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Relief device inlet piping: Beyond the 3 percent rule

With careful consideration, an engineer can be certain that an installation will not chatter

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Good engineering practices (API STD 520 and ASME B&PV Code Section VIII) have long specified/required that inlet piping pressure drop from the vessel to the safety relief device should be limited to no greater than 3% of the safety relief valve's set pressure. Many companies have taken a more lenient approach to the inlet pressure loss limits; consequently, many installations do not meet the 3% design guideline, as the prevailing company logic assumed that existing installations were "safe" as long as the inlet losses were less than the safety relief device's blowdown with some built-in safety margin. Up until recent fines by OSHA, there have been no hard and clear industry requirements or penalties for companies to adhere to the 3% inlet pressure loss rule. However, OSHA recently rejected this argument and has now begun levying fines against companies violating this 3% rule. In an April 2010 letter to the API STD 520 Committee, OSHA stated that higher inlet losses may be considered acceptable if safety relief valve stability could be assured with an engineering analysis.

This monumental shift has added serious financial consequences for violations of this rule, making compliance no longer an academic argument. This article details a procedure to assist facilities to ensure that existing relief devices with inlet losses greater than 3% are properly designed and will not chatter. It is not the goal of this article to confirm the criteria for an installation to chatter, but instead to give engineering guidance as to which installations are acceptable as they are not expected to chatter. To ensure that this methodology actually solves problems associated with real installations, an entire refinery was subjected to the methodology, and it was found that over half of the installations that have inlet pressure losses greater than 3% are acceptable as is and are not expected to chatter.

Based on a review of literature, the design requirement of "limit the inlet losses to 3%" has been taken as a rule to design safety relief device inlet piping for two primary reasons:[1, 15]

1. Ensure that the pressure in the vessel will not increase beyond what is allowed by pressure vessel codes
2. Ensure that the valve will operate stably and will not chatter or flutter.

The first concern associated with high inlet pressure losses is elevated vessel pressures beyond the allowable limit, which is 110% for ASME Section VIII vessels with a single relief device.[15] This concern is not expected to result in loss of containment from relief device failure and, in most cases, is simple to solve by setting the relief valve opening pressure low enough such that any accumulation in pressure due to excessive inlet line losses does not result in the vessel pressure increasing above the largest pressure allowed by the applicable vessel construction code. However, the second concern is related to the opening of a relief device from a closed position transitioning into a stable operation without the system damaging itself from chatter. The second concern is the more complicated to solve and critical to the overall facility safety.

The inlet piping for safety relief devices has been required to be designed to limit inlet losses to less than 3% per API STD 520 and ASME B&PV Code Section VIII. Many engineers in operating companies that use safety relief devices have taken a more liberal approach to the inlet pressure loss limits for existing facilities. Some companies allow for as much as 5% to 7% inlet losses prior to requiring facility changes based on the argument that the valves will perform as designed without chatter with inlet losses less than the relief device blowdown.[18] Up until recent fines by OSHA, there have been no hard and clear industry requirements or regulatory nudges to adhere to the 3% inlet pressure loss rule. So, logic went that existing installations were safe as the inlet losses were less than the safety relief devices' blowdown. However, OSHA rejected this argument and levied a ~$7 million fine against BP.[19] In this fine, OSHA rejected the argument that the valve would operate safely if the installation has inlet losses greater than 3% without a corresponding engineering analysis that shows the installation will not chatter. It should be noted that according to the BP press release, this citation is being fought in the US courts (outcome unknown at press time).[18]

Thus, the determination of "if inlet piping pressure losses that are greater than 3% are acceptable" is no longer an academic argument, but one that has caught the attention of engineers and plant management. Industry needs a cost effective way to confirm that existing installations that have inlet pressure losses in excess 3% are acceptable. This article is meant to detail a procedure to assist facilities in ensuring that existing relief devices with inlet losses greater than 3% are acceptable. It was not the goal of this article to confirm the criteria for an installation to chatter, but to give guidance as to which installations are acceptable and will not chatter. High inlet pressure losses may also result in relief device capacity reduction, which is also outside the scope of this article.

Cost to industry. Based on industry statistics, between 5% and 10% of existing relief device installations have piping configurations such that the inlet line pressure losses are greater than 3%. To ensure that the methods presented are not just academic, but actually can reduce the costs associated with changes to inlet piping, an entire mid-sized US-based refinery was reviewed using the presented methodology. The value of these methods to industry is that this analysis allows a facility to focus modifications on installations that may chatter, not just those with high inlet pressure losses.

