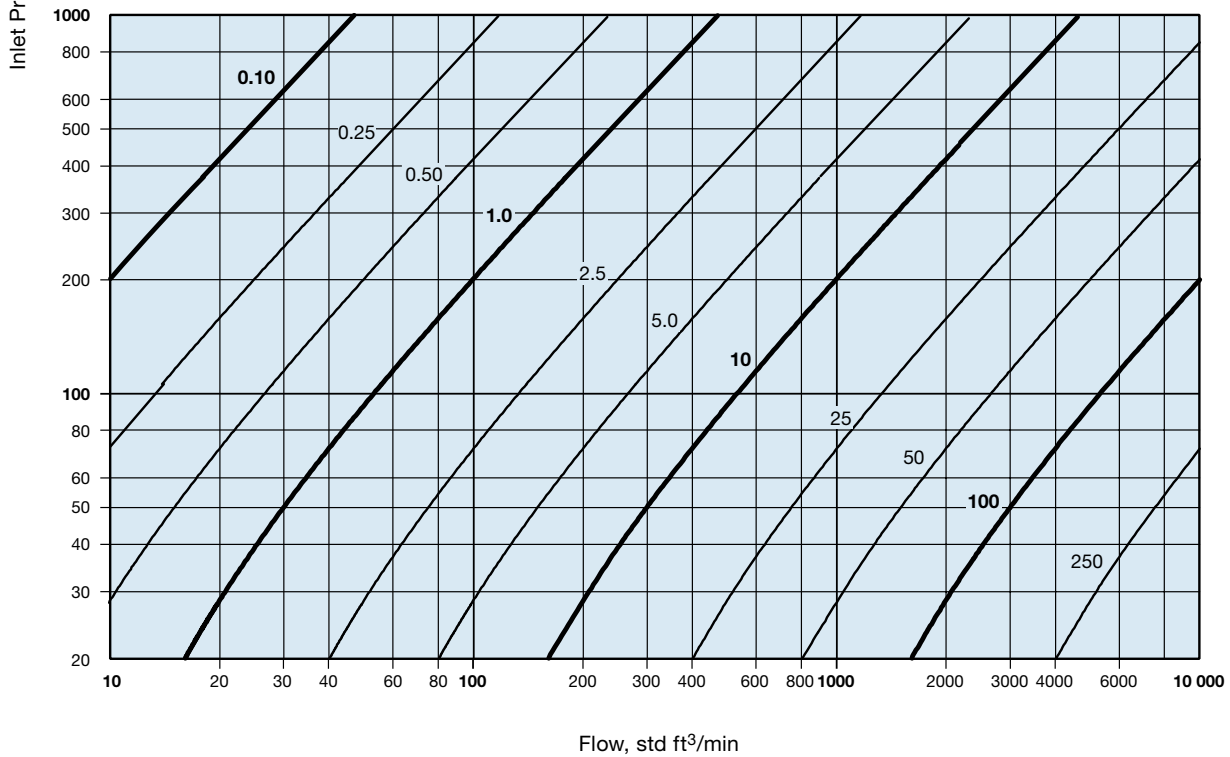
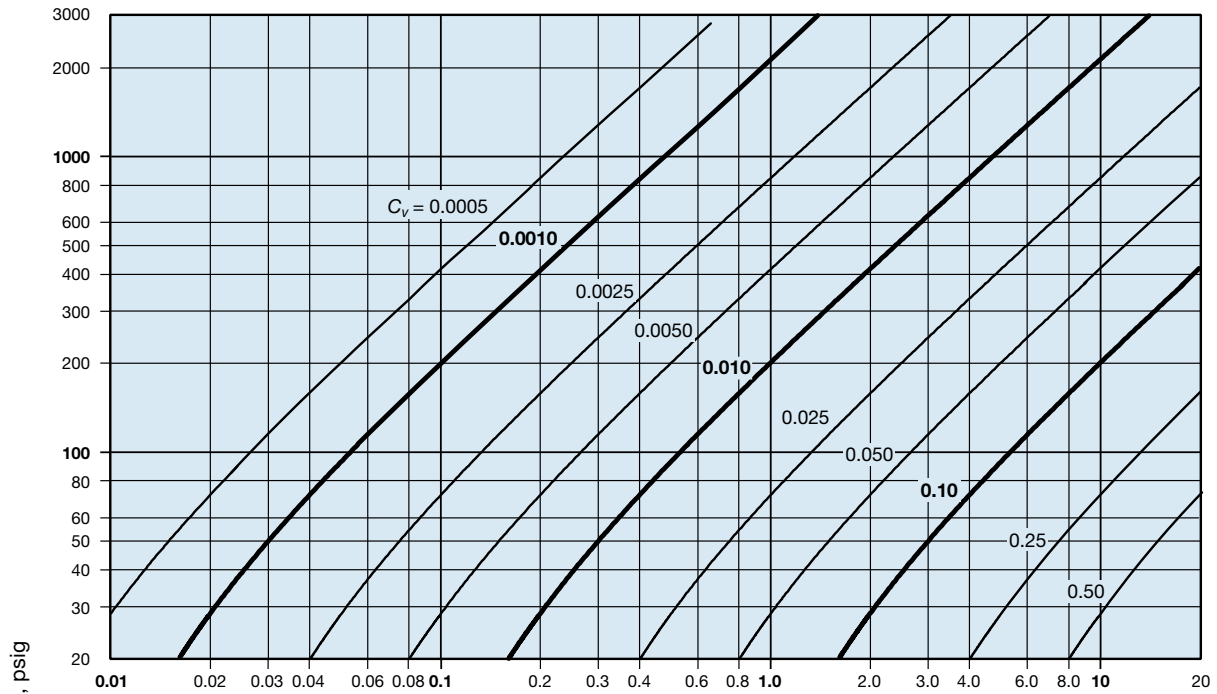
Low Pressure Drop Air Flow—Metric Units



