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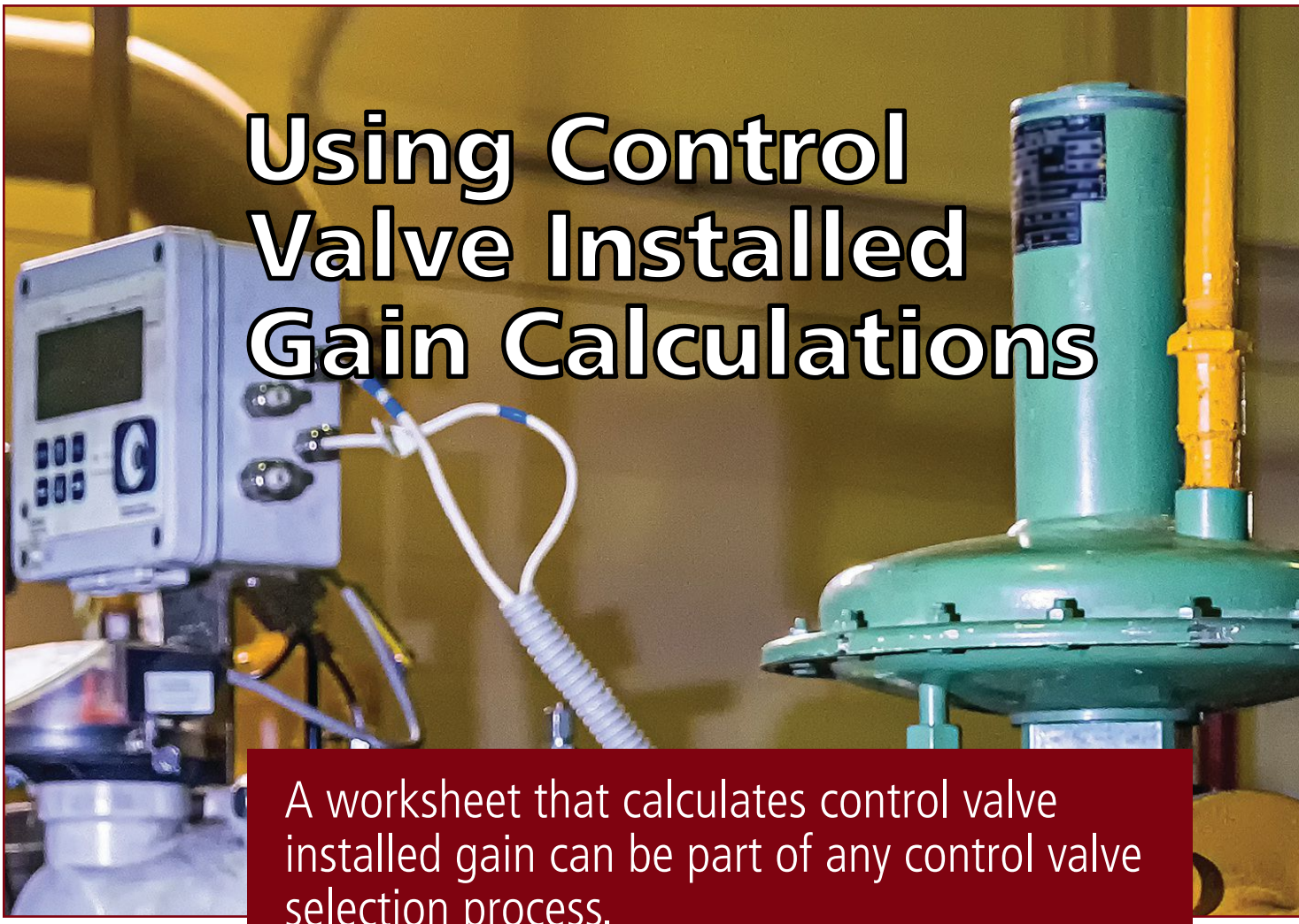


Using Control Valve Installed Gain Calculations

A worksheet that calculates control valve installed gain can be part of any control valve selection process.

By Jon F. Monsen, PhD, PE

For many years, the author has used, and promoted the use of, control valve installed flow and gain graphs as part of the control valve selection process (references 1–3). For all those years, the author has had the benefit of being associated with a valve manufacturer with a publicly available control valve-sizing application that included installed flow and gain graphing capability. Users who preferred other brands of control valves, and thus those manufacturers' control valve-sizing applications, were hesitant to learn to use a new application to take advantage of the graphing capability.

