

Control valves for stock and white water: reducing cavitation damage by specifying the correct size

Ed Andrews and Marti Husu

New studies in Finland provide more accurate data for predicting the pressure loss in control valves for handling pulp stock.

Paper and pulp mills use control valves for throttling the flow of pulp stock and white water. The pumping costs are largely determined by how well the piping and control valves are sized and selected. If the piping and control valves are selected correctly, then pumps of optimum sizes can be chosen.

In properly specifying control valves, problems are growing in two areas. First, with higher consistencies being used with pumps for medium-consistency stock, there is a real need for more accurate data for sizing pipes and control valves. Second, higher water temperatures for thin stock and white water and higher pressures for shower water have caused more cavitation problems. Here, we will look at these problems separately.

Background

Cavitation as related to consistency

As reported recently (1), noise and vibration tests showed that cavitation induced by high-pressure drops was less pronounced in pulp stock at a consistency of at least 2% than it was in white water alone. Figure 1 shows the curves from that work.

In both graphs of Fig. 1, the ratio of the pressure drop to the inlet pressure minus the vapor pressure is given as:

$$\text{Pressure ratio} = (p_1 - p_2) / (p_1 - p_v) \quad (1)$$

where

p_1 = upstream pressure, or inlet pressure

p_2 = downstream pressure, or outlet pressure, after the throttling valve

p_v = vapor pressure.

These curves show that at consistencies of 2% and higher, we have substantially fewer cavitation problems than with white water alone. At less than 2% consistency, we can have severe cavitation problems. Apparently, the pulp stock lessens the effects of cavitation somewhat. Not only does the fiber network cushion the high-pressure shock wave, but presumably some of the air bubbles stick to the fiber surface (1). Even with this advantage, however, there are still problems in sizing valves for medium-consistency stock flows.

Pulp stock flow modes

From previous studies to evaluate consistency effects on pipe flow, we know that the behavior of pulp stock flow depends strongly on velocity (2). When the velocity of pulp stock is low, the pulp flows in the pipe like a solid plug and forms "rolls" that spin between the plug and pipe wall.

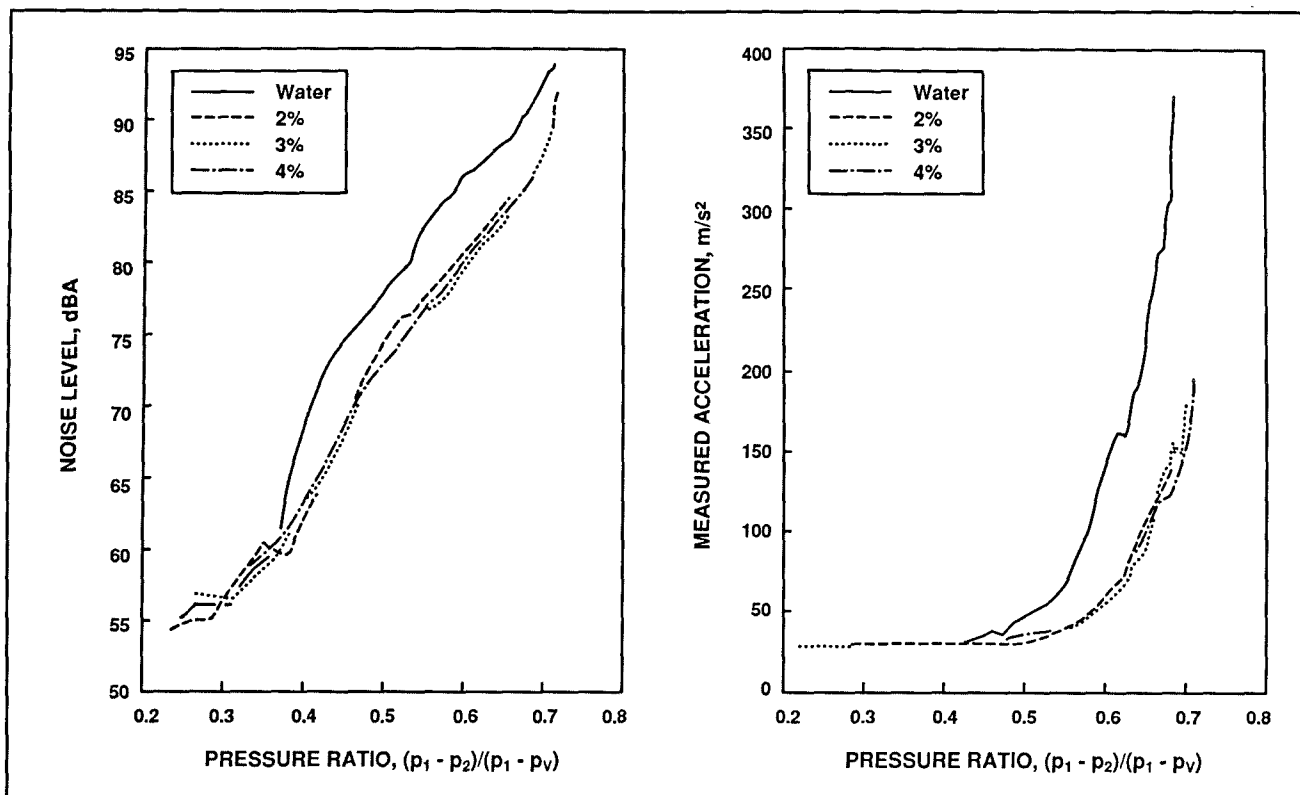
As the velocity increases, the flow changes into plug flow, as depicted in Fig. 2. The fibers no longer touch the pipe wall, but there is a narrow boundary layer between the plug and the inside diameter of the pipe. In this mode, the pressure loss stays relatively constant in spite of velocity changes and can even have an inverse relationship to velocity increases. In Fig. 3, this uncertain relationship between pressure and velocity is represented as the unstable region.

