BACK TO BASICS

As seen in the Summer 2015 issue of . . .
VALVE MAGAZINE

A high-power boiler burner in a co-generation plant

Flashing and Cavitation

BY BERT EVANS AND RICHARD L. RITTER III

Some of the following questions may seem unrelated, but they all involve key concepts that explain the sometimes-misunderstood phenomena of flashing and cavitation:

- How can relatively clean and clear water damage a valve?
- Why does it take longer to hard boil an egg in Denver than in Los Angeles?
- Why does water squirt farther out of a garden hose when I place my thumb over the end?
- How can the gas in my liquid propane grill last so long?
- What is that noise I hear in a pump when I fail to charge the downstream line?
- Can I prevent flashing and cavitation? If not, can I minimize the damage they cause to valves?

Executive Summary

SUBJECT:

Although flashing and cavitation are often discussed together, there are differences between the two and how they occur. Both can cause significant damage to valves and related equipment.

KEY CONCEPTS:

- The key distinctions
- How each condition occurs
- Strategies for protecting valves

TAKE-AWAY:

The different strategies can help to prevent or eliminate what happens. They also can be combined.

Figure 1. Normal post-guided plug (left) and flashing-damaged post-guided plug (right)

Flashing and cavitation is the answer to that very first question because it can occur with very clean and clear water—with the potential to cause severe erosion damage to valves, piping and other equipment—even without any erosive solids in the water. Figure 1 shows an undamaged post-guided control valve plug (left) and a damaged identical plug that has been severely eroded by flashing (right). Note how the damaged surfaces of the plug on the right appear shiny and scalloped—and how the beveled seating surface (i.e., the geometry that allows the valve to shut off) is completely missing. This illustrates how severe flashing damage can be despite the pureness of the medium.

Figure 2 shows a plug and cage damaged by cavitation. Notice the very different appearance: The plug is dull, dark and grainy (e.g., it looks similar to pumice or lava rock).

These two figures show that, while cavitation damage looks very different compared to flashing, the result is the same: loss of throttling and shut-off capability. Both kinds of damage are the result of related, but very different, processes.

Figure 2. Cavitation damaged plug and cage

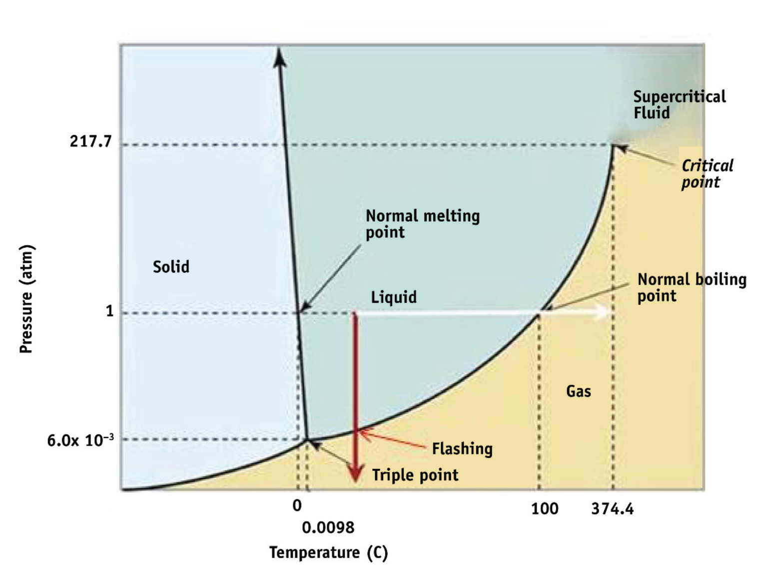


Figure 3. Phase diagram showing boiling and flashing (Machado, 2009)

PROCESS PRESSURE AND VAPOR PRESSURE

The place to begin in understanding the differences is by exploring what the terms “flashing” and “cavitation” actually mean. But to get to that point, we should first discuss another term: “vapor pressure.” The vapor pressure (PV) of a fluid is the pressure at which a liquid will begin the thermodynamic process of changing to vapor.

Figure 3 shows a phase diagram of a single component process fluid such as water and graphically depicts the difference between flashing and boiling. Under a condition of constant temperature, a change in pressure can result in transition from one phase to another. When the local pressure ($P_{process}$) is reduced below the fluid PV, for example, vaporization will begin. In the process industry, if $P_{process}$ does not recover above PV, the fluid will remain in the vapor phase. This process is flashing.

