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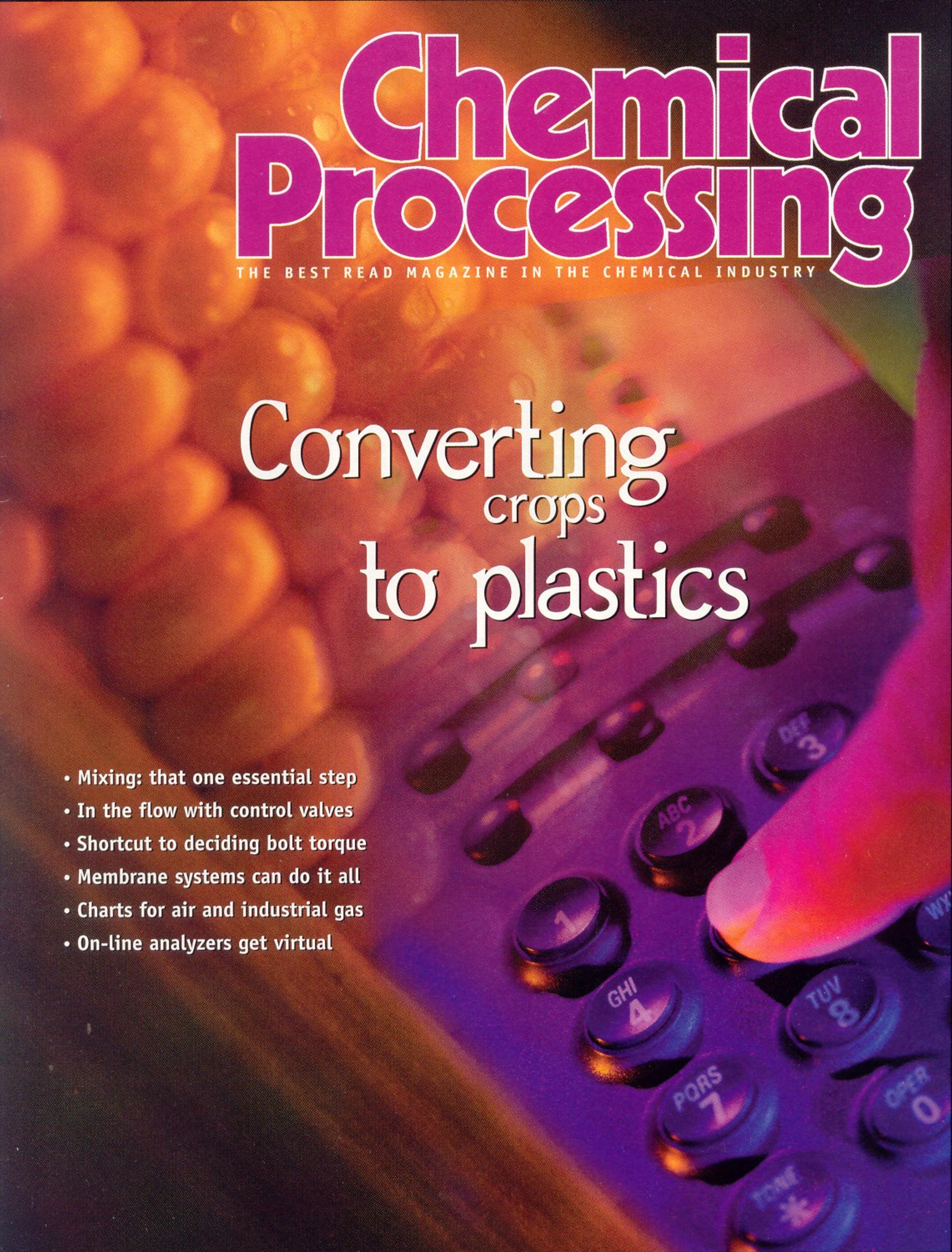

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In the flow with control valves

Undersized valves won't work at all, and oversized don't offer extra benefit

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Selecting the right-sized control valve can help a plant achieve the highest possible degree of process control. An undersized control valve won't handle the required flow, and one that's too big costs more without offering any additional benefits.