As the velocity is increased, the thickness of the boundary layer increases. Turbulence appears in the boundary layer and at the surfaces of the plug, but the center of the plug retains its identity. This mode is called "mixed flow" (Fig. 2). When the velocity increases further, the plug disappears, and the flow becomes turbulent across the entire cross section of the pipe.

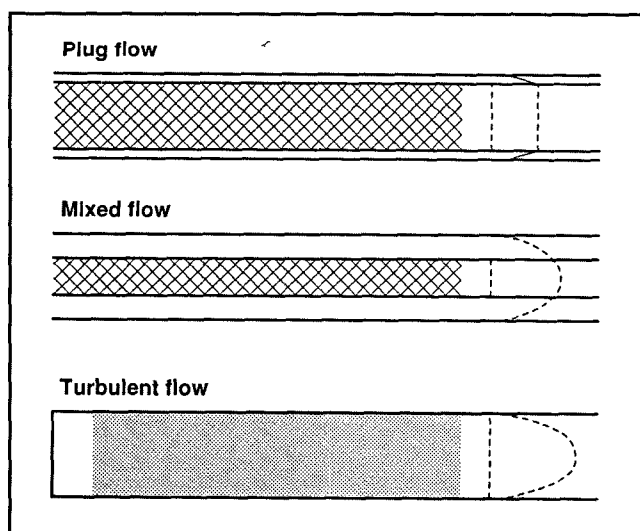
Note also in Fig. 3 that at high velocities the pressure loss of pulp stock can be lower than that of water (2).

Andrews is director of sales engineering with Pande Controls, Box 279, Pelham, Ala. 35124-0279. Husu is manager of control valve marketing with Neles-Jamesbury, Helsinki, Finland.