Recently, the author published an article that included detailed instructions for constructing a Microsoft Excel worksheet (www.control-valve-application-tools.com) that generates installed flow and gain graphs in conjunction with valve-sizing calculations made with any valve-sizing application. This makes it practical for anyone to incorporate graphing installed flow and gain into their valve selection process (reference 4). This article explains how to use control valve installed gain calculations.

Figure 1 is an example of a properly sized valve compared to an oversized valve. One valve manufacturer suggests the following gain criteria for installed gain within the specified flow range:

- Gain > 0.5
- Gain < 3.0
- As constant as possible
- As close to 1.0 as possible
- Gain (max) / Gain (min) < 2.0.

Extremely low gains are undesirable, because a low gain means when the valve moves, the flow does not change by much. It might not be as obvious why high gains are undesirable. An audio amplifier with a high gain may be desirable. But control valves are mechanical devices, and parts that move while in contact with each other tend to stick when not moving. If a valve, because it tends to stick when not moving, can only be positioned within 2 percent of the desired position and has a gain of 4, the flow can only

FAST FORWARD

- An Excel worksheet makes it practical to include the graphing of installed flow and gain in the valve selection process.
- Extremely low gains are undesirable, because a low gain means that when the valve moves, the flow does not change by much.
- Pump selection affects installed gain and installed flow.

be adjusted within 8 percent steps, which may not be desirable. The reason for limiting the gain change within the required flow range to 2:1 is so it will be easier to tune the controller for stable and fast response throughout the required flow range.

To calculate and graph the installed flow and gain using the reference 4 worksheet, the process model and the worksheet require the following information about the process:

- The minimum design flow, Q_{min}
- The maximum design flow, Q_{max}
- The valve inlet pressure at the minimum design flow, $P_{1\ minQ}$
- The valve inlet pressure at the maximum design flow, $P_{1\ maxQ}$

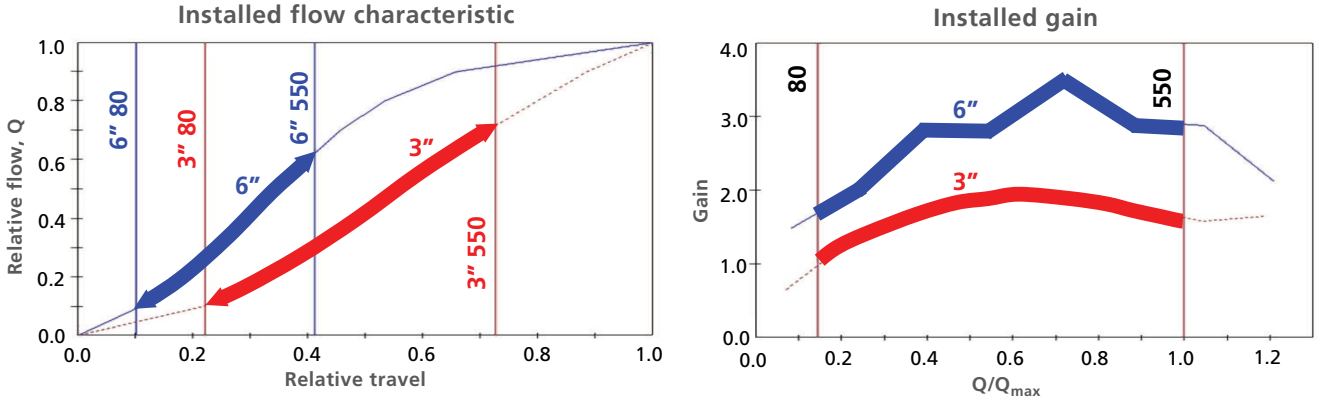


Figure 1. Control valve installed flow and installed gain characteristics comparing a properly sized 3-inch valve and an oversized 6-inch valve in the same system. Emphasis is added to show the portion of the graphs that fall within the user's specified flow range between minimum and maximum required flow of 80 to 550 gpm.