In fact, the more expensive oversized valve won't allow for as much accuracy as will the the right-sized valve. Oversized valves have a wider range of control (permitting flows perhaps several times the maximum required for the process), so they're more sensitive to changes in position or to position error.

Because of the relatively high sensitivity (or gain) of an oversized valve, a position error of, say 1%, could cause flow errors of 4% or more, making process control difficult or impossible. Correctly sized and selected control valves typically have flow errors of 1% to 2%, for the same 1% position error.

Calculating size

Use a modern control valve sizing computer program to perform the valve sizing calculations, or work them out by hand with the methods presented in *CP's Fluid Flow Annual.*

> *The right-sized control valves can help a plant achieve the highest possible degree of process control.*

Table 1. Comparing control-valve styles

	Top-guided globe	Cage-guided globe	Segment ball	Eccentric rotary plug	High-perf. butterfly
Cost	High	High	Medium	Medium	Low
Weight	High	High	Medium	Medium	Low
Flow capacity (compared to globe)	1 X	1X	2 X	1 X	2X
Cavitation potential	Low	Low	Medium	Medium	High
In-line repairable	Yes	Yes	No	No	No
Inherent flow characteristic	=%, Linear, quick opening	=%, Linear, quick opening	=%	Modified linear	Modified =%
Cavitation/noise reduction options	No	Yes	Some	Some	No
Suitable for high-pressure differential	Limited	Yes	Limited	Yes	Limited
Suitable for dirty service	Yes	No	Yes	Yes	Yes
Suitable for slurries	Limited	No	Yes	Yes	Limited
Suitable for pulp stock	No	No	Yes	No	Limited

Picking control valve style

The choice of control valve style, such as globe, ball or butterfly, is often based on habit or plant preference. Most of the control valves in pulp and paper mills, for example, are usually ball or segmented ball valves. Petroleum refineries often use lot of globe valves, although concern over fugitive emissions has fostered a trend toward rotary valves. With rotary, it's usually easier to obtain a long-lasting stem seal.

Globe valves offer the widest range of options for flow characteristic, pressure, temperature, and noise and cavitation reduction. Globe valves also tend to be the most expensive.

Segment ball valves tend to have a higher rangeability, and, size for size, nearly twice the flow capacity of globe valves. The segment ball models are also less expensive than globe valves.

Still, segment ball valves are limited in availability for extremes of temperature and pressure and are more prone to noise and cavitation problems than are globe valves.

High-performance butterfly valves are even less expensive than ball valves, especially in larger sizes (say 8 in. and larger). They also have less rangeability than the ball valves and are more prone to cavitation.

The eccentric rotary plug valve combines features of rotary valves, such as high cycle life stem seals and compact construction, with the rugged construction of globe valves. Unlike other rotary valves, whose flow capacity is approximately double that of globe valves, the flow capacity of eccentric rotary plug valves is on a par with globe valves.

See Table 1 for a comparison of control-valve styles.