Fig. 1 shows the inlet pressure loss percentages for relief devices for a refinery located in Texas. The calculations for determining if chattering is possible based on the listed methodology were performed in software developed by the authors for this refinery.

At the facility, there were approximately 550 relief devices installed in the process units, of which 64 relief devices were identified as having inlet line losses greater than 3% (~12% of the total). Of these relief devices, 34 were not expected to chatter, based on known mechanisms that cause chatter. This methodology eliminates the need to review (or modify) ~50% of the relief devices with inlet pressure losses greater than 3% and allows the management team to focus its efforts on the remaining valves as potential concerns which may chatter.

Since the use of the presented methodology reduced the number of installations that needed further review or piping modifications from 64 to 30 (representing a reduction in potentially unacceptable relief devices from 12% to 6%), this allows an owner/operator to focus time and capital on high risk relief devices. Assuming an average cost of $20,000 to re-pipe the inlet lines for these relief devices, this analysis could save this refinery nearly $700,000. The review and application of this methodology to this refinery shows that sorting relief devices into *"those that will not chatter"* and *"those that may chatter"* and focusing time and effort on the relief devices that may chatter is a strategy that presents a real cost savings for operating facilities that use safety relief devices and have inlet pressure losses greater than 3% of the set pressure. The alternative of doing nothing is even more costly.[19]

Spring operated relief device. When the pressure in the vessel is below the set pressure of the relief device, the spring holds the valve closed. When the pressure in the vessel approaches the set pressure of the relief device, the relief valve opens. When the pressure at the inlet of the relief device drops below its blowdown pressure (which may be changed based on backpressure), the valve closes. Thus, if a relief device that has been sized and installed properly is needed, it will "pop" open at its set pressure, allow fluid to leave the system, and either depressure the system or keep the pressure from rising above the design limits. It will close when the overpressure event is finished. If the required capacity is nominally more than 60% of the relief device rated capacity (see discussion on h/h_{max} below), the pressure will increase as the PSV slowly opens to the specified pressure. If the required relief rate to prevent overpressure is less than ~25% of the valve's rated capacity, the equipment protected by the safety valve will depressure the system until it closes, at which point the system will begin to pressure up again, and the cycle will be repeated (this is examined more closely later in the article).

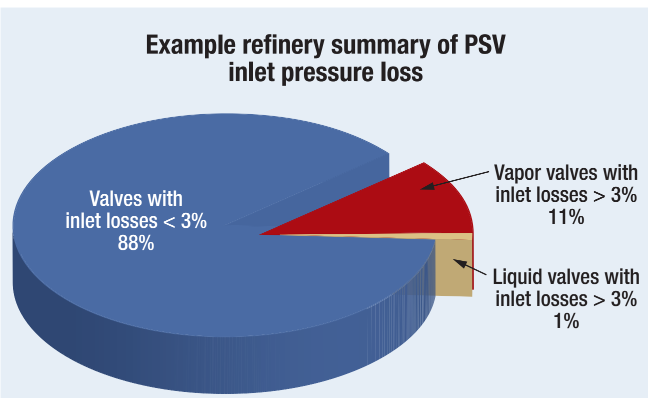


FIG. 1 PSV inlet pressure loss summary for the example refinery in Texas.

While the previous discussion does not introduce any new concepts to industry, the basic operation of the safety relief device is the basis for this discussion on destructive chattering. High frequency (destructive) chatter can best be defined as the rapid cycling (> 1 hz) of a relief device open and closed which may lead to the loss of containment of a system through a mechanical failure in the relief valve or inlet/outlet piping or by the friction welding of the relief device (either open or closed).

Two related phenomena are flutter, the cycling of a valve open and closed without the seat contacting the disk, and short cycling, the non-destructive opening and closing of a relief device (at a frequency < 1 hz), both of which may result in damage to the safety relief valve internals but not expected to result in a loss of containment. Thus, flutter and short cycling are not considered significant safety hazards, and facility modifications should be focused on mitigating the risk associated with high frequency chatter. Based on discussions with various valve manufacturers, when the frequency of the relief device chatter exceeds ~1 hz, the potential for destructive chatter is greatly increased.

Known causes of chatter. Chatter is caused by the rapid fluctuation of pressure beneath the relief device disk. Thus, with the absence of all the known causes of high frequency chatter, destructive valve operation is not expected and the inlet piping does not need to be modified. Some examples:

- Excessively long inlet lines
- Excessive inlet pressure losses
- Frequency matching/harmonics
- Oversized relief devices
- Improper installation.