Control valve sizing: Liquid				
Flow	gpm	Q	200	1000
Inlet pressure	psiA	P_1	90	60
Pressure drop	psi	DELTA_P	35	5
Specific gravity		G	1	1
Vapor pressure	psiA	P_V	0.5	0.5
Critical pressure	psiA	P_C	3208	======>
Recovery factor		F_L	0.94	0.8
Inlet pipe diameter	inch	D_1	8	======>
Outlet pipe diameter	inch	D_2	8	======>
Valve size	inch	d	6	======>
Valve style SPL code		VSC	2	======>
Pipe wall correction	dB(A)	DeltaLp	-2	======>
Required flow coef. (Cv or Kv)		Cv	33.81	458.78

Metal seated V-port segment valve

SIZE		Relative opening h									
DN	INCH	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
	6	13.9	34.1	67.2	115	178	258	352	484	719	1260

About 20% to 78% open

Figure 2. User's calculation of required valve C_V at maximum and minimum design flows and valve manufacturer's C_V table for a 6-inch segment ball valve.

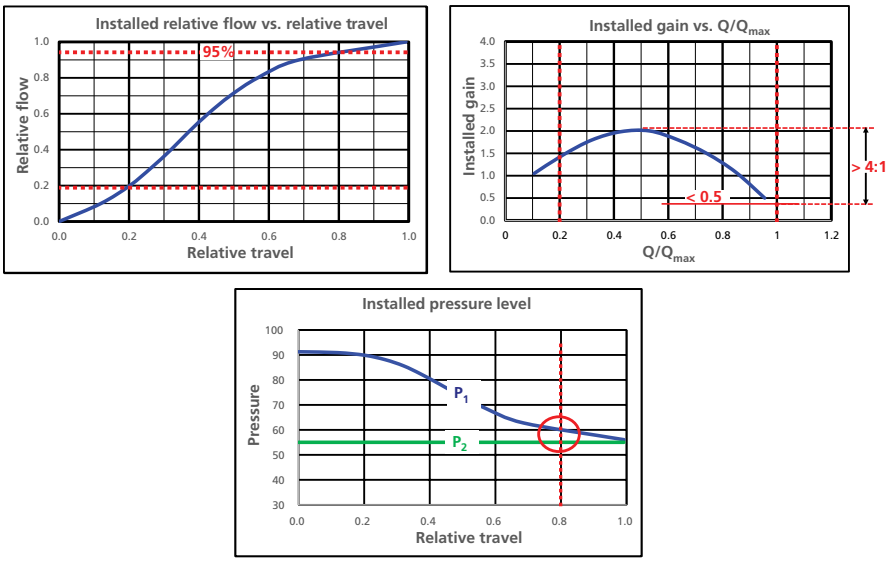


Figure 3. Installed characteristics of the valve proposed in figure 2.

- The valve outlet pressure at the minimum design flow, $P_{2\ minQ}$ (calculated from the user's input of the valve pressure drop at the minimum design flow, DELTA P_{minQ})
- The valve outlet pressure at the maximum design flow, $P_{2\ maxQ}$ (calculated from the user's input of the valve pressure drop at the maximum design flow, DELTA P_{maxQ}).

The values of P_1 and P_2 at the minimum and maximum design flow need to be obtained by an analysis of the frictional pressure losses and static pressure changes in the system upstream and downstream of the control valve (references 5–6).

Reference 4 prompted several inquiries as to what applications would be candidates for installed flow and gain graph analysis. Below are some of the most common.

Surprising results

Figure 2 shows a user's Excel control valve-sizing worksheet. The calculated C_V range appears to show a 6-inch segment ball control valve would be operating at about 20 percent to 78 percent open from the minimum design flow to the maximum design flow. An installed flow and gain calculation yielded surprising results (figure 3).

The installed flow graph shows the minimum specified flow intersecting the installed flow graph at 20 percent relative travel, and the maximum design flow intersecting the installed flow graph just a bit below 80 percent relative travel, which agrees with the user's calculation. What the user's calculation did not show is 95 percent of the valve's fully open flow is at the maximum design flow, leaving no safety factor at the high end.

At about 60 percent travel (relative travel of 0.6), the installed flow graph starts rounding off to a much shallower slope. This fact is identified on the installed gain graph where the installed gain drops to below 0.5, emphasizing the fact that changes in valve position would have only a small effect on flow in the system. The gain change from the maximum design flow (Q/Q_{max}) and the maximum gain on the graph is greater than 4:1, making it difficult to tune the controller for fast and stable control. It turned out the problem lies with the user's pump choice.