Flow characteristics

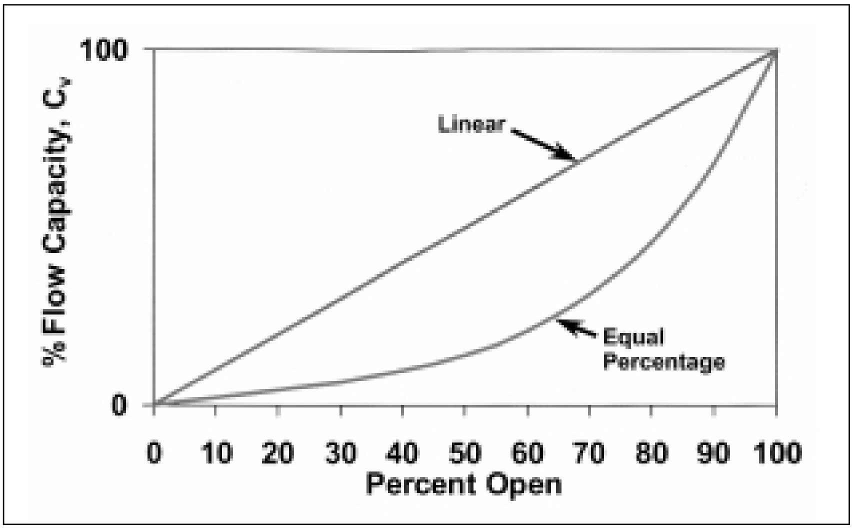
Selecting a valve with the right flow characteristic (the relationship between valve opening and flow) can be as important as the selection of the valve size. Actually, a control valve has two characteristics—inherent and installed.

The inherent characteristic is the one published by the manufacturer. It's based on tests in a system where great care is taken to ensure that the pressure drop across the test valve is held constant at all valve openings and flowrates.

So the inherent characteristic represents the relationship between valve flow capacity and valve opening when no system effects are involved. Fig. 1 shows the ideal linear and equal percentage characteristics. The source of the name of the linear characteristic is self evident from the graph.

The name of the equal percentage characteristic comes from the definition: "Equal changes in valve position cause equal percentage changes

Fig. 1. Linear and equal percentage inherent characteristics



in flow."

The result, shown in Fig. 1, is a characteristic where a small increment of valve position at small openings results in a small increase in flow capacity, while the same increment of valve position at large openings results in a larger increase in flow capacity.

Globe valves are available with either linear or equal percentage inherent characteristics, giving them a versatility not generally available with the rotary valves.

In fact, most globe control valve designs can be changed from linear to equal percentage (and vice versa) by changing the trim. The ball valves (both full ball and segmented ball) exhibit a nearly perfect (more so than equal percentage globe valves) equal percentage inherent characteristic.

High performance butterfly valves exhibit an inherent characteristic approximately midway between equal percentage and linear.

Eccentric rotary plug valves vary, depending on the manufacturer. Some have an inherent characteristic on the equal percentage side of linear, while others are on the quick opening side.

Most control systems give the best performance when they behave in a linear manner. "Why," one might ask, "use the equal percentage valve?" It's not at all linear. The answer: because of the installed characteristic.

The installed characteristic is the relationship between valve position and flow in the system, taking into account changes in the pressure differential available to the control valve because of the flow squared relationship between flow and piping pressure losses or a centrifugal pump curve.

Many process systems include a significant amount of pipe and a number of fittings (elbows, Ts, isolation valves and others), resulting in a relationship between flow in the system and pressure drop available to the control valve similar to Fig. 3. Refer to Fig. 4, and imagine a control valve with an inherent equal percentage characteristic installed in a system that has a characteristic like that of Fig. 3.

When the control valve is wide open, the flow will be at its maximum. Moving the control valve in the closing direction decreases the flow. As soon as the flow starts to slow, the pressure drop across the valve tends to increase (as shown in Fig. 3), resisting the decrease in flow through the valve.

The result of the interaction between control valve and system produces a nearly linear installed characteristic.

As a general rule, systems with a significant amount of pipe and number of fittings (the most common case) are best suited to equal percentage inherent characteristic valves. Systems with very little pipe (where the pressure drop available to the control valve remains constant and, as a result, the inherent characteristic of the valve is also the installed characteristic) are better for linear inherent characteristic valves.

Process data

A valve sizing calculation is reliable only if the process data accurately represents the process. Bad data enters the picture in two areas. The first is the addition of safety factors to the design flowrate, and the second involves the selection of the sizing pressure drop, Δp.

