Title: *Effects of Valve Trim Geometry in Flashing Service*

Author: Dell Grunenberg, Jordan Valve Product Manger, Richards Industries Valve Group, Cincinnati, Ohio

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Abstract:

As the pressure of a liquid falls below its own vapor pressure, flashing occurs. Flashing service can cause particular difficulties for various types of valve designs by eroding parts of the valve body or trim. This paper investigates the solution to a specific problem encountered by a major chemical company located in Rotterdam, Netherlands with flashing condensate. Initially, the customer had been using a cage-guided valve with the hot condensate flowing into the cage (as opposed to flowing out of the cage in gas services) before passing the vena contracta and exiting the valve. The issue with this application and the valve being used centered on the damage to and longevity of the valve body and trim.

The temperature of the condensate was 120ºC. Downstream of the valve, a pressure of 0,31 bar(a) existed which generated flash steam as medium passed through the valve orifice. The entrained water in the flash vapor regularly impinged upon and damaged the valve trim, but particularly the bottom interior portion of the valve body. The damage was significant enough to require regular maintenance and repair. Not only was this a disruption to the system as the process had to be shut down to replace the valve with a spare, but it also caused added costs due to the spare parts themselves and labor associated with the frequent repairs.

In looking for a solution to this problem, several valve trim designs were considered. Given the condensate was under pressure upstream and a vacuum was present downstream, the development of flash steam was imminent. After consulting closely with the client, the decision was made on a trim design that exhibited a straight thru flow geometry, which directed the flash steam away from the valve body surfaces. The final test came when, approximately nine months after the initial installation, the customer removed the valve during a scheduled shutdown to examine its condition. Having already outlasted the existing cage-guided valve by several months and recognizing no damage to the valve body or trim, a solution to this application was recognized.

The ultimate explanation behind the success in this application lies with the geometry of the valve trim and flow path in which it directs the medium. This paper identifies the problem encountered, discusses the options considered and explains the solution found.

In a variety of processes, the potential for a medium to change state, from a liquid to a gas, often exists. While this phenomenon is typically associated with high differential pressure applications, some processes (i.e. production of caustics, condensate return systems) are designed to promote flashing conditions in low pressure systems. In such cases, care must be still taken to ensure the control valves used are capable of withstanding the damaging effects such vaporized medium can cause.

For conventional valve geometries, this can be a difficult task. The typical flow path of most control valves often directs the flow to a particular region of the valve body and trim, often resulting in some degree of material damage. Options exist to help counteract this, however the user must always weigh the benefits of these options against the cost of implementing them. In many cases, the initial purchase costs outweigh the benefits and the user becomes accustomed to regular maintenance of the valve. In cases where the efficiency of the valve is not limited and the maintenance requires inexpensive spare parts and falls into normal shutdown schedules, this may be acceptable. However, if the damage is significant to the point that frequent maintenance is necessary to keep the valve in good operating condition and unexpected shutdowns occur, the efficiency is affected and will be deemed unacceptable. At that point, the client will typically invest in upgraded valve materials and configurations, normally at substantially higher costs than that of the original valve.

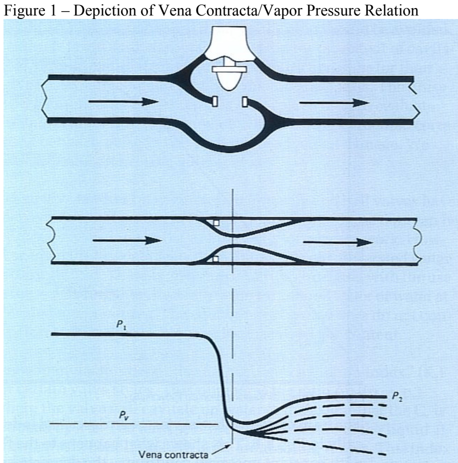
However, it may be possible to limit additional costs significantly, if the valve trim geometry is conducive for handling flashing service without being damaged and without compromising efficiency. This was the case, when a major chemical company changed from a rising stem valve with the conventional ‘S’shaped trim geometry, to a valve with a direct, straight through flow geometry. This article investigates this specific application and the problems the customer faced as well as the ultimate solution found.