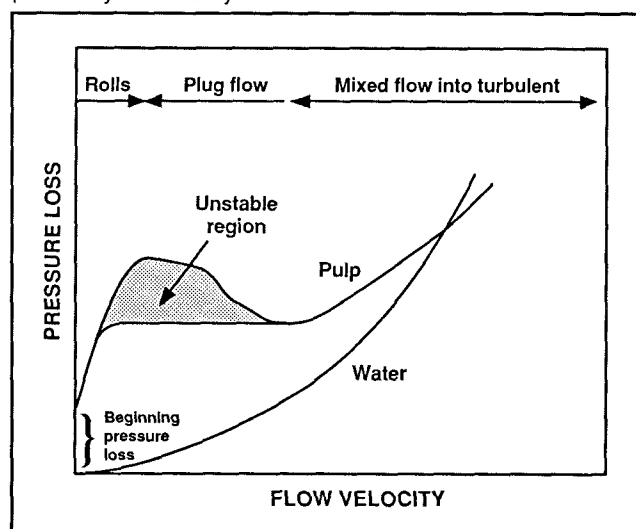
1. The effect of consistency on noise level and on pipe vibration for water and for pulp at three consistencies (1)



2. As its velocity increases, the mode of pulp transport changes from "plug flow" to "mixed flow" to "turbulent flow."



3. The modes of pulp flow change with increasing velocity, but there is an unstable zone through which the pressure does not increase predictably with velocity.



New studies on sizing control valves

New studies at the University of Oulu in Finland provide more accurate data for predicting the pressure loss in control valves for pulp stock. These studies, sponsored by Neles-Jamesbury, included over 2000 measurements of pulp stock flow as it moved through control valves.

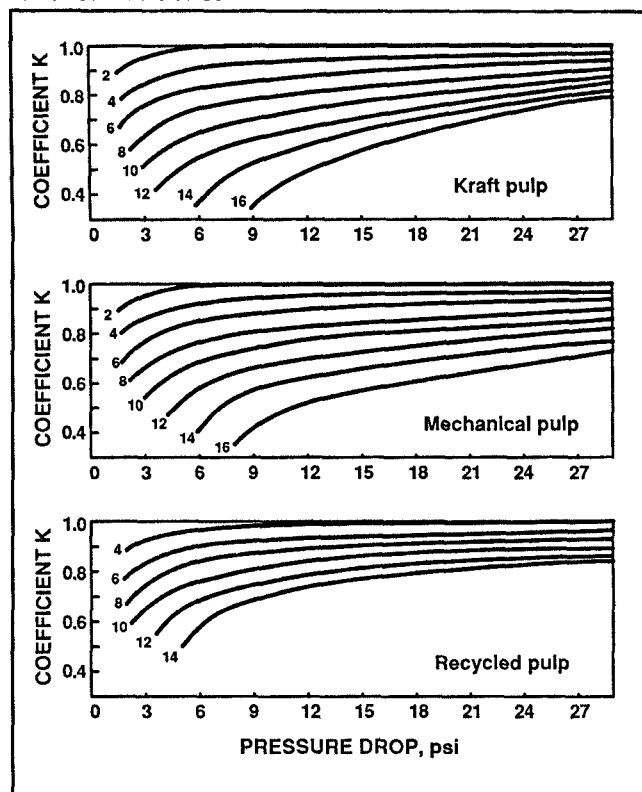
Several pulp stocks were studied, and these fell into three groups: bleached kraft pulp, thermomechanical

pulp, and recycled pulp. The control valve styles were: ball valve, V-ball (segmented) valve, and butterfly valve. The valve sizes were 50 mm (2 in.), 100 mm (4 in.), and 200 mm (8 in.). Each style of valve was tested in all three sizes for all three types of pulp.