Once an engineer analyzes and eliminates each of these potential issues for a safety relief device installation, the system can be designated as one that is not expected to chatter and does not need further modifications to the installation to improve the facility's safety. For most of these system characteristics, there are differences between the analysis for liquid filled systems and for vapor filled systems. Therefore, most sections on known causes of chatter have a sub-section for each fluid type that specifies details of how to analyze each criterion for that fluid case. The term vapor is used to describe systems that contain either vapors or gases.

In 1983, research was published[31] that listed the minimum blowdown pressure required for stable valve operation with various inlet piping configurations. The required blowdown for stable operation ranged from 3.5% to 8.4% of the safety valve set pressure. The methodology in this article was used to analyze these installations and in each case predicted the potential for chatter. Since the blowdown for these valves was experimentally determined to be the minimum possible for which chattering would not occur, any simplified method to rule out the possibility of chatter, that is conservative, would be expected to predict that these valves could chatter. In addition, the analysis has predicted chatter could occur in five other installations known to have chattered.

Two phase fluid. The primary cause of chatter is based on the flow of pressure waves through the fluid on the inlet of the piping and the subsequent interaction on the relief device.[6, 9, 31, 32] Based on fluid dynamic work in two-phase flow, systems that are mostly liquid that contain dispersed bubbles have pressure wave flow patterns similar to pure liquids (albeit the vapor significantly reduces the speed of sound in the liquid). Similarly, vapors that contain dispersed liquid droplets have pressure wave flow patterns similar to the vapors. The inability to predict how pressure waves move through a two-phase fluid occurs when the phases slip to the point that the dispersed bubbles or droplets merge and combine.[21] Thus, for the analysis of PRV chattering, any installation that could result in the formation of slug flow cannot be designated as stable and chatter free.

Flow in horizontal piping that is "dispersed," "bubble" or "froth" should remain mostly homogeneous and not result in slugging or other transients. Eq. 1 below is derived from Mr. Baker's[26] flow pattern regimes figure and corresponding equations to ensure stable two-phase flow:

$$w > \frac{d_i^2 \sigma_l \rho_l^{2/3}}{28.8 \mu_l^{1/3} (1-x)} \tag{1}$$

Stable flow in vertical piping falls into the "bubble flow" regime for mostly liquid cases with interspersed vapors. For primarily vapor flow with entrained liquid, the "heavy phase dispersed" regime in vertical piping sections is stable flow. Therefore, the following criteria should be satisfied:[30]

Mostly liquid (bubble), vertical piping section(s)

$$w < \left(\frac{\sigma_l}{\rho_l}\right)^{1/4} \frac{\rho_g^{0.67} d^2}{57x} \tag{2}$$

Mostly vapor (heavy phase dispersed), vertical piping section(s)

$$w > \left(\frac{\sigma_l}{\rho_l}\right)^{1/4} \frac{\rho_g^{0.67} d^2}{3.5x} \tag{3}$$

Any two-phase flow that may develop unstable flow regimes (slug flow or plug flow) or is unstable (like transitioning from supercritical dense phase to liquid) is inherently unstable. The instability of the flow regime makes it difficult to predict with certainty the stability of the relief device, and such installations should be subject to additional engineering analysis or piping modifications.

Excessively long inlet lines. When a valve opens, a vacuum forms: in the physical space beneath the disk. If the pressure wave does not travel from the seat of the disk to the pressure source and is reflected back to the disk inlet prior to the relief valve beginning to close, the disk may not be supported by the returning pressure wave and close. Once closed, the pressure will cause the safety relief device disc to open creating a cycle that has been shown to cause high frequency and destructive chatter.[6]

$$t_O > \frac{2L}{c} \tag{4}$$

If Eq. 4 is satisfied, the time it takes to open the relief device is greater than the time it takes for the pressure wave to travel to the source of pressure, get reflected and return. Once the disk starts to close, the returning pressure wave may not provide enough force on the disk to change direction and lift it again. Therefore, the opening time was used for the relief device and not the cycle frequency. According to Dresser, steam valves open between 35 milliseconds and 55 milliseconds.[7] When the *UK Health and Safety Executive* (HSE) tested relief devices, they found that in the case of a very high overpressure, 2H3 and 3K4 relief devices could open in as little as 5 milliseconds.[4, 5] Kruisbrink found that relief devices open in an average of 25 milliseconds.[8] The following correlation, Eq. 5, was developed based on the 1982 ERPI test data and was verified to satisfactorily predict the opening times.[9]

$$t_{open} \approx \left(0.015 + 0.02 \frac{\sqrt{2 d_{PSVi}}}{\left(P_s / P_{ATM}\right)^{2/3} \left(1 - P_{ATM}/P_s\right)^2}\right) \left(\frac{h}{h_{\max}}\right)^{0.7} \tag{5}$$