To better appreciate the solution, a brief explanation of flashing flow and it's affects on a valve is useful. This will provide some background into the specific application involved and the problems it presented to the user. These problems were causing significant disruptions in the process, affecting virtually the entire plant. To help solve this problem, a variety of trim designs were considered keeping mind their associated costs, benefits and drawbacks. The ultimate solution was a control valve exhibiting a straight through flow path which required no special materials or expensive trim configurations. It is hoped that the in-depth examination of the trim design incorporated in this application will provide other users with another option when selecting valve trim for similar applications.

FLASHING SERVICE – WHAT IS IT AND WHAT DOES IT DO?

When a liquid passes through a valve and the resulting outlet pressure is below the upstream vapor pressure of that liquid, part of the liquid vaporizes. This change in state is known as flashing. As the medium passes through the vena-contracta of the valve, it is at that point where the pressure drop is the highest and where the medium begins to flash. Unlike cavitation, the vapor remains in the downstream flow as the outlet pressure does not recover above the vapor pressure of the liquid (Figure 1). This contributes to the fact that the severe damage typically associated with cavitating flow is often experienced in a flashing pipe.

Figure 1 – Depiction of Vena Contracta/Vapor Pressure Relation



Courtesy of Jordan Valve

Although damage due to cavitation is usually more severe and considered more troublesome than damage due to flashing, significant material erosion to valves and piping can still result from the high velocities and entrained moisture of the vapor when they contact process components. In many cases, this damage will be contained in the valve subassembly, particularly in the trim and on the wall of the valve body. Depending on the flow path through the valve and whether or not the liquid is near saturation at the inlet of the valve, damage to both the valve trim and body can occur.

The damage associated with flashing is often described as a very smooth, almost polished, appearance. Over some degree of time, this results in the removal of material to the point that, if left unchecked, performance decreases. In the downstream piping, the moisture entrapped in the vapor can also damage piping. Elbows or fittings placed directly after the valve can be affected and will eventually need replacement.

To counteract the affects of flashing service, a variety of options are available to the user. Options such as hardened materials, expanding outlet piping and unobstructed outlet flow paths can allow the user to manage the flashing medium. These options can be significantly higher in cost than a standard trim design, but may be required to handle the flow.

TROUBLESOME APPLICATION AND THE OPTIONS CONSIDERED

At a production facility of a large chemical company, the condensate from the steam process piping was being returned to a condensate holding tank. From there it was further directed to a low pressure flash tank for use elsewhere in the plant. The process conditions were:

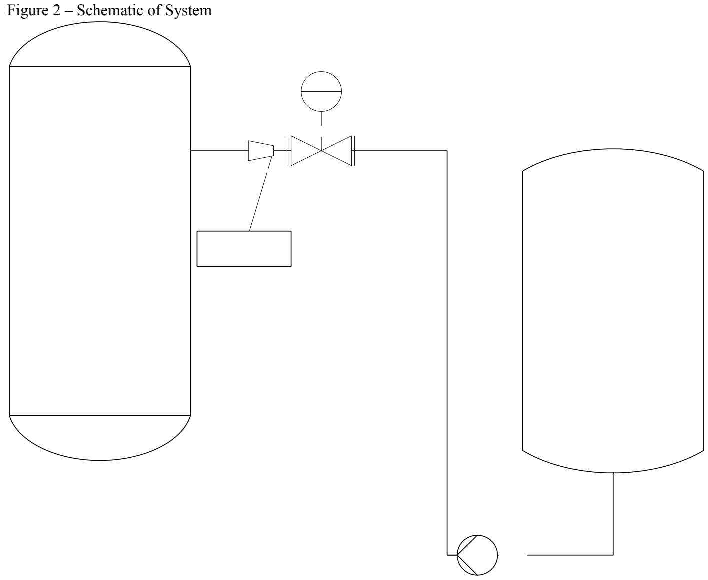
Medium: Condensate
Temperature: 248ºF (120°C)
P1: 41.3 psia (2,85 bara)
P2: 4.5 psia (0,31 bara)
State: Flashing
Inlet Pipe Diameter: 4" (100mm)