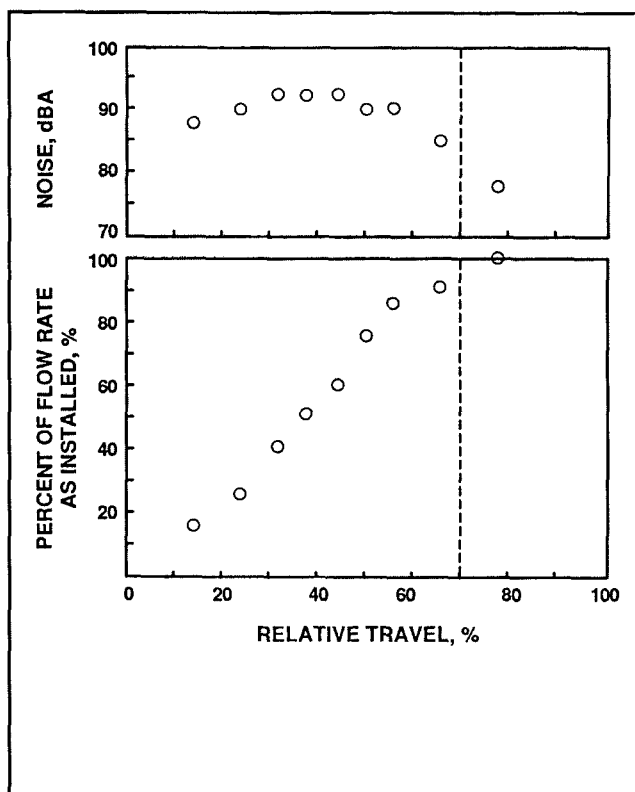
Correction coefficient

An empirical correction coefficient K was found in the tests, where K is determined by Eq. 1:

4. Correction curves for each type of pulp stock at consistencies from 2% to 16% as indicated



5. Noise level and the installed flow characteristic of a typical control valve



I. Parameters of the computer program for sizing control valves

	Flow rate, gal/min	
	2500.0	500.0
Pipe diameter, in.		
Inlet	10.00	10.00
Outlet	10.00	10.00
Consistency, %	6.00	6.00
Temperature, °F	140.00	140.00
Pressure, psi	65.00	80.00
Vapor pressure, psia	2.889	2.889
Pressure differential, psia	25.00	40.00
Rated reducer corrected maximum capacity, $F_p C_v$	1314.90	1314.90
Calc. required capacity, C_v	530.58	79.60
Calc. percent of opening, %	71.951	26.37
Angle of opening, °	66.44	28.16
Noise, dBA	81.7	76.0
Fluid velocity (inlet), ft/s	17.059	3.238
Terminal pressure drop, psi	45.36	66.88
Fluid		
Description: Mechanical pulp		
Consistency: 6.0%		
8-in. V-ball control valve.		

$$K = Q_s / Q_w \quad (1)$$

where

Q_s = flow stock

Q_w = equivalent flow of water.

Note that the corrected water flow rate, Q_w , is used in calculating the size. In this way, the valve is sized with correct sizing parameters (F_L , F_p) that relate to the actual opening of the control valve. (F_L is the liquid pressure recovery factor in ISA and ANSI calculations. F_p is the pipe swage factor, needed because the valve is usually smaller than the pipe: an 8-in valve for a 10-in. pipe, for example.) Previously, a correction factor was applied to the required water capacity, C_v , after the calculation.

The results on different size control valves and different quarter-turn valve types were found small enough to justify using a single set of correction curves for each type of pulp stock. These curves are presented in Fig. 4.

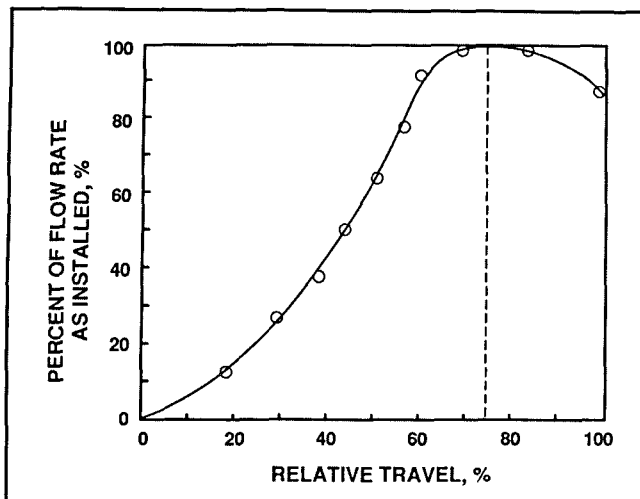
The effect of differential pressure

The differential pressure across a pulp stock control valve has the greatest effect on the correction coefficient K . Low differential pressures require a large correction (a small K value). The higher the differential, the less the correction needed.