Similarly, under a condition of constant pressure, a change in temperature can also result in a phase change. PV of a fluid increases as the fluid temperature increases. If the fluid temperature is increased to the point where PV exceeds the local pressure (which is often the atmospheric pressure), vaporization will occur. This process is boiling.

In other words, flashing occurs when we lower the pressure at a constant temperature, and boiling occurs when we raise the temperature at a constant pressure. (This ties back to our egg example: It can take a bit longer to boil an egg in Denver than Los Angeles because the average atmospheric pressure is slightly lower

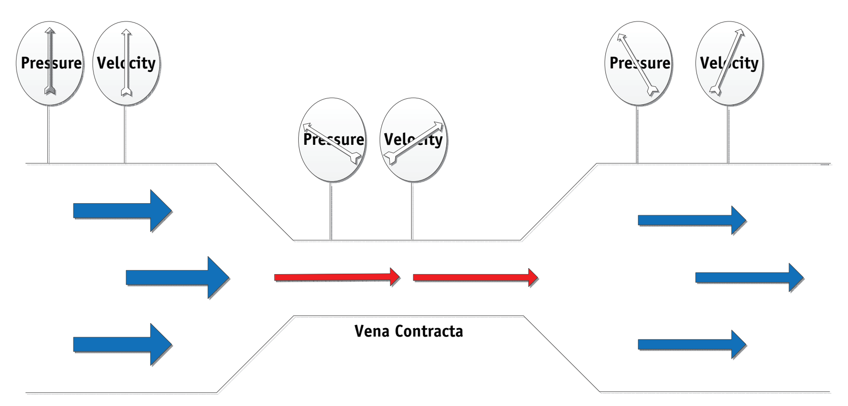


Figure 4. Bernoulli’s principle and the impact of velocity on static pressure

Figure 5. Pressure profile showing vaporization (flashing) of liquid propane, similar to the LP tank on a gas grill

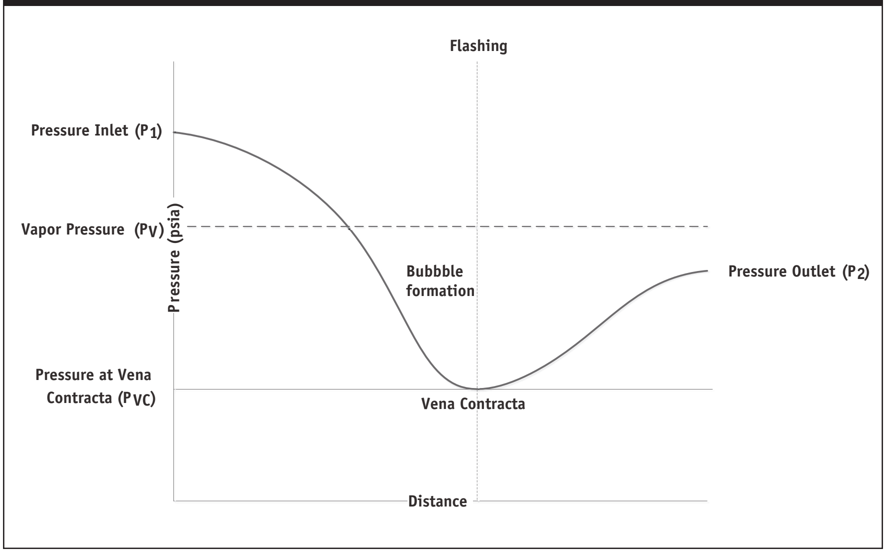
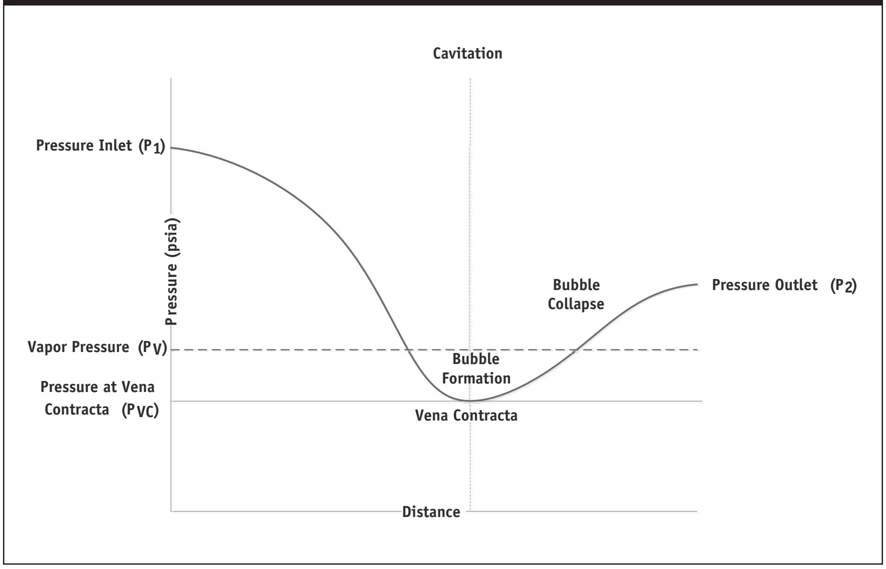