Reference 4 does not include the ability to graph what is happening to P_1 and P_2, and thus the pressure differential available to the valve. However, the reference 4 worksheet has a tabulation of P_1 and P_2, so constructing a graph of P_1 and P_2 versus relative valve travel was simple. In the installed pressure level graph, as valve relative travel approaches 0.8 (80 percent valve travel), the pressure drop available to the valve decreases rapidly.

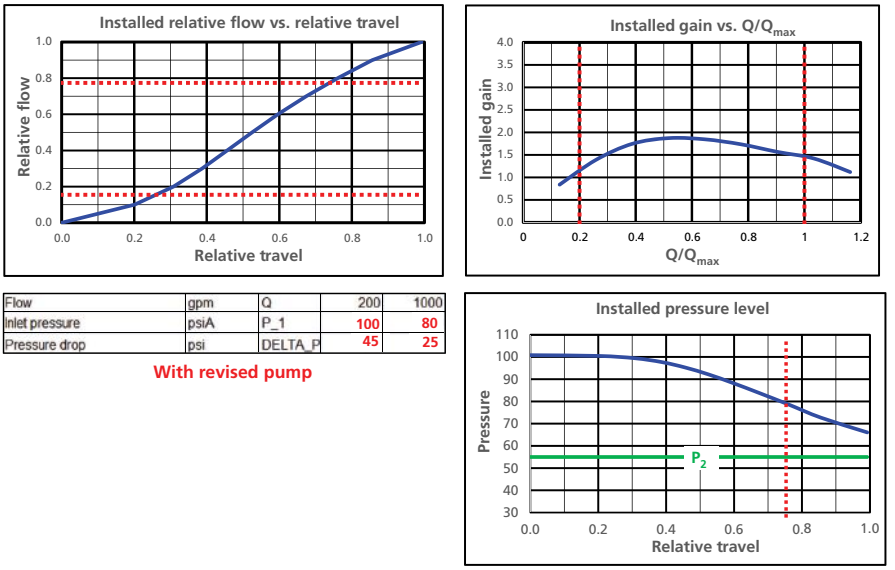
Different pump, different valves

The user found a pump with a slightly higher and flatter head curve. A new analysis of the upstream system gave the revised values of P_1 and DELTA P shown in red in figure 4. Putting these new values of P_1 and DELTA P into the user's valve-sizing program and into the reference 4 worksheet gives the graphs of figure 4. The valve is now operating between 25 percent and 75 per-

cent travel. The maximum design flow is now at slightly less than 80 percent of the fully open flow, giving ample safety factor at the high end of the range. The installed gain graph is much flatter and well within the suggested limits.

Figure 5 is based on an application where the system designer recommended a 10-inch segment ball valve after examining the installed flow and gain graphs and determining the segment valve was a good choice. The purchasing agent commented that a 10-inch high-performance butterfly valve would cost approximately one-third less than the segment ball valve. The system designer agreed to investigate the applicability of a high-performance butterfly valve, knowing the two valve styles have quite different inherent flow characteristics. Segment ball valves tend to have a nearly perfect equal percentage characteristic. High-performance butterfly valves tend to have an inherent flow characteristic between linear and equal percentage.

The upper right graph in figure 5 compares the inherent flow characteristics of the two valves being considered. The installed characteristics are linear between the design minimum and maximum flows. The installed gain of each valve meets the suggested gain limits between the minimum and maximum design flows. The gain of the segment valve is slightly closer to 1.0. The maximum gain change of the butterfly valve is 1.4:1, where the maximum gain change of the segment valve is 1.6:1. In this system, either valve would likely control satisfactorily. In a system with different valve pressure drop versus flow characteristics, this might not be the case.



Flow	gpm	Q	200	1000
Inlet pressure	psiA	P_1	100	80
Pressure drop	psi	DELTA_P	45	25

With revised pump

Figure 4. Installed characteristics of the valve with the revised figure 2 pump pressures shown in red.