Outlet Pipe Diameter: 4"(100mm), with downstream expansion to 14" (350mm).
A sketch of the process (Figure 2) shows the valve was situated between the condensate return tank and the downstream flash tank. The existence of flash steam was obviously imminent, so measures were taken to help control the erosive nature of the medium.

One measure incorporated by the client was the use of a deflector in the flash tank itself. This was situated across from the inlet of the tank, where the steam vapor was directed. The purpose of this deflector plate, made in Monel, was to prevent the backside of the tank from being eroded by the high velocity, erosive vapor. The pipe expansion was helpful in dissipating the flow over a larger area to prevent the medium from being concentrated to one particular area of the tank, exacerbating erosion.

In terms of the valve used, a typical cage-guided trim had been in service. The cut-away drawing of the actual valve is used is shown in Figure 3.

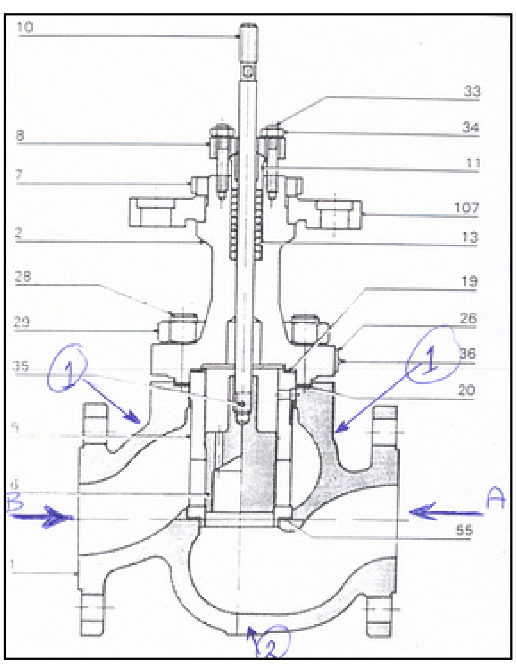
Figure 2 – Schematic of System



Courtesy of Jordan Valve

This copy was obtained directly from the user's files, with notes made on the drawing. Those notes were part of an internal process that documented the history of the valve and any problems they experienced. Taking information supplied directly from the user, the valve's history, as corresponds to the markings in the figure, was as follows:

Figure 3 – Diagram of Cage Guided Valve Used



Courtesy of Jordan Valve

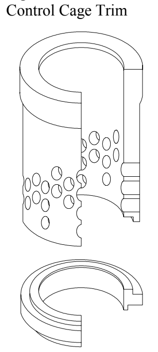
Figure 3.
19.04.1999 – Valve Installed, flow in direction 'A'.
03.04.2000 – Hole in body at positions '1'.
27.04.2000 – Valve repaired, returned to service.
04.10.2000 – Buy new type of same valve.
24.10.2000 – Valve installed, flow in direction 'B'.
15.04.2002 – X-ray valve body at position '2'.
17.05.2002 – Minimum wall thickness measured at 9,0 mm.
11.11.2002 – Install Sliding Gate valve.
18.11.2002 – Minimum wall thickness of replaced valve measured at 6,8 mm
10.15.2003 – Inspection of Sliding Gate reported, results "good".

Based on the log of the valve above, it was quite obvious to see the customer expended a significant amount of energy maintaining this valve. Although the application, per se, was not a difficult one – low pressure control – the fluid dynamics made for unexpected (and undesired) erosion problems. Besides the lost production time and spare parts costs in repairing the valve, there was also a safety and environmental concern due to the recurring leakage through the body housing. This was a problem the customer absolutely had to solve and without spending inordinate amounts of time, effort and money.