The term h/h_{max} represents the fraction of total travel when relief devices open. Several researchers have indicated that the initial valve lift varies greatly and can range from between 40% and 100% of their full lift.[4–6, 8, 9] When the relief devices are not suddenly subjected to severe overpressure (as in the HSE testing;[4, 5]), the use of 60% to 70% initial lift, for the purposes of calculating t_{open}, is reasonable and in line with the API guidelines.[28]

Compressible fluids (vapors). A critical design criterion in determining that a relief device will not chatter is the time it takes for the pressure wave to travel to the pressure source and back to the safety relief device.[6, 9] Due to the nature of compressible fluids, there is a recovery of pressure due to the expansion of the gas in the piping. Thus, an initial estimate of the maximum acceptable length for the inlet piping can be determined as follows (for a perfect gas):

$$c = 223 \sqrt{\frac{kT}{MW}} \tag{6}$$

Eq. 6 was obtained from API STD 521[29] to calculate the speed of sound in a perfect gas. Thus, if the pressure disturbance can travel to the pressure source and back prior to the disk starting to close, then chattering from this phenomenon is not expected. This equation was obtained by substituting Eq. 6 into Eq. 4 for the speed of sound and solving for length.

$$L < 111.5 t_{open} \sqrt{\frac{kT}{MW}} \tag{7}$$

Additionally, Fromman has suggested a pressure surge criterion that establishes a maximum inlet line length based on the magnitude of the expansion wave, taking into account the decay in the wave as it travels from the disk to the vessel and is then reflected back to the disk.[6] The allowable pressure change in the expansion wave is specified as follows:

$$\Delta P_{JK} < \left(\frac{P_s - P_{rc}}{P_s}\right)\left(P_s - P_B\right)\frac{t_o}{2t_w} \tag{8}$$

Eq. 9 is obtained using the Joukowski equation (Eq. 8) for the expansion wave (ΔP_{JK}), substituting *L/c* for t_w, and solving for the maximum allowable inlet line length.

$$L_i < 45{,}390 \frac{d_i^2}{w_{\%O}} \left(\frac{P_s - P_{rc}}{P_s}\right)\left(P_s - P_B\right) t_o \tag{9}$$

For cases where the inlet piping is the same diameter as the inlet relief device nozzle, the results of the correlation proposed by Frommann (Eq. 8 and Eq. 9) are very similar to the straight wave correlation (Eq. 4 and Eq. 7), and it is suggested that both criteria be satisfied. For installations where the diameter of the inlet piping is greater than the diameter of the relief device, the Frommann equation. indicates that longer inlet lines may be acceptable than the limitations presented in Eq. 7. However, reviewing the installation based on the criteria represented in both Eq. 7 and Eq. 9 captures the concerns about the correlation presented by Fromman.

Incompressible fluids (liquids). For liquids, the criterion is more straightforward, as the fluid does not expand to fill the vessel. Thus, as soon as sufficient material is discharged to create a void space, the pressure that is the driving force to keep the relief valve open is removed. If there is no liquid to support the disk when the valve starts to close, then chatter will occur due to the oscillations in pressure. Since the speed of sound in liquids is generally quite high, cases that do not meet these criteria can result in very high frequency and destructive chatter. For liquids, the speed of sound is calculated as:

$$C = 1.09\ (K_S/\rho)^{\wedge 1/2} \tag{10}$$

Thus, if the length of the inlet line meets the criteria in Eq. 11, then chattering from this phenomenon is not expected. The following equation was obtained by substituting Eq. 10 into Eq. 4 and solving for length.

$$Li < 0.55\ t_o\ (K_S/\rho)^{\wedge 1/2} \tag{11}$$

The speed of sound in two phase mixtures is lower than that of a pure liquid.[21] As Eq. 4 shows, the maximum length of the inlet line decreases with a decrease in sonic velocity. Thus, for two phase flow the designer must determine what phase behavior is the best indicator of performance and evaluate accordingly.