The effect of consistency

The effect of consistency on the correction coefficient was considerable. When consistency increases, the value of correction coefficient K decreases. For all consistencies

6. The installed flow characteristic for a V-ball control valve, with a pressure drop at maximum flow equal to 1/3 of the pressure drop at zero flow



less than 2%, the correction coefficient is 1.0; in other words, it is treated like water.

The effect of stock type

Of the stocks tested, all fell within only three types, each of which has its own set of factors and family of curves. The three were bleached kraft pulp, thermomechanical pulp, and recycled pulp.

The effects of other factors

The following had too little effect to warrant separate K factors for practical purposes:

1. Valve size
2. Valve style, among one-quarter turn valves
3. Freeness
4. Inlet pressure.

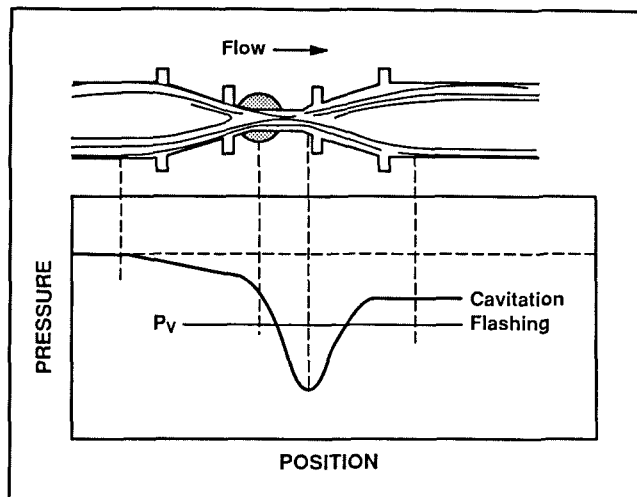
Sizing

To facilitate the use of these new data, the new factor K and the widely used C_v and F_L sizing factors have been included in the database of a computer program for sizing control valves. Highlights of this program are shown in Table I and in Fig. 5.

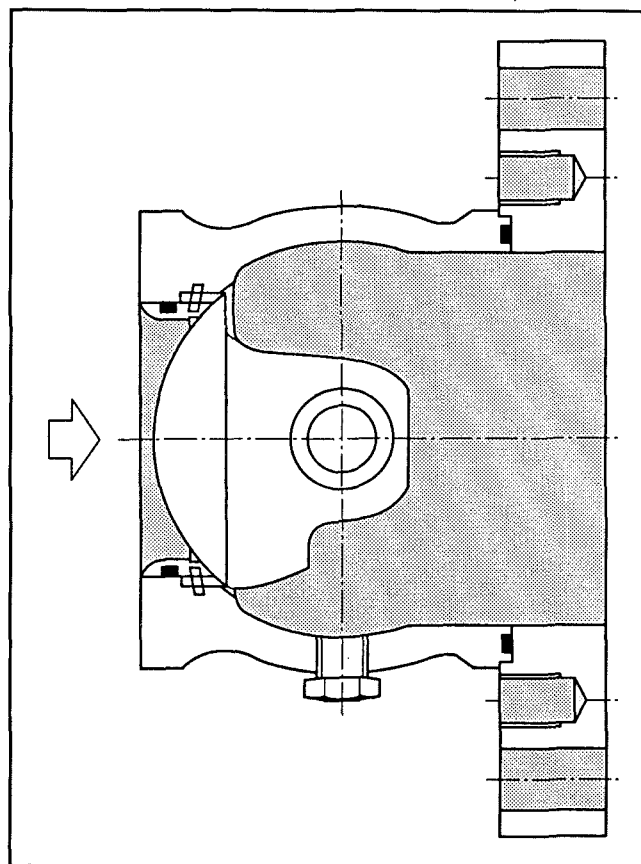
After the sizes have been calculated (for up to four flow rates), you can calculate a curve for installed flow characteristics vs. travel (% of maximum opening). (A gain curve can also be calculated.) The flow rates and pressure drops used must be from actual pump calculations, which are seldom available. If only one flow rate and pressure drop has been entered, the program calculates flow and gain under the assumption that the pressure drop at maximum flow is 1/3 of the pressure drop at zero flow. (At zero flow, the valve is completely closed. Incidentally, the fraction can be changed by the user.)