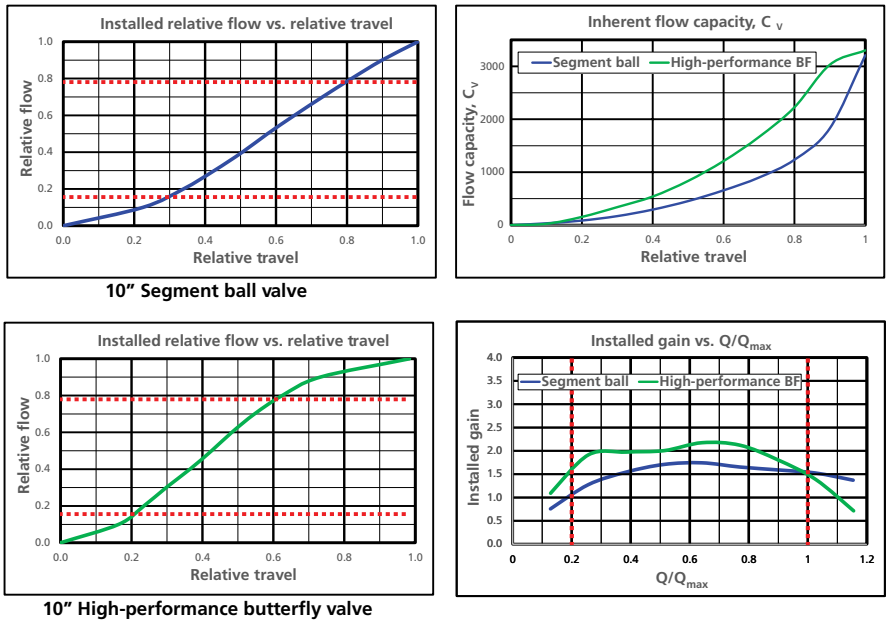


Figure 5. Comparison of a segment ball valve and a high-performance butterfly valve in the same system. The installed gain of both valves is plotted on a single graph.

Which pressure drop?

A question arose regarding the pressure drop to use when sizing a control valve. Assuming a system that has already been designed, the sizing pressure cannot be arbitrarily assigned, but the values of P_1 and P_2 need to be obtained by an analysis of the frictional pressure losses and static pressure changes in the system both upstream and downstream of the control valve. The ideal situation is where the person selecting the control valve has a say in determining what the control valve pressure drop will be, most often by specifying the pump that will be used. Using an installed gain analysis of various pumps that might be suitable can be helpful.

To demonstrate how this can be done, three possible pumps for the system shown in figure 6 will be considered, and the one that allows satisfactory controllability while minimizing energy consumption will be selected. Curves of P_1, the pressure just upstream of the valve, are shown for each of the three pumps, along with the power required by each at a normal flow rate of 400 gpm. These curves slope downward in proportion to the flow squared from the 100 gpm pump head (45, 60, and 75 psig, respectively, for pumps A, B, and