Figure 6. Pressure profile showing how cavitation occurs



in the "Mile-high" city of Denver—water boils at a slightly lower temperature there than it does near sea level.)

Next we look at why flashing happens in industrial processes and piping systems.

When a liquid is flowing through a conduit, such as a pipe or a garden hose, and it encounters a restriction, such as a valve (or your thumb on the end of the hose), it accelerates to a higher velocity. Why does this happen? It occurs because, when a liquid encounters a smaller flow area, the liquid must accelerate to maintain continuity—that is, to retain a relatively constant volumetric flow rate. This is much the same as the way a river tends to meander and run slowly when it's flowing through a wide plain, but becomes fast-moving rapids or whitewater when the river encounters a narrow canyon. Boyle's law, Bernoulli's principle and Euler's formula show us that the pressure in a restricted flow area (such as a valve) will be lower than in a larger pipe section.

These ideas are shown graphically in Figure 4.

FLASHING

If the local pressure within the restricted flow area drops below the vapor pressure of the liquid, which is a condition called the "vena contracta," vaporization occurs (i.e., vapor bubbles would form in the liquid). If the downstream pressure remains below the vapor pressure, the process is said to be a flashing service, and the outlet stream will be predominantly in a vapor phase. When this flow impinges on valve components, it can cause the kind of erosive damage shown in Figure 1. This erosion can be severe and may occur even when no abrasive solids are present in the liquid.

Figure 5 shows an example of flashing that occurs when using a liquid propane (LP) gas grill. At temperatures above -44°F (-42°C), the vapor pressure of propane is greater than atmospheric pressure. However, the tank that contains the LP is typically pressurized to greater than 10 psig so the propane remains as a liquid within the tank. As the liquid passes through the tank-mounted valve and pressure regulator, fluid pressure drops well below its vapor pressure, causing the LP to flash entirely to a vapor. For typical conditions, propane has almost 300 times greater volume as a gas at standard atmospheric pressure (known as 1 atmosphere) than as a liquid within a pressurized tank. That is why the relatively small volume LP tank can last so long on a gas grill.

The gas grill example would be called an "open system," because it ultimately vents to the atmosphere and can exchange matter and energy with that much larger system (our atmosphere). When a liquid flows through a piping system, it often is considered a "closed system," because it can exchange energy but not exchange matter with an external

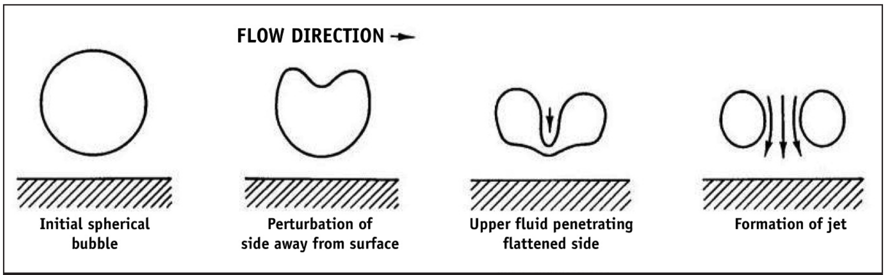


Figure 7. Vapor bubble collapsing as static fluid pressure recovers to above PV

system such as the atmosphere. In closed systems, all process conditions need close consideration to determine whether flashing may occur.