In discussing various solutions with the customer, several types of trim designs were considered – all of which were available from the same valve manufacturer. These trim geometries each had characteristics which would provide some degree of improvement over the existing valve design.

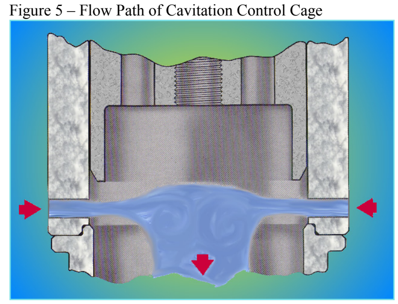
The first trim considered was that of multi-hole cage guided trim, similar to that used in cavitation service. The idea was to provide a cage with many more holes in it, which are diametrically opposed and would diffuse the medium into smaller streams. Presumably, this would reduce the effects of the flash steam. An example of this trim and the flow geometry is shown in Figures 4 and 5, respectively.

Figure 4 - Cavitation Control Cage Trim



Courtesy of Jordan Valve

Figure 5 – Flow Path of Cavitation Control Cage



Courtesy of Jordan Valve

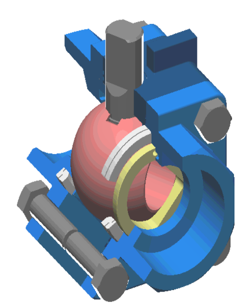
In Figure 4, the trim design provides many more holes to dissipate the flow than in the cage-guided design already being used. In liquid service, the flow typically comes in as shown in Figure 5, from the outside of the cage inwards, to allow the medium to collide from each side and hold the erosion flow away from any valve trim components.

For gas service, the flow would be in the opposite direction – flowing from inside the cage outwards. This is often done to reduce the high noise levels sometimes found with gas service. The problem with either flow path direction in this case was that the medium was still going to flash into a moisture containing vapor. The pressure in the tank was below the vapor pressure of water at that temperature. So, with flow 'into the cage' direction, the flash steam would be directed at the lower wall of the valve body. With a flow 'out of the cage' path the flash steam would likely damage the upper wall of the valve body. Although the muli-hole trim would likely improve the situation to some degree, it was not felt to be an adequate solution.

A second trim design considered was that of a rotary, ball-type control valve. An example of this is shown in figure 6. With this type of design the flow patch is much more linear. The internal geometry does not have the typical 'S' shape associated with the globe or cage type control valve.

Figure 6

Figure 6 – Characterized Ball Trim



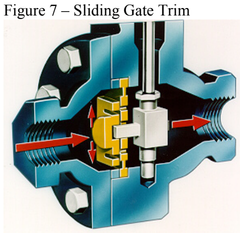
Courtesy of Jordan Valve

The design shown in Figure 6 utilizes and characterized plate that is situated in front of a ball. This characterized ball valve, coupled with a pneumatic actuator and valve positioner, will enable the user to control the parameter as is possible with conventional rising stem valves. While these valves are typically supplied with soft seats to seal the flow when closed, such as Teflon or similar materials, metal seats for higher temperatures are available.

In reviewing this design with the customer, it was clear the direction of the flow would have a much lower tendency to damage the valve trim and body. However, understanding that flash steam was imminent, there was concern about the wall of the body when the valve was operating at partial stroke positions. The contour of the inner diameter of the ball would tend to guide the flow at an angle towards the side of the valve body, instead of straight downsteam. It was felt that the high velocity and liquid filled vapor would still cause material damage to the valve. A likely improvement over the cage guided design in use, it was believed this option would still not create the long term, maintenance free solution desired.

The third trim geometry considered was that of another reciprocating stem design. The primary difference between this design and that employed by the cage design was in the orientation of the variable orifice. Rather than having a large, single open seat with a reciprocating cage or plug, this method utilized a moving, slotted disc situated in front of a stationary, slotted plate. This design is called the *sliding gate*. The flow through the seat set is perpendicular to that of the pipe, as opposed to being parallel to the pipe like in a typical cage or globe control valve. The result is a much more streamlined flow path (Figure 7).