Excessive inlet pressure losses. In the current standards (both ASME and API) the direction for relief device installation is to the inlet frictional pressure losses to no greater than 3% of the set pressure.[1, 15] The implication is if inlet losses plus a safety factor are less than the blowdown, the valve will operate stably and not chatter. The results of research done by both the Electric Power Research Institute (ERPI) and Oak Ridge National Laboratory (ORNL), indicate that frictional pressure losses alone are insufficient to predict valve stability and that a relief system designer must allow include the affects of pressure waves.

Compressible fluids (vapors). Based on experimental data, EPRI published correlations that show if the sum of the acoustic and frictional inlet pressure losses is greater than the blowdown of the relief device, the system may chatter.[32] Eq. 12 presents a method to estimate the acoustic pressure losses. [32]

$$\Delta P_{Acoustic} = \frac{Lw_{PSV}}{12.6 d_i^2 t_O} + \frac{1}{10.5\rho}\left(\frac{w_{PSV} L}{c\, d_i\, t_O}\right)^2 \tag{12}$$

And,

$$P_S - P_{RC} > \Delta P_{Total} = \Delta P_{Frictional} + \Delta P_{Accustic} \tag{13}$$

Eq. 13 is taken from the work by Singh[32] but simplified based on the assumption that the initial pressure at which the valve stem lift is reduced (prior to stable flow being established) is lower than the reclosing pressure of the relief device. To ensure valve stability under all modes of operation, Eqs. 12 and 13 should be verified for the initial opening conditions, at full capacity, and at closing conditions.

Incompressible fluids (liquids). ORNL published work that shows for liquid filled systems, the sum of the wave pressure and frictional inlet pressure losses should be less than the blowdown of the relief device. If not, the system may chatter.[33]

$$\Delta P_{Wave} = \frac{c\rho}{4,636.8}\left(V_o - V_F\right) \tag{14}$$

And,

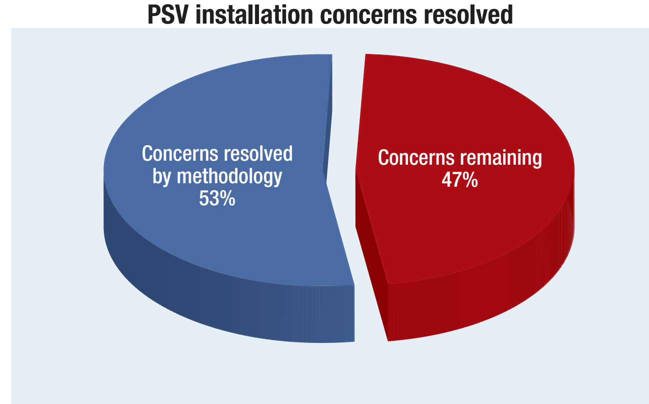
$$P_S - P_{RC} > \Delta P_{Total} = \Delta P_{Frictional} + \Delta P_{Wave} \tag{15}$$

As with compressible fluids, Eq. 14 and Eq. 15 should be verified for opening, full flow and closing conditions. Based on the analysis for an entire refinery, the inlet line length limits (Eq. 9 and Eq. 11) and inlet pressure loss limits (when acoustical and wave pressure losses are included, Eq. 13 and Eq. 15) tend to predict similar maximum inlet line lengths.

Frequency matching/harmonics. Based on a review of the literature, there are two primary phenomena that cause vibrations in relief device inlets associated with harmonics:

- **Standing waves**—resonance caused by the combination of waves such that the reflected waves interfere constructively with the incident waves. Under these conditions, the medium appears to vibrate and the fact that these vibrations are made up of traveling waves is not apparent. This phenomenon is caused by a high velocity fluid passing over the inlet to the relief device.
- **Matching relief device natural frequency**—A cavity tends to exhibit a single resonant frequency. This is caused if a pressure wave pushes fluid into the volume and then is released; the excess pressure will drive the fluid out. The momentum of the fluid flow out of the vessel will result in excess fluid being pushed out and produce a slight decrease of pressure in the cavity. Fluid will tend to fill the vessel; the cycle will repeat and oscillate at the natural frequency of the container.[36]

PSV installation concerns resolved



PSV installation concerns are resolved.

Standing waves. Flow induced vibration becomes a problem when the fluid velocity passing by a relief device inlet nozzle is high enough to create standing waves caused by vortex shedding. Based on research done in the power plant industry[10] the following correlation has been used to predict failures in steam service:

$$L_i < \frac{d_i c}{2.4U} \tag{16}$$

Thus, to avoid relief device chattering problems associated with standing waves from vortex shedding, the length of the inlet line should be limited to meet the criteria in Eq. 16.[10] Note that these equations are valid for other vapor systems, as well as steam.