CAVITATION

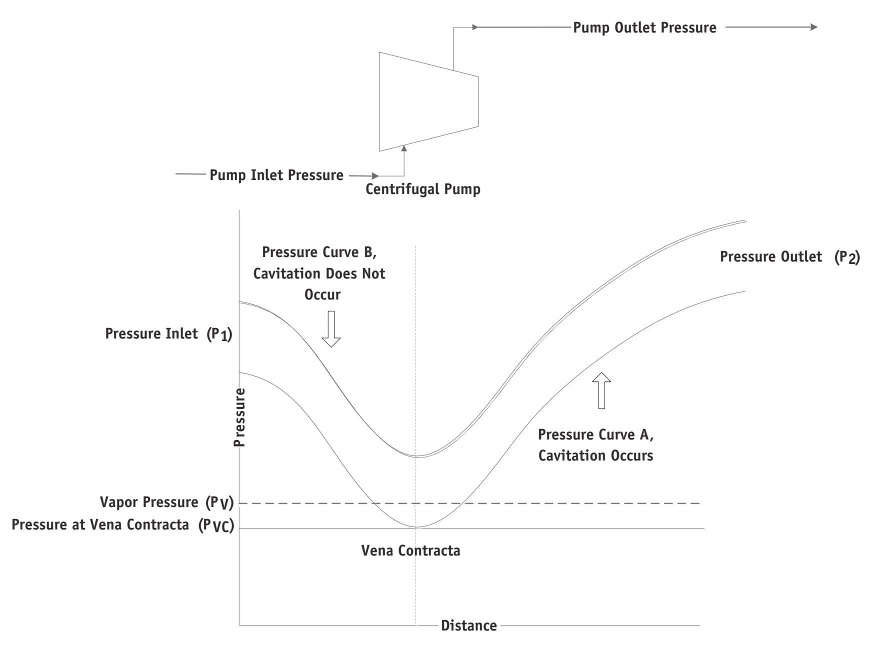
Figure 6 depicts the pressure profile of a process fluid moving from left to right in a closed system. If the PV of the fluid is below the upstream pressure (P_1), above the vena contracta pressure (P_{VC}) and below the downstream pressure (P_2), vapor bubbles can form as pressure drops. In this case the bubbles can suddenly collapse or implode as the pressure recovers, a condition known as cavitation. Cavitation is often energetic, and it has great potential to damage valves in a manner similar to what is illustrated in Figure 2.

The bubble implosions create "micro-jets" of fluid that can impinge on valve component surfaces at high velocities. The bubble collapse can also create shock waves of up to 100,000 psi. Figure 7 shows a schematic of a single vapor bubble collapsing as the surrounding fluid pressure recovers to above the vapor pressure.

When shock waves from local bubble implosion impact against valve component surfaces, typical materials of construction for industrial valves can be work-hardened and fatigued. As the surfaces become brittle and less resistant to local fracture, they also are subjected to liquid micro-jets that essentially deteriorate the material with time. This process creates the grainy appearance unique to cavitation damage.

Figure 8 shows how cavitation occurs in a centrifugal pump. If the pressure at the eye of the pump impeller drops below PV as shown in curve A, vapor bubbles form, then subsequently collapse downstream when system pressure recovers to above PV. A centrifugal pump requires that pressure, temperature and velocity be maintained within the pump design specifications to prevent cavitation. This prevention is essential because cavitation can cause significant damage to the pump impeller, extreme vibration and high noise levels. Ensuring a pump is operated within conditions for which it was selected will ensure the pump does not cavitate, as shown in curve B. In this case, the pressure at the eye of the impeller still drops below the inlet suction pressure of the pump, but the pressure of the liquid at the eye of the impeller remains above the liquid vapor pressure so no cavitation occurs.

Figure 8. Simple pressure drop curves for a centrifugal pump



PROTECTING VALVES FROM DAMAGE

Generally speaking, valve manufacturers use one or more design strategies to protect valves from the potentially detrimental effects of flashing and cavitation. These strategies can be described as "resistance," "isolation" or "elimination."

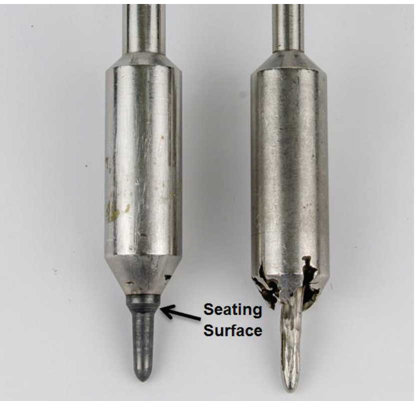


Figure 9. The valve plug on the left has a very hard Alloy 6 tip; the valve plug on the right is made of a softer alloy. Both plugs were exposed to similar flashing conditions for similar durations.