Figure 7 – Sliding Gate Trim



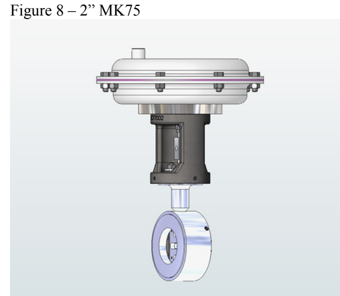
Courtesy of Jordan Valve

This figure depicts the sliding gate design. An obvious characteristic of this configuration is that the slots in the disc and plate will permit a truly straight through flow, even at partial strokes.

Figure 7 shows a typical threaded connection sliding gate valve. In the flanged version, a similar body construction exists. The area of concern on this application, given the imminence of flash steam, was the reduction in flow path near the outlet connection. While it was felt the majority of the flow would be directed in the center of the valve due to the slot arrangement in the disc and plate, there was a risk of body corrosion. As well, the stem is located just past the vena contracta and would be subjected to the flash steam. So another variation of the sliding gate design was proposed.

In the wafer form, Figure 8, the body is extremely compact and the outlet portion of the orifice also serves as the outlet of the valve (Figure 9). This arrangement is remarkably similar to a slim plate orifice. It is generally accepted that water flowing through such an orifice at saturated temperatures will flash only after it has passed through the plate (Driskell pg. 161). After discussing this design with the customer, it was felt this would dramatically reduce valve body (and trim) erosion and therefore, this trim geometry was selected.

Figure 8 – 2" MK75



Courtesy of Jordan Valve

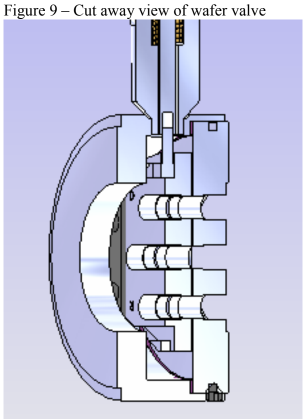
DETAILS OF THE SELECTED DESIGN

While the trim geometry played the major role in the decision by the customer to use the sliding gate trim over the other options considered, several related factors contributed to the selection as well. These factors, often applied in cavitation service, were:

1. **Directing the flow away from valve(pipe) surfaces.** The wafer design ensured the body would not be in contact with the vapor and the straight through flow path ensure the medium was directed to the center of the pipe, away from the pipe walls.
2. **Reducing the flow energy.** By throttling flow through a series of slots in the disc and plate, the medium was spread into several smaller flow streams instead of one large flow stream, thereby helping to reduce the erosive energy of the medium.
3. **Utilizing wear resistant materials**. The sealing surfaces of the trim are coated with an extremely hard ceramic composite material called Jorcote. Converted to a Rockwell scale, this material has a hardness of approx 85Rc which, compared to various grades of Stellite, is significantly higher than other hardened trim materials.

A cutaway view of the valve subassembly shows the multi-slot, straight through flow path (Figure 9).

Figure 9 – Cut away view of wafer valve



Courtesy of Jordan Valve

Instead of a single orifice through which the medium flows as is the case in a traditional rising stem valve valve, this design has several slots. Depending on the CV selected, the number, size and shape of the slots may change.

It is also clear from Figure 9 how the orifices are located in the center of the valve body, which is essentially exactly in the center of the outlet flange. Since the inner diameter of the flange connection is much larger than the diameter of the flow path through the slots, the medium is prevented from immediately contacting the outlet pipe wall and damaging the neighboring pipe and fittings.

Finally, the hardened seat coatings would add excellent wear resistance to the base stainless steel disc and plate. This hardened coating also has the benefit of a very low coefficient of friction (approx. 0.1) to allow the throttling elements to move smoothly during normal operation.