Figure 6 shows the installed flow characteristics for a V-ball control valve on medium-consistency mechanical pulp in typical process piping in which the pressure drop at maximum flow is 1/3 the pressure drop at zero flow.

8. The phenomena of cavitation and flashing relate to the loss of pressure.



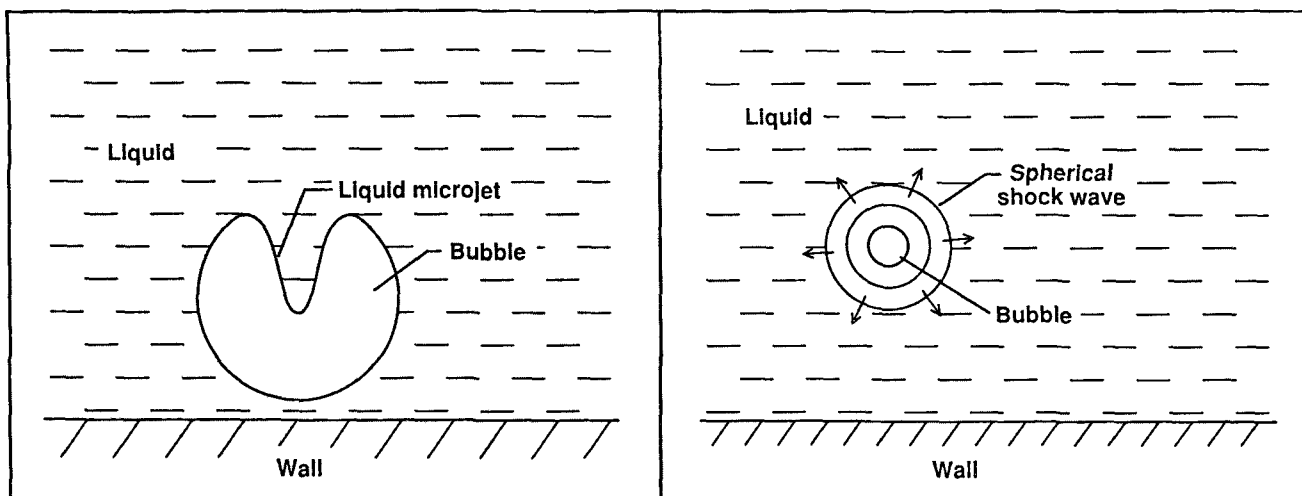
7. A V-ball control valve with an expanded outlet. The inlet is 8 in. (about 200 mm), and the outlet is 10 in. (about 250 mm).



Note that the actual flow capacity falls off although the valve is opened wider and wider. For the process, this would be an unacceptable condition indicating dynamic instability (cycling). This kind of problem can occur in a control valve for discharge control using a medium-consistency pump, a difficult application.

One solution is to mechanically limit the valve's

9. When the vapor bubble collapses close to a wall, the pressure shock takes the form of a microjet. Otherwise, a spherical shock wave develops.



maximum opening to about 60% or 70% open in order to maintain process stability. A better solution is to use an expanded-outlet V-ball control valve with a higher C_v (flow capacity) than a standard V-ball valve. An example is illustrated in Fig. 7. This new and unique valve was developed for this specific purpose for medium-consistency pulp with a small stock-correction coefficient K .

Cavitation, noise, and damage

Cavitation has been covered in many earlier works (3, 4). Figure 8 shows the plot of pressure vs. position of liquid flowing through a control valve that is partly open. When the outlet pressure leaving the valve is at the vapor pressure P , we have flashing.

When the pressure leaving the valve has recrossed and is above the vapor pressure, the vapor bubbles collapse, and we have cavitation, a much worse condition. The collapsing vapor bubbles cause a high-pressure shock wave.

Damage

As illustrated in Fig. 9, the pressure shock from the collapsing vapor bubbles takes the form of either a liquid microjet or a spherical shock wave. If the vapor bubble is very close to a solid wall or in contact with it, the collapsing bubbles generate microjets that can hit the wall collectively with a pressure shock on the order of 10,000 MPa (1,450,000 psi).