Resistance strategies use materials that are very hard, that have a high fracture toughness or fatigue strength or that are less vulnerable to erosion damage through other means. Isolation design strategies involve designing flow paths that minimize the impingement of flashing or cavitation onto critical valve surfaces. Elimination strategies include using tortuous paths or true engineered staging of pressure drops across the valve. They also include adding a valve or orifice plate to split the pressure drop across multiple devices; this creates a greater P_2 at the first device, reducing the potential for cavitation. Aspirating atmospheric air or injecting higher-pressure air into a valve is a third example of an elimination strategy. Manufacturers may also combine these strategies for heightened protection against damage.

Resistance

Materials of construction should be chosen to resist both mechanical attack and chemical attack. Mechanical attack occurs in two forms: erosion (including abrasive, flashing and/or cavitation) and material deformation and subsequent failure. After a period of mechanical attack, many of the protective coatings of a material (films, oxides, etc.) are physically removed,

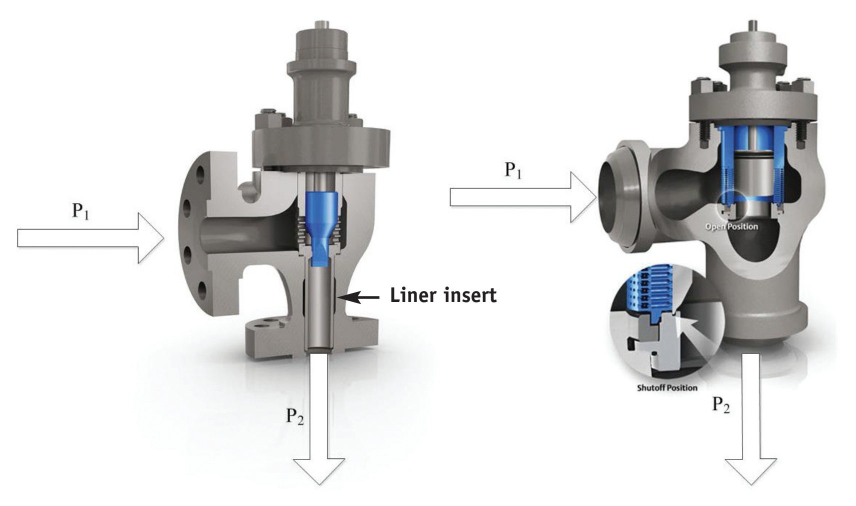


Figure 10. Angle body cutaways

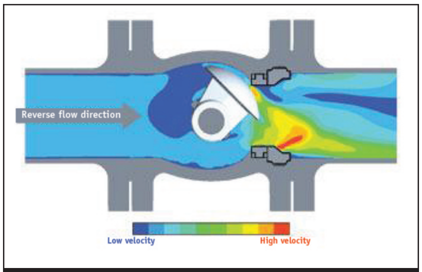


Figure 11. Eccentric plug reverse flow computational fluid dynamics image, showing high velocity region downstream of the plug

making the base material more vulnerable to chemical attack. Figure 9 shows two valve plugs exposed to similar flashing conditions for similar durations.

Isolation

Generally, internal wetted valve components (often called trim) are subject to the highest flow velocities as they control the flow and pressure drop across the valve. These high velocities accelerate abrasive or erosive wear so that wear is a function of duration of exposure and proximity to high-velocity flow regions.

Isolation means directing the flow path in a way that prevents or minimizes impingement of the process fluid onto critical surfaces. Figure 10 shows cross-sectional views of angle body valve designs. Angle valves, when oriented so that the flow passes through the valve as shown in this figure (commonly called a flow-down orientation), allow flashing or cavitation to primarily occur after the fluid has passed through the trim. Ideally, most energy—and potential for damage—associated with flashing or cavitation will then dissipate in the flow stream rather than come in contact with the trim or other valve flow passages.

Also, hardened materials can be used as liners to protect the outlet of the valve as shown in the figure. This is a way to combine the resistance and isolation strategies.

Figure 11 shows a computational fluid dynamics model of an eccentric plug rotary valve, specifically designed for erosive service, in a reverse flow orientation. The high-velocity region of the flow, where the vena contracta occurs downstream of the valve plug, actually occurs past the plug at the valve outlet. Again, isolation and resistance strategies can be combined by flowing in this reverse orientation and using wear-resistant materials for the seat and outlet liner.