Helmholtz resonators and cavity resonance. Sallet has implied that chatter due to harmonics caused by the release from a pressure relief device is caused by cavity resonance.[34] For this phenomenon to occur, the natural frequency of a piping system would have to match the natural frequency of a relief device, and a constant flow would have to occur as the pressure oscillations in the system build. Per the Consolidated catalog, matching the natural frequency of the piping system and relief device would result in the premature opening of the relief device and not in destructive chatter.[35] For destructive chatter to occur due to cavity resonance, the relief device would need to cycle at a frequency almost exactly equal to the resonance frequency of the system and stabilize at that cyclic frequency.[36] Since the cyclic rate of the relief device is a function of the valve lift (required relief rate) and the system frequency is a function of the material being relieved and the system piping, the authors have concluded that the phenomenon of destructive resonance is unlikely to occur and difficult to predict in advance for systems with varying materials and flows.

Oversized relief valves. Safety relief devices close at approximately 25% of their rated capacity.[22, 29] Therefore, if a relief device is oversized, the system will be more prone to chattering. This is because there is not enough fluid flowing through the relief device, and the combination of the momentum and pressure forces are insufficient to hold the valve disc open. Once the valve closes, the pressure can build quickly (depending on the system) and re-open the valve. Thus oversized relief devices create a cyclic opening/closing chatter prone cycle.

Compressible fluids (vapors). Once a valve is open (assuming an installation in line with good engineering practices), the flow through the relief valve is dependent only on the relief valve disc position (which generally determines the orifice area and capacity) and the inlet and outlet pressures (the driving force). The amount the relief valve is open is determined by the inlet and outlet pressure for the valve. Although the required relief rate determines whether the vessel pressure will increase or decrease once the relief valve opens, the flow through the relief valve is based only on the inlet and outlet pressures and not the required relief rate nor the rated capacity of the valve. If the required relief rate is greater than the actual flow rate through the valve, for the given inlet and outlet pressures, the vessel pressure will increase. If the required relief rate is less than the actual flow rate, for the given inlet and outlet pressures, the vessel pressure will decrease. However, the rate at which the inlet pressure will increase or decrease is based on a mass balance that takes into consideration the accumulation of mass in the system along with the volume of the inlet system. All other variables being equal, a larger inlet system will pressure or depressure more slowly than a smaller system. Therefore, the only way that a vapor relief valve can have high frequency chatter from being oversized, is for the system to de-inventory and depressure to the valve's closing pressure and then re-pressure to the valve's opening pressure in the specified high frequency cycle time, 1 second or less. Thus, the following two conditions are required for high frequency chatter to be a potential for a vapor filled system assuming a safety factor of 500% (specifying the system cycling time as five seconds instead of one second):

$$w_{PSV} < 0.20 \cdot V_{System}\left(\rho_{Set} - \rho_{Shut}\right) + w_{required} \tag{17}$$

And,

$$W_{PSV} > 4W_{Required} \tag{18}$$

A further conservatism built into Eq. 17 is that a safety relief valve typically only "pops" open to ~60% of the full lift. Therefore, the safety relief device's capacity at the valve's set pressure is significantly lower than the rated capacity which will tend to increase the time it takes to depressure a system. After reviewing the industrial relief systems that are known to have chattered and the installations used in the literature, the most prevalent instances of chatter caused by oversized safety relief valves in compressible service seem to be in academia and not industry.

Incompressible fluids (liquids). For liquids, this criterion is more critical than for vapor systems as the incompressible fluid does not expand to fill the vessel. Thus, if there is not enough liquid flow to keep the safety relief valve open, it will close. Based on the published limits in API STD 521, the safety relief valve is expected to close with a flow rate of 25% or less. While these phenomena usually results in short cycling and not chatter, to eliminate the possibility of chattering, Eq. 18 should be satisfied for a liquid safety relief valves.

Relief valves with liquid trims or safety relief valves with very small relief loads are not known to chatter. Liquid trim relief valves are designed to open proportionally to the flow rate and operate more stably in liquid service.[35] Per conversations with relief device manufacturers, safety relief valves with very small loads (2–5% of the capacity) do not fully lift the relief device, and thus short cycle, and are not expected to chatter.