Shock waves are generated when the bubbles collapse further away from solid walls, inside the liquid. The pressure shock in this case is on the order of 1000 MPa (145,000 psi). The further away from the wall, the less the effect. A microjet or shock wave can cause yield or surface cracks on the material. The appearance of a cavitation-damaged surface is rough and spongy, with sharp edges where it undercuts hard chrome-plated or hard alloy surfaces.

The mechanical damage of cavitating valves has been shown to correlate closely with the noise level (4, 5). The maximum noise level is reached before or as the valve

becomes choked with vapor, at which point we have "choke flow," as it is known. When cavitation occurs, the location of bubble collapse and the source of noise can be in the valve itself or in the downstream piping. If it is downstream, the cavitation damages the piping unless there is a sudden enlargement, such as would occur should the stream enter a flash tank.

The focus of an earlier paper was on various approaches that could be used to avoid cavitation by selecting the proper control valve and changing process conditions (3). There is no firm guideline or design limit that will ensure that no damage will occur. For gas or steam noise, by contrast, there are OSHA limits that are well below the point of valve or pipe damage. Thus, the engineer has a much more difficult task in setting limits on the conditions of valve selection to ensure that the installation will not be troublesome.

Noise

The coefficient of cavitation K_c (an ISA/ANSI control valve factor, published in table or curve form by most manufacturers) was developed primarily for the globe-style control valve. It is defined as the conditions that give a 2% reduction in capacity, which is hard to measure accurately with high-capacity rotary control valves. Occasionally, its use has led to bad cavitation. Note in Table I that the control valve sizing program displays only the terminal pressure drop and not the value of "incipient cavitation."

The program does display the noise generated by the cavitation, or more specifically the implosions of vapor bubbles against metal. This noise indicates what is going on in the valve and is therefore a good measure of potential cavitation damage. The size of the control valve is a factor in the prediction, and this factor is reflected in the program's noise limits:

- Less than 75 mm: 80 dBA
- 100–150 mm: 85 dBA
- 150–350 mm: 90 dBA

- 400 mm and up: 95 dBA.

From these values can be deducted the noise reduction shown in Fig. 1, typically 5 dBA for pressure ratios of 0.4 and higher.

Cavitation and corrosion

Although cavitation damage can be a purely mechanical phenomenon, it is often related to corrosion. In this case, the shock waves or microjets break the passivating film covering a metal surface. The passivating film is essential to the corrosion resistance of the material. Base metal is consumed in renewing this passivating film, and this causes a loss of material from the metal.

Erosion from two-phase liquid-vapor or from flow of very high velocity causes material wear and damage, but the damage appears as a smooth surface. When the fluid is corrosive, the passivating film is broken by erosion and therefore is subject to greater damage than from either separately. In this case, damage depends on the corrosive nature of the fluid, the fluid velocity, and the valve material.

Predicting the wear rate

An equation for expressing the relation between wear and flow velocity is:

$$E = k \times V^N \quad (2)$$

where

E = wear rate

k = a constant

V = velocity

N = wear exponent.

The value of the wear exponent in this equation can be as high as 7, but in normal erosion the value of the exponent is roughly 2.5. The wear exponent is also closely related to the materials used.

Where there is cavitation, close attention should be paid to selecting the correct trim style and materials to avoid damage related to cavitation and corrosion. Equation 2 gives basic means for doing this:

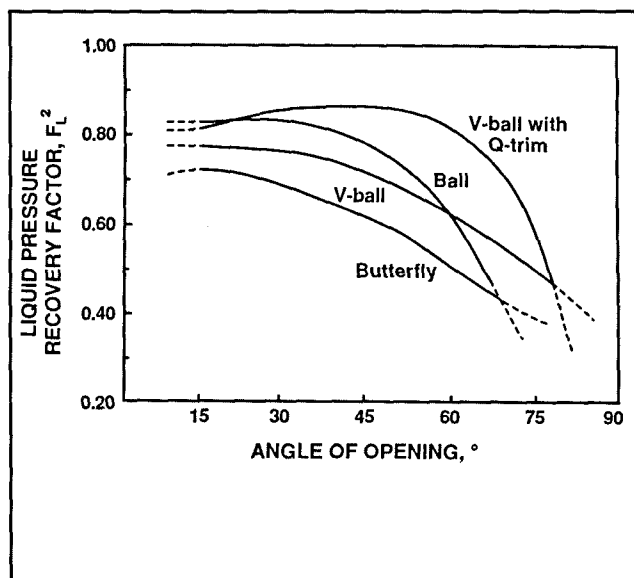
1. Reduce flow velocity V inside the valve. Use multistage pressure drop trim to reduce valve trim velocities.
2. Reduce the wear exponent N . Use materials to minimize its value.

Selecting the valve trim material

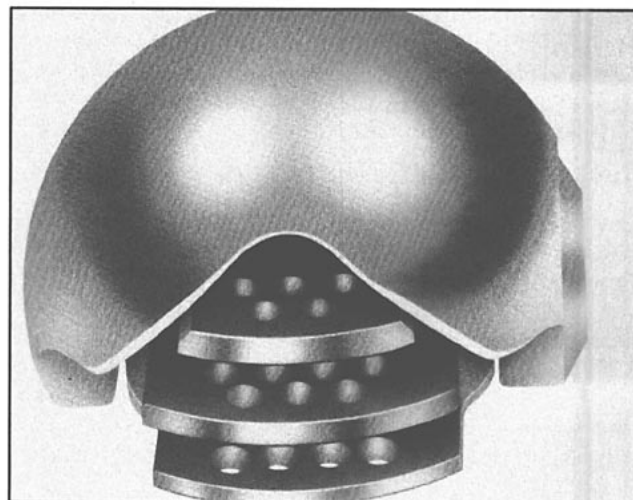
The resistance to damage of various materials has been ranked in order of decreasing resistance by Driscoll (6). Based on more recently developed trim materials, we have amended that list:

1. Tungsten carbide, solid
2. Strengthened ceramics
3. Solid Alloy 6 (chrome-cobalt)
4. 440C stainless steel
5. Alloy 6 over 316 stainless steel

10. Angle of opening for several types of rotary control valves



11. Inlet view of the Quiet V-ball inlet view



6. 400 series stainless steel
7. 17-4 PH hardened stainless steel
8. 316 stainless steel
9. Cast iron
10. Chrome moly steel
11. Nodular iron
12. Carbon steel (WCB)
13. Brass (B-16).

Note the low standing of carbon steel and the high ranking of cast iron, a material of lower cost. For condensate service, a globe control valve with a cast-iron body and hardened stainless steel trim material is a cost-effective choice.

For pulp stock and white water, stainless steel pipe is commonly used. Because the body should be 316 or 317 stainless steel, the choice of material should be based on selecting trim material for a cost-effective control valve.

A new valve configuration

The choice of control valve style is more involved, as discussed earlier (3), and **Fig. 10** shows the key variables. Since then, another unique valve configuration has been developed. It is a V-ball (segmented ball) control valve with built-in multi-stage diffuser plates called "Q-trim" to reduce the velocity. The valve is a cost-effective solution to many cavitation problems.

This control valve is shown in **Fig. 11**. Note that the flow is through the trim at an angle. This angle changes as the valve opens, so that on closed-loop control it tends to be self-cleaning. Its use is limited to pulp stock up to 3% consistency, provided the pulp has been screened of shives and knots. Fortunately, this is a consistency level at which cavitation damage is less of a problem.

The sizing program calculates the cavitation noise as a guide and a warning of potential damage. At high levels of noise, it flashes the noise value. As a consequence, cavitation is substantially reduced or even eliminated. As mentioned, the noise reduction of up to 5 dBA for stock should be deducted manually and noted in printout remarks.

Conclusions

As the result of laboratory studies in Finland and better

data, engineers are better able to correctly size and select control valves for pulp stock and white water service. A control valve sizing program has been developed based on the results of those studies. Recent variations added to the V-ball control valve render it more suitable as a cost-effective control valve. □

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