Elimination

An elimination strategy also can be used in combination with other strategies, including both resistance and isolation, to treat cavitation. Cavitation can be eliminated by creating more back pressure locally within the valve. However, this approach will not eliminate flashing because the downstream pressure will never recover above the fluid vapor pressure. In rare circumstances, the entire system pressure can be raised above the fluid vapor pressure for all process conditions. (This will eliminate flashing, but may introduce cavitation.) Still, it is much more common to use a design-based elimination strategy to minimize or prevent damaging cavitation.

Drilled hole cages, tortuous paths and other trim designs are used by valve manufacturers to carefully manage the internal vena contracta pressure so it is always above the fluid vapor pressure. This minimizes or prevents the bubble formation altogether,

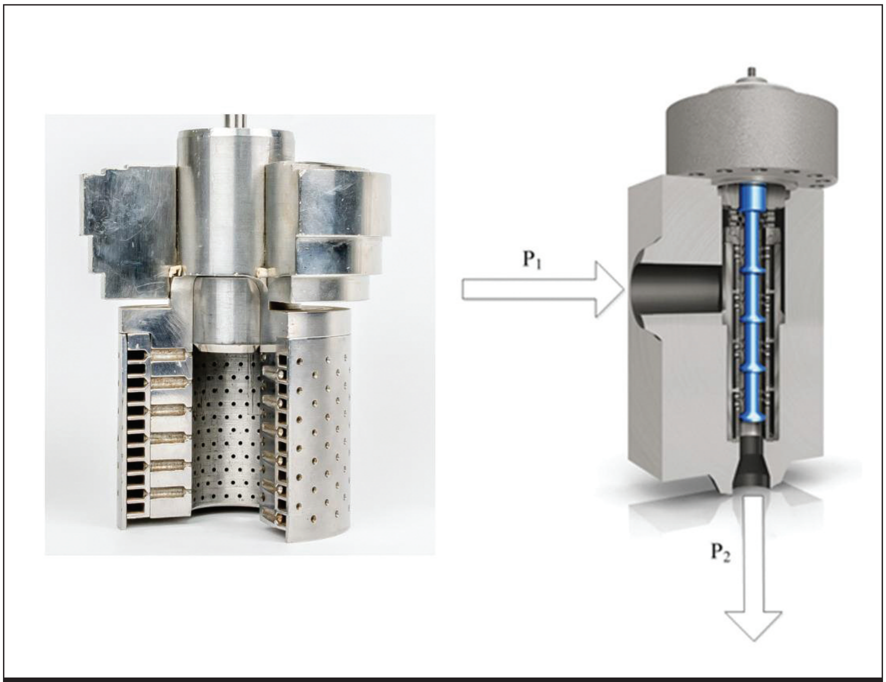


Figure 12. Drilled-hole cage (left) and angle body with drilled-hole cage and axial pressure staging (right)

which eliminates the cavitation as well. Figure 12 shows a drilled hole cage (left) that combines all three design strategies: resistance (hard materials), isolation (flow down) and elimination (pressure staging). If carefully designed, the hole geometry, diameter and spacing also help to isolate the individual jets as the flow passes through the cage.

A more severe cavitating service may require additional design strategies, such as those shown on the right of Figure 12. This design uses all of the approaches previously discussed with the addition of axial pressure staging as the flow passes through the valve trim. This particular design is capable of handling up to 6,000 psid pressure drops while minimizing or eliminating cavitation and associated damage.

CONCLUSION

Flashing and cavitation are thermodynamic processes resulting from process fluid properties and process conditions. It is important to know both the fluid properties (such as vapor pressure) and the system properties (such as process pressure and temperature) to understand whether cavitation or flashing are potential issues to address in valve selection and application. Flashing and cavitation can cause significant valve damage, even with clean fluids that do not contain any solids. Many valve design approaches will handle flashing and cavitation, but they generally can be categorized as using resistance, isolation and elimination. Understanding these three general principles can help in selecting the ideal valve design for tough applications. VM

Bert Evans is manager and **Richard L. Ritter III** is instructional designer for Emerson Process Management (www2.emersonprocess.com), Fisher Product Training. Reach Evans at bert.evans@emerson.com.

REFERENCES

1. Fisher Controls International LLC. (2011). Control Valve Source Book Pulp & Paper. In F. C. LLC, Control Valve Source Book Pulp & Paper (pp. 4-6, 4-7). U.S.A.: http://www.documentation.emerson-process.com/groups/public/documents/book/d103540x012.pdf.
2. Machado, G. (2009, 08 01). Polymeric Solution for Pump Cavitation. Retrieved 05 07, 2015, from Electric Power: http://www.powermag.com/polymeric-solution-for-pump-cavitation/