Nothing's wrong with judiciously applying a safety factor to the design flow. Problems arise when several people each add a safety factor without realizing others have done the same.

Perhaps the most misunderstood area of control valve sizing is the selection of the pressure drop, Δp, to

Fig. 2. Inherent characteristics of common control-valve types

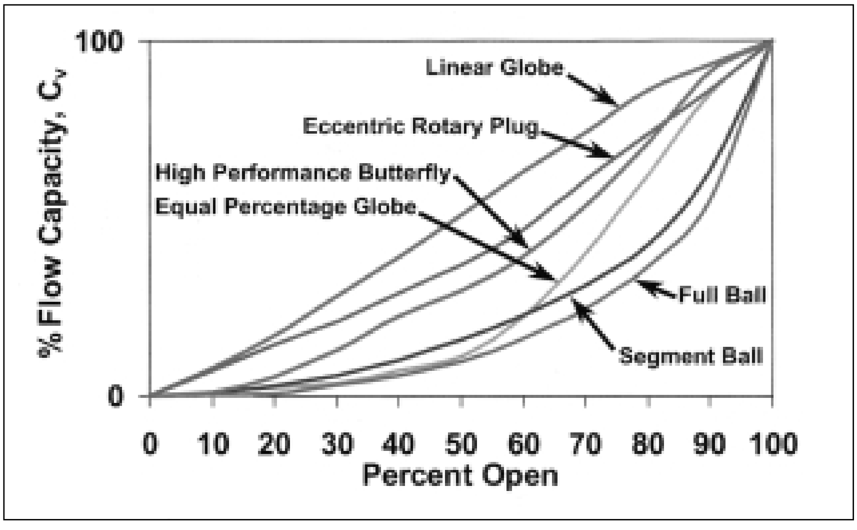


Fig. 3. Valve pressure drop vs. flow in a typical system with a significant amount of pipe

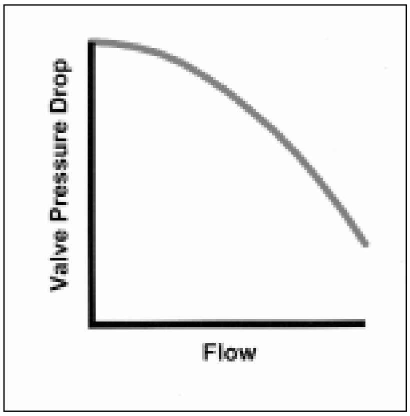
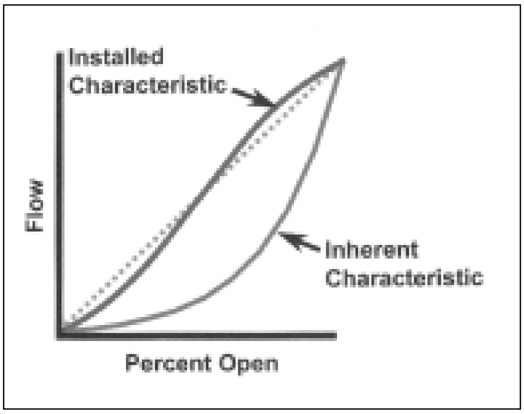


Fig. 4. Installed characteristic of an equal percentage valve in the system shown in Fig. 3



use in the sizing calculation. The Δp cannot be arbitrarily specified without regard for the system where the valve will be installed.

Keep in mind that all of the components of the system, except for the control valve (pipe, fittings, isolation valves, heat exchangers and others), are fixed.

At the flowrate required by the system—to cool a hot chemical to a specified temperature, maintain a specified level in a tank or perform another function—the pressure loss in each of the fixed elements is also fixed.

Only the control valve is variable, and it is connected to an automatic control system. The control system adjusts the control valve to establish the required flow and thus achieve the specified temperature, tank level or whatever.

At that point the portion of the overall system pressure differential (the difference between the pressure at the beginning of the system and at the end of the system) that is not consumed by the fixed elements must appear across the control valve.