While the design features of the sliding gate valve made for a convincing argument, the real proof was in the actual performance compared to that of the original cage guided valve. An actual picture of the valve installed is shown in Figure 10.

Figure 10 – Wafer Control Valve

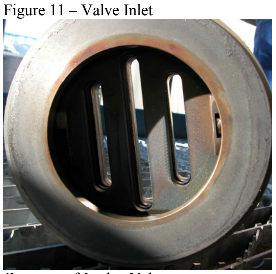
Courtesy of Jordan Valve

This valve was supplied with an emergency handwheel and digital positioner as specified by the customer. The green actuator was also a customer requirement to indicate a normally closed valve configuration, recognizable by users from a distance.

After installed, the user decided to remove the valve for inspection during the next plant shutdown. Approximately 10 months after installation, during which time the valve was in continuous operation, the valve was removed. To the technician's delight, there was no visible damage to the valve body or trim area.

Figure 11 is a picture of the inlet side of the valve. The slightly darker look of the slotted disc is due to the Jorcote coating. Although one may not have expected damage to the valve inlet, since the condensate was near saturation at the valve inlet, material damage would have still been possible. There were signs of heat stresses, but no visible signs of wear.

Figure 11 – Valve Inlet



Courtesy of Jordan Valve

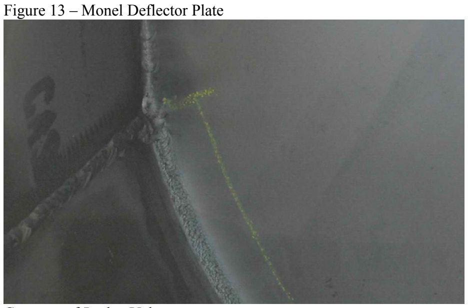
For the outlet side, Figure 12 shows the condition of the downstream area of the valve after having been in use for nearly 10 months. There are signs the valve has been in used in a hot environment (discoloration), but no visible signs of erosion or wear from the media. The orifices do not display any scratches, burrs or other damage. Based on the customer's experience with this valve and the previous valve, it appeared the valve was in good working condition still.

Figure 12 – Valve Outlet

Courtesy of Jordan Valve

Downstream of the valve, however, was the Monel deflector plate. To recall, this plate was installed to protect the wall of the flash tank from erosion. The plate was also removed by the user for inspection. The condition of the plate was much different than that of the valve. Clear evidence of damage was immediately noticeable (Figure 13). Approximately 10 mm of material had been worn away during the past months, indicating the flash steam was highly erosive as had been experienced previously. The Monel plate certainly performed its expected task, however, the extent of the damage was noteworthy, especially given the fact that the valve was in sufficiently good condition to be placed back into the pipeline without any maintenance or repair being done – which was done.

Figure 13 – Monel Deflector Plate



Courtesy of Jordan Valve

The yellow markings indicate the area of damage from the flash steam. Keeping in mind this plate was made of an alloy material, located several meters downstream of the valve and after a significant expansion in the downstream pipe diameter, it was clear the medium had potential to damage any metal surface in its flow path. The fact that neither the valve nor the intermediate piping before the tank were damaged is a testament to merits of a streamlined flow path for this type of service. The user was so impressed with the performance and life of this valve trim design that similar cage valves throughout the flash steam system were replaced with the sliding gate wafer design.

In conclusion, it is vital for the user to know their systems and process thoroughly as well as what affects trim geometry have on the medium flowing through a valve and on the downstream piping. When faced with flashing or cavitating liquids, a common practice is to switch from the conventional globe or cage trim to a very expensive multi-stage or labyrinth-type trim design. For high-pressure drop applications or other severe service conditions, this is often the correct practice. However, for lower pressure systems (i.e. ANSI 300/PN40 and below), simply utilizing a truly straight through flow geometry, like that found in the sliding gate design, can be sufficient to provide the user options to effectively manage the flashing situations encountered, both efficiently and economically.

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