Improper installation. If the valve is improperly installed, there is no way to confirm that the relief device will not chatter. The following installation guidelines are based on experience and code requirements. This section does not separate vapor from liquid installations, as improper installations are not dependent on valve service.

Inlet restriction—if the minimal inlet line flow area is less than the sum of the area of the inlet nozzles, the installation may chatter. This is also a violation of UG-135(b)(1) in ASME B&PVC Sec. VIII.

Outlet restriction(s)—if the minimal outlet line area is less than the area of the sum of the outlet nozzles of the valves, the installation may chatter. In addition to this not being generally considered acceptable per industry recognized and generally accepted good engineering practices, the cases listed above under excessive backpressure document instances where restrictions in the outlet lines near the discharge flange result in relief device instability.

Backpressure—installations that result in backpressure greater than the limits specified by the valve manufacturers may result in chatter. For cases where the backpressure exceeds the valve manufacturer's limits, the increased backpressure has been shown to either increase the likelihood of chatter or the vessel pressure.[3, 9, 12, 23, 25] The installation of bellows relief devices was explicitly shown to increase the stability of the installation for the given backpressure.[12, 23]

Plugged bellows vent(s)—Based on the information in the methodology section of the DIERS Safety Valve Stability and Test Results,[24] tests were performed to assess the capacity and stability of a relief device with and without balanced bellows installed. The safety valve tests that were performed with bellows installed had the bonnet plugged. The DIERS study found that bellows valves, with the bonnet plugged, have a higher likelihood of chatter when compared to conventional relief valves. Furthermore, the DIERS study found that when the valve disc vibrations occurred (with a bellows valve with a plugged bonnet vent), the vibrations were more severe, having a higher peak-to-peak amplitude than a conventional relief device.

The authors of the DIERS study stated that they re-ran a few tests without the bellows plugged, and it did not affect the test results. Since the authors of the DIERS study are not clear as to what tests or how many were rerun or what results that were not affected are, and other authors have indicated that bellows relief devices increase the stability of relief devices, [9, 12, 23, 25] it is believed that the incorrect use of the relief valves, e.g. plugging the bellows vent, is what led to the increased instability. It is summarized that the DIERS finding of a decrease in relief device stability and increase amplitude of vibrations is due to plugging the bonnet vent, not on the installation of the bellows. A recent incident of loss of containment due to relief device chatter that involved topped crude with a liquid trimmed relief device that had the bellows vent plugged further supports this conclusions.

Pocketed/liquid filled discharge piping—If the discharge of a safety relief device is pocketed or is normally filled with liquid, such that the outlet bowl of the device is filled with liquid, the potential for chatter increases. A specific relief device must be used to provide overpressure protection or the installation may chatter (or disintegrate) when the valve opens and tries to accelerate a stagnant liquid.

Safety valves designed to operate with liquid in the outlet chamber (e.g. on a pump discharge) have been documented to chatter destructively when the fluid heats to near the vapor pressure of the pumped fluid.

Waterhammer style chatter—Waterhammer arises from the pressure waves generated from velocity changes in liquid flow in response to valve closure. The impact of waterhammer on chatter due to inlet piping configuration is addressed in the section on excessive inlet pressure losses. All other instances of waterhammer are outside the scope of this article.

Multi device installations—It has been shown that when a system has multiple relief devices installed that staggering the set pressure of the relief devices reduces the tendency to chatter.[25]

While no listed source could be found to link a horizontally mounted relief device to chatter, it is a poor practice and any section on proper relief device installation would be remiss without this warning.

Orientation. With careful consideration of inlet line lengths, harmonics, relief device sizing and the specifics of each installation, an engineer can be certain that an installation will not chatter. Based on the large number of relief device installations existing in industry that have inlet pressure losses greater than 3%, this methodology can help responsible engineers focus corporate resources appropriately. In the sample refinery reviewed, half of the installations with inlet pressure losses greater than 3% were found to not chatter and are acceptable as-is. This methodology does not predict that valves will chatter, so installations that fail to meet all the listed criteria could either further studied or physically modified. When the methodology was checked against instances that were known to chatter, it always predicted chatter was possible. **HP**

NOTATIONS

c = speed of sound (ft/s)
d = diameter (in)
h = valve lift (in)
k = isentropic expansion factor (C_p/C_v for an ideal gas, dimensionless)
k_s = the isentropic bulk modulus of elasticity (psi)
k_{xt} = spring constant (lb/s)
L = length (ft)
m = mass (lb)
MW = relative molecular weight of the fluid (dimensionless)
t = time (s)
T = temperature (°R)
U = Process fluid velocity as it passes the PSV nozzle (ft/s)
x = mass vapor fractions (dimensionless)
w = mass flow rate (lb/s)