To determine the pressure drop across a control valve, start upstream of the valve at a point where the pressure is known. An example is a pump where the pressure can be determined from the head curve.

Subtract the pressure loss in each of the fixed elements. When you get to the valve inlet, you know p1, the pressure immediately upstream from the valve. At that point you cannot directly calculate the pressure drop across the valve, because you have yet to determine its size and the percentage of opening at which it will operate.

The next step is to go to a point downstream from the control valve where the pressure is known. Go to a tank, for example, where the head is known and then work upstream toward the control valve, adding the pressure loss of each of the fixed elements. Add the pressure losses because you are working in the direction opposite to the flow.

When you get to the valve outlet, you know p2, the pressure immediately downstream of the valve. The pressure drop across the control valve is the difference between the upstream and the downstream pressures, that is Δp = p_1 - p_2.

To balance economics and control performance, add a pressure drop of one-half the dynamic losses.

If you plan to perform sizing calculations at more than one flowrate (for example, at design flows) you must repeat the calculation of p_1 and p_2 at each flowrate, because the system pressure losses (and pump head) depend on flow.

In some situations you can have a hand in determining the pressure drop across the control valve. A typical situation of that sort is a pumped system where you know the required pressure at the end of the system, and you are in a position to select the pump.

Calculate the dynamic pressure losses in all of the fixed elements of the system at the design flowrate. The droop in the pump head curve from zero flow to the design flow should be included with the dynamic pressure losses.

For a good balance of economics and control performance, add a pressure drop of one half the dynamic losses for the control valve. Add to this total the required pressure at the end of the system and any changes in elevation head, and then select a pump whose head at the design flow matches the required pressure as closely as possible.

Because you will probably have to select a pump that does not exactly match the calculated required pressure, recalculate the actual valve sizing Δp as described in the preceding paragraph.

Designing a pressure drop for the control valve that is significantly less than one half the other dynamic losses is likely to result in a system that does not control well. Designing a valve pressure drop that is significantly higher will create unnecessarily high pumping energy and may introduce noise and cavitation problems.

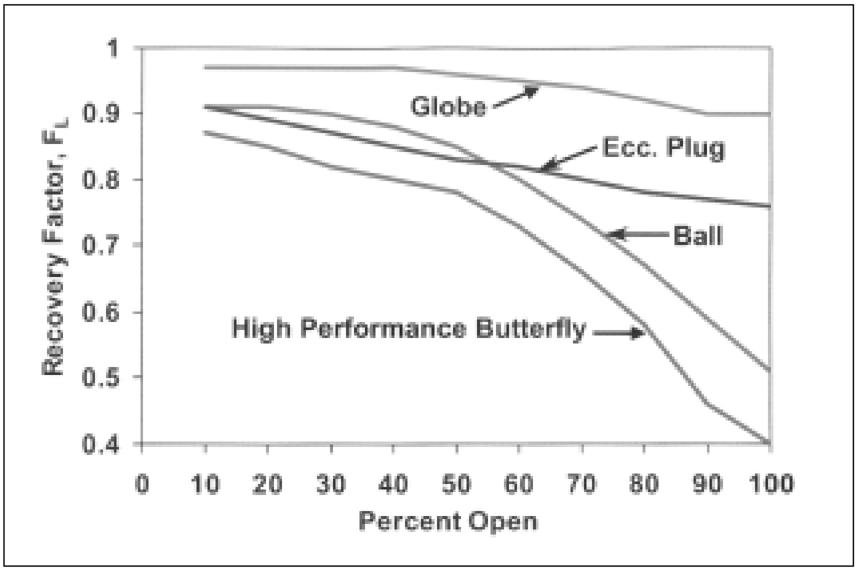
Types of valves

When a liquid flow stream in a control valve passes through the *vena contracta*—the point where the cross sectional area of the stream is at a minimum—the flow velocity reaches a maximum.