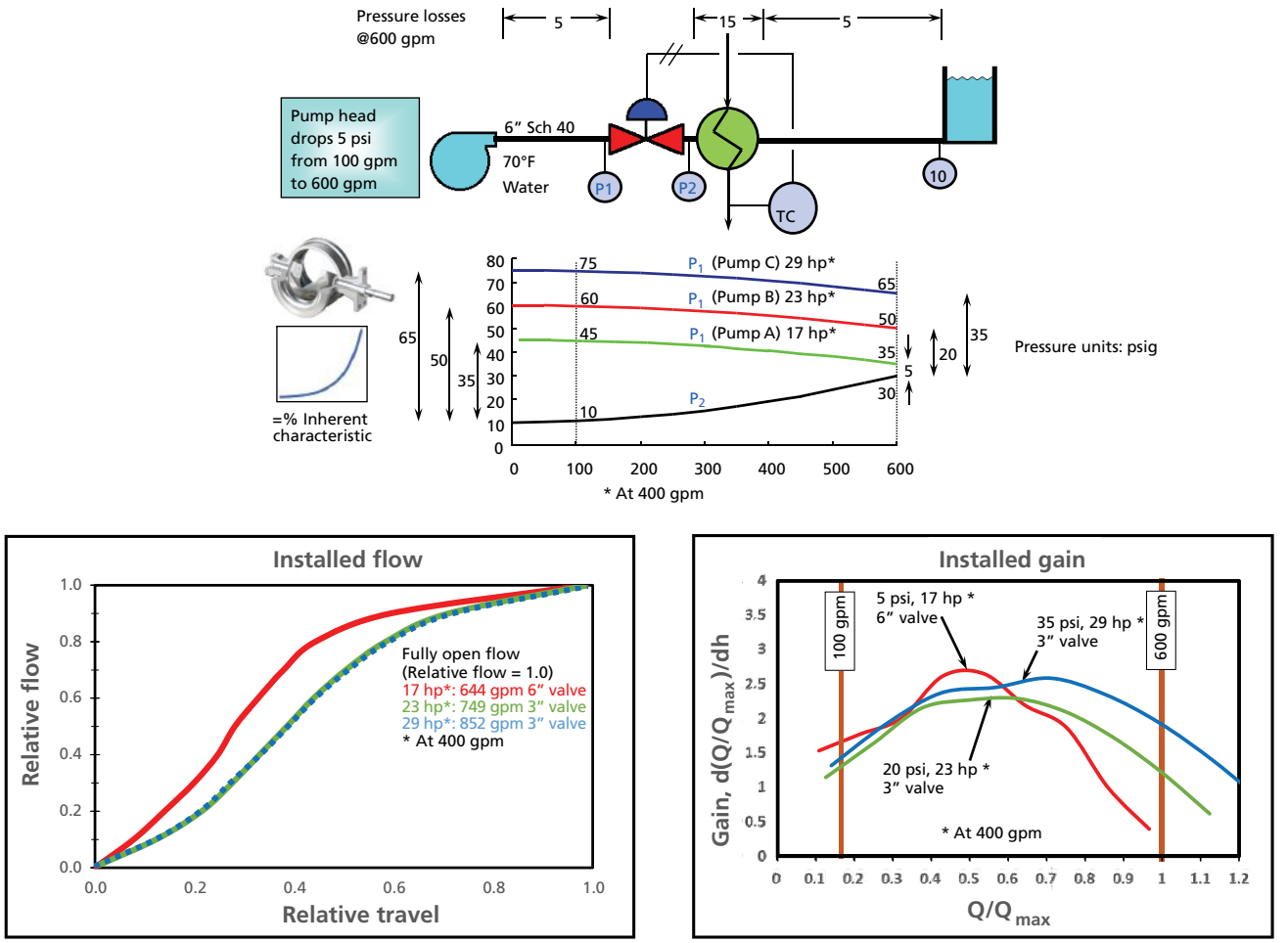


Figure 6. Control valve installed gain analysis helps balance pumping energy and process controllability.
Segment valve graphic courtesy of Neles

C) to a pressure 10 psi lower due to the combined effect of the 5 psi pressure loss in the upstream piping and the 5 psi decrease in pump head from 100 gpm to 600 gpm stated in the figure. The curve for P_2, the pressure at the control valve outlet, starts with the 10 psig static head of the tank at very low flows and increases in proportion to the flow squared to 30 psig as the downstream piping and heat exchanger pressure losses increase to their 600 gpm values.

The control valve pressure drops (the difference between P_1 and P_2) are indicated in the figure by the arrows at the left side of the figure for 100 gpm and at the right side of the figure for 600 gpm.

The ideal situation is where the person selecting the control valve has a say in determining what the control valve pressure drop will be, most often by specifying the pump that will be used.

The analysis is performed based on using a segment ball valve. The graph in the lower left of figure 6 shows the calculated installed flow characteristics. Keep in mind the installed flow graphs generated by the worksheet of the reference 4 graph is relative flow, so 1.0 is 100 percent of the fully open flow, which is different for each of the three cases. What is interesting is the installed gain graphs.

With the 17-hp pump, besides requiring a more expensive 6-inch valve, the gain graph looks terrible. The installed gain is the highest of the three (meaning a larger flow error for the same valve position error), it drops to 0.4 as it approaches the maximum design flow (the red vertical line at 1.0 on the Q/Q_{max} scale), and the variation in gain over the flow range is almost 7:1, much greater than the recommendation of 2:1. This is large enough that it would be difficult to come up with proportional-integral-derivative (PID) tuning parameters that would provide good and stable control over the entire required flow range. The gain graphs of the 23-hp and 29-hp pumps fall within the recommended gain criteria, but the 23-hp pump is the winner, because its gain is closer to 1.0, and it also is the more economical of the two to operate. ■

ABOUT THE AUTHOR

Jon F. Monsen, PhD, PE, (jmonsen@valin.com) is a control valve technology consultant for Valin Corp. , the author of the chapter on "Computerized Control Valve Sizing" in the *ISA Practical Guides Book on Control Valves,* and the author of the book *Control Valve Application Technology: Techniques and Considerations for Properly Selecting the Right Control Valve*. With his more than 40 years of experience, he has lectured nationally and internationally about control valve application and sizing, and he hosts a website (www.control-valve-application-tools.com) where he offers free information and Excel worksheets for those who specify or use control valves.

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RESOURCES

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