Living with Oversized Relief Valves

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Pressure relief valves are sized to protect pressurized systems from excessive pressure by providing relief capacity at least equal to the largest required flow associated with the credible overpressure scenarios. Most systems have more than one credible overpressure scenario (e.g., external fire and blocked outlet). Furthermore, the overpressure scenarios are developed with conservative assumptions for the contributing factors (e.g., no credit for instrumentation or operator response). This typically results in a pressure relief valve having enough capacity for the worst credible case but having excess capacity for the other credible cases.

Recognized engineering and design standards (e.g. API STD 520 Part II) have long said that an oversized relief device (one with a scenario that requires less than 20% of the relief device capacity) may exhibit instability [1]. There is a distinction between low frequency periodic motion (e.g. < 10 Hz), referred to as cycling, and high frequency periodic motion, referred to as chatter. Relief valve cycling is largely a function of the relief valve capacity compared to the required relief rate. Relief valve chatter is most heavily influenced by the acoustic coupling of the relief device with the inlet piping (or system, in some cases) and, to a much lesser extent, the required relief rate.

Design Rate = Worst Case:

As mentioned above, work process of sizing a pressure relief device can result in a wide range of required relief rates in the design cases. In addition, for each design case, the relief systems designer must assume that corrective instrumentation and operation actions fail to prevent or mitigate the situation or rate in order to ensure that the relief device is sized to prevent unacceptable pressure accumulation in the vessel. Furthermore, relief systems designers often use time saving conservative assumptions to perform the analysis (these assumptions should not be used when the existing installation is not deemed adequate). Therefore, the rate used to select the pressure relief device size is not only based on the highest required relief rate among the design overpressure scenarios, but the required rates for each overpressure scenario are based on the least likely credible outcome for that scenario. This is acknowledged elsewhere in API STD 521; for example, in the guidance on dispersion, which offers as an example a rate of 25% of the rated capacity as "conditions affecting relief are corrected".

To illustrate the point above, consider the loss of reflux overpressure scenario for the Depropanizer tower system depicted in Figure 1, caused by either a failure of the Reflux Pump P-1/2 or a closure of the flow control valve FV-2. For this scenario, we are to assume that all other instrumentation does not respond and stays in the same position (per API STD 521 §4.2.6)[2]; therefore, a loss of reflux can be expected to flood the overhead condenser. This results in a loss of overhead condensing as the contact area between the vapor and the cooling medium is blocked, and a corresponding rise in internal system pressure due to the accumulation of uncondensed vapor. The conservative worst case required flow rate (the design case for sizing the relief device) does not allow for the following credits. However, the most likely real-world scenario for the relief device would include some or all of the load reductions listed below:

- *LIC-1 Opening* – The overhead accumulator level control valve is programmed to maintain the liquid level in the Overhead Drum. If reflux to the tower is lost, then the liquid level in the Overhead Drum will rise. The level controller LIC-1 will likely respond by further opening LV-1 to increase outflow and prevent the Overhead Drum from overfilling (or allow for a partial cooling by increased liquid product outflow).

- *LIC-2 Closing* – The upset will result in less liquid traffic in the tower and lower liquid rates in the bottom of the tower. These lower rates will result in a reduction of the liquid level in the Depropanizer bottoms. This level control will tend to close the valve and reduce the bottoms product. A reduction in the bottoms product will result in less heating of the feed stream which will in turn reduce temperature of the feed to the tower and could lower the required relief rate.

- *PIC*-01 Opening – As the reflux is lost, the tower pressure will increase. The overhead pressure controller is programmed to limit the tower pressure and opens when the pressure exceeds this limit. In the event of a loss of reflux, this valve will likely open and vent some or all of the accumulated vapor out of the system, reducing or eliminating the required load on the relief device. *This single action has the most direct effect on the load through the relief device.*

- *TIC*-01 Closing – As the reflux is lost, the tower temperature will increase due to the bubble point elevation that accompanies a rise in pressure. This temperature controller will tend to close to maintain a constant pressure in the bottom of the Tower. The closure of this control valve will reduce the heat transfer in the reboiler and lower the relief rate. Steam control valves are often not 100% leak tight, so even if the control loop signals for a 100% reduction in steam, the physical limits or damage may result in some continued heat input to the Depropanizer.