Conservation of energy dictates that because kinetic energy at the vena contracta has increased to a maximum, potential energy in the form of static pressure must decrease to a minimum.

For a fixed value of the upstream pressure, p_1, as the pressure drop across a control valve increases, the

Fig. 5. Liquid pressure recovery factors (F_L) for typical control valves



flow also increases, but the pressure at the *vena contracta* decreases.

If the pressure drop across the control valve increases to a point where the vena contracta pressure decreases to slightly below the vapor pressure, p_v, of the liquid, vapor bubbles form in the *vena contracta*.

Once that happens, additional increases in pressure drop across the valve do not result in additional flow, and flow is said to be choked. Call the limiting or choking pressure drop the terminal pressure drop, Δp_T. It's sometimes referred to as the allowable pressure drop or Δp allowable.

The calculation of Δp_T is important because when the actual pressure drop, Δp, is greater than Δp_T, then Δp_T and not Δp must be used in the sizing equations to prevent undersizing the valve.

Choked flow produces one of two conditions—either flashing or cavitation. Flashing results if the pressure downstream of the valve, p_2, is less than the vapor pressure of the liquid. In this case the vapor bubbles that formed at the vena contracta continue downstream. Flashing conditions have the potential for erosive damage to the valve because of drops of liquid entrained in high-velocity vapor. Selection of erosion resistant materials is advisable. For example, stainless steel or chrome moly steel valve bodies are more resistant to flashing damage than are those of carbon steel. Hard trim materials, such as 17–4 pH stainless steel or hard-faced materials, resist flashing damage better than softer trim materials, such as 316 stainless steel. Flashing conditions are dictated by the system (p_2 is less than p_v), and the valve selection neither causes nor prevents flashing. The noise caused by flashing is usually below 85 dBA, and the author knows of no way to calculate flashing noise.

Cavitation results from choked flow when p_2 is greater than p_v. In this case, as the vapor bubbles travel downstream from the vena contracta, the higher pressure causes them to collapse violently, resulting in vibration, noise and damage to the valve and in some cases the downstream piping. Unlike flashing, the use of hard or erosion resistant materials is not effective in preventing cavitation damage. As a general rule, avoid cavitation.

Use any of several methods to increase the value of Δp_T and thus reduce the potential for cavitation:

- Increase the value of p_1 while keeping Δp the same by moving the control valve upstream;
- Decrease vapor pressure by installing the valve where the liquid temperature is lower, such as the cool side of a heat exchanger;
- Select a valve style with a higher value of F_L. In general, as the F_L increases, so does the price. Special cavitation-resistant adaptations of many of the valve styles have larger values of liquid pressure recovery factor, F_L, than those shown in Fig. 5, yet retain the style's other desirable features.

The internal geometry of control valves is complex enough that the onset of choked flow and cavitation is not as sudden and clearly defined as the above discussion would suggest. In practice, at pressure drops approaching, but below the calculated value of Δp_T, there is usually some formation of vapor bubbles and some degree of cavitation. That phenomenon is more pronounced in ball and butterfly valves than globe and eccentric rotary plug valves.

Because cavitation can rapidly cause severe damage, it's risky to simply apply the old rule of not allowing Δp to exceed Δp_T. A more reliable method of preventing cavitation damage is to avoid valve applications where the calculated noise exceeds limits based on broad application experience. That works because the noise and the damage are caused by the same thing—the collapse of vapor bubbles.

Experience has shown that for valves 3 in. and smaller in nominal size, cavitation damage can be kept to a minimum if the sound pressure level (SPL), based on uninsulated schedule 40 pipe, does not exceed 80 dBA. For 4-in. and 6-in. valves the limit can increase to 85 dBA, and for valves 8 in. and larger the limit is 90 dBA.

Before buying a control valve, ask for the manufacturer's comments on your selection.

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