Example:

- Enter the vertical scale with the inlet pressure at the valve ($p_1 = 100$ bar).
- Read across to the diagonal line for the pressure drop across the valve ($\Delta p = 1$ bar).
- Read down to the horizontal scale for the flow rate through a valve with a C_v of 1.0 ($q = 4000$ std L/min).
- Multiply that flow rate by the valve C_v to determine the actual flow rate.

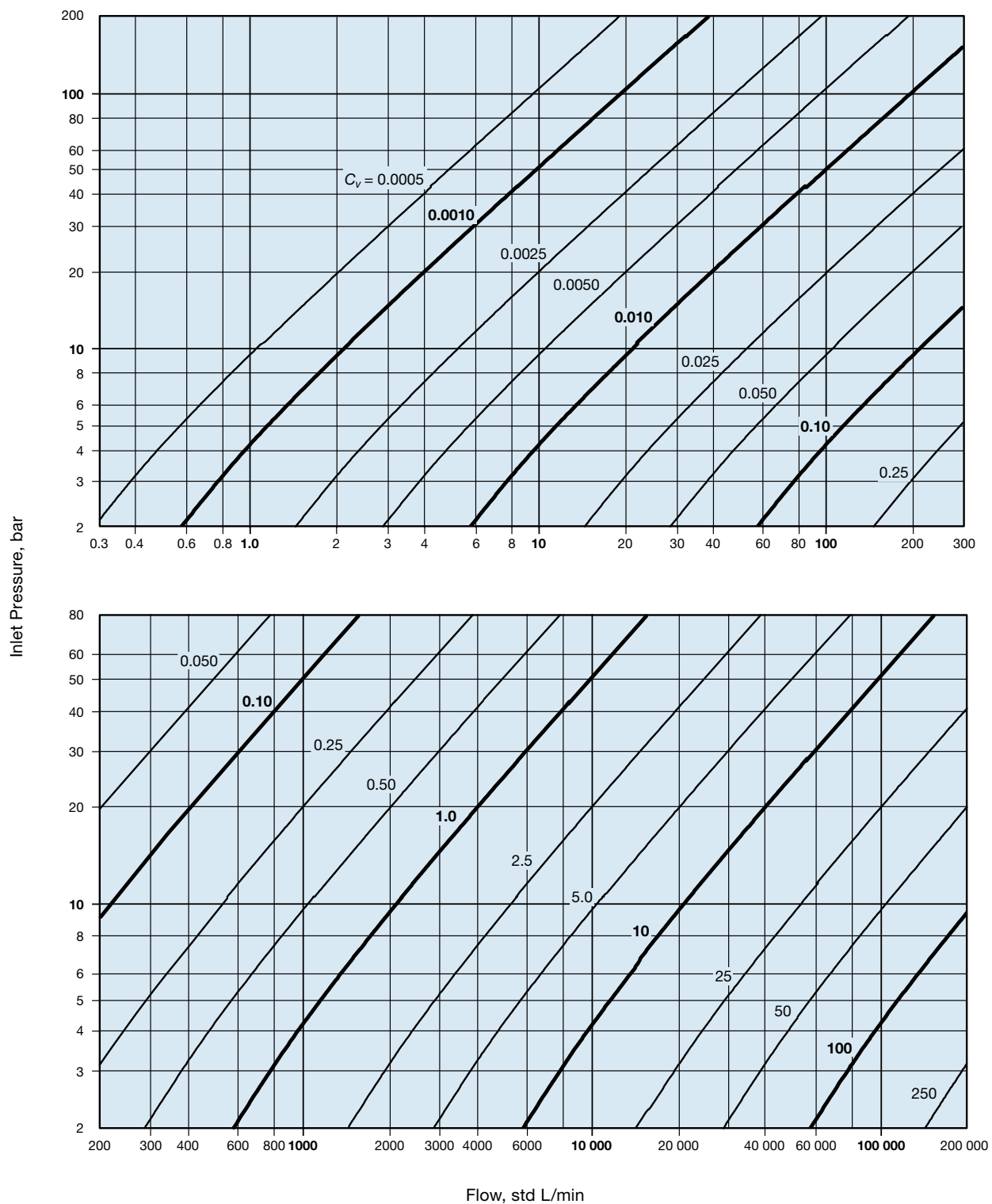
High Pressure Drop Air Flow—U.S. Units



Example:

- Enter the vertical scale with the inlet pressure at the valve ($p_1 = 200$ psig).
- Read across to the desired flow rate ($q = 10$ std ft³/min).
- The diagonal line is the desired Cv value ($C_v = 0.10$).

High Pressure Drop Air Flow—Metric Units



Example:

- Enter the vertical scale with the inlet pressure at the valve ($p_1 = 20$ bar).
- Read across to the desired flow rate ($q = 4000$ std L/min).
- The diagonal line is the desired C_v value ($C_v = 1.0$).

Safe Product Selection

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.