GREEK LETTERS

ρ = fluid density (lb/ft^3)
μ = fluid viscosity (cP)
σ = surface tension (dynes/cm)

SUBSCRIPTS

ATM = atmospheric
b = backpressure on relief device
i = inlet
jk = Joukowski pressure losses
l = liquid
max = maximum
o = opening
PSVi = inlet PSV flange
rc = valve reclosing pressure
s = relief device set pressure
v = vapor
%O = Flow rate at the valves percent open

LITERATURE CITED

Complete literature cited available at HydrocarbonProcessing.com.

Dustin Smith, P.E., is the co-founder and principal consultant of Smith and Burgess LLC, a process safety consulting firm based in Houston, Texas. As a consultant, Mr. Smith has extensive experience with helping refineries and petrochemical facilities maintain compliance with the PSM standard. He has more than a decade of experience in relief systems design and PSM compliance. His experience includes both domestic and international projects. Mr. Smith is a chemical engineering graduate of Texas A&M University and a licensed professional engineer in Texas.

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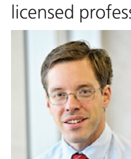

Craig Powers has seven years of experience in relief system analysis. He has been a principal developer of two pressure relief systems analysis software packages. He holds a BS degree in chemical engineering from Northeastern University and MS and PhD degrees in chemical engineering from the University of Notre Dame.

Relief Device Inlet Piping: Beyond the Three Percent Rule:

With careful consideration, an engineer can be certain that an installation will not chatter

Dustin Smith P.E., John Burgess P.E. & Craig Powers Ph. D.

Hydrocarbon Processing, November 2011

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Errata for

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PLANT SAFETY AND ENVIRONMENT SPECIALREPORT

Relief device inlet piping: Beyond the 3 percent rule

With careful consideration, an engineer can be certain that an installation will not chatter

D. SMITH, J. BURGESS, and C. POWERS, Smith and Burgess, Houston, Texas

1. Equation 12 for the acoustic pressure loss is incorrect and should be

$$\Delta P_{Acoustic} = \frac{Lw_{PRD}}{11.5 d_i^2 t_o} + \frac{17.5}{\rho}\left(\frac{w_{PRD}L}{c{d_i}^2 t_o}\right)^2$$

2. Equation 18 for the ratio of mass flows is incorrect and should read

$$w_{PRD} < 4w_{required}$$

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$$\Delta P_{Acoustic} = \frac{Lw_{PRD}}{11.5d_i^2 t_o} + \frac{1}{8.2\rho}\left(\frac{w_{PRD}L}{c{d_i}^2 t_o}\right)^2$$

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1. Equation 9 for the maximum allowable inlet length was not consistent with the unit set defined and should be the following when $w_{\%O}$ is lb/s

$$L_i < 12.6\frac{d_i^2}{w_{\%O}}\left(\frac{P_s - P_{rc}}{P_s}\right)(P_s - P_B)t_o$$

2. Equation 10 for the speed of sound in a liquid is incorrect and should read

$$c = 68.1(k_s/\rho)^{1/2}$$

3. Equation 11 printing had a notation capitalization error for k_s

$$L_i < 0.55t_o(k_s/\rho)^{1/2}$$

4. Equation 12 for the acoustic pressure loss is incorrect and should read

$$\Delta P_{Acoustic} = \frac{Lw_{PSV}}{11.5d_i^2t_o} + \frac{17.5}{\rho}\left(\frac{w_{PSV}L}{cd_i{}^2t_o}\right)^2$$

5. Equation 14 printing had a notation capitalization error for v_o and v_f

$$\Delta P_{wave} = \frac{c\rho}{4{,}636.8}\left(v_{initial} - v_{final}\right)$$

6. Equation 16 for the standing waves was not consistent with the unit set defined and should be the following when d_i is in and L_i is ft

$$L_i < \frac{d_i c}{28.8U}$$

7. Equation 18 for the ratio of mass flows is incorrect and should be the following as well as a printed notation capitalization error for w

$$w_{PSV} < 4w_{required}$$

Notations Omitted

P = pressure (psi (a) (g) or (d), as appropriate)

v = velocity (ft/s)

V = volume (ft^3)

Subscript Abbreviations Omitted

g = gas

Version 2. April 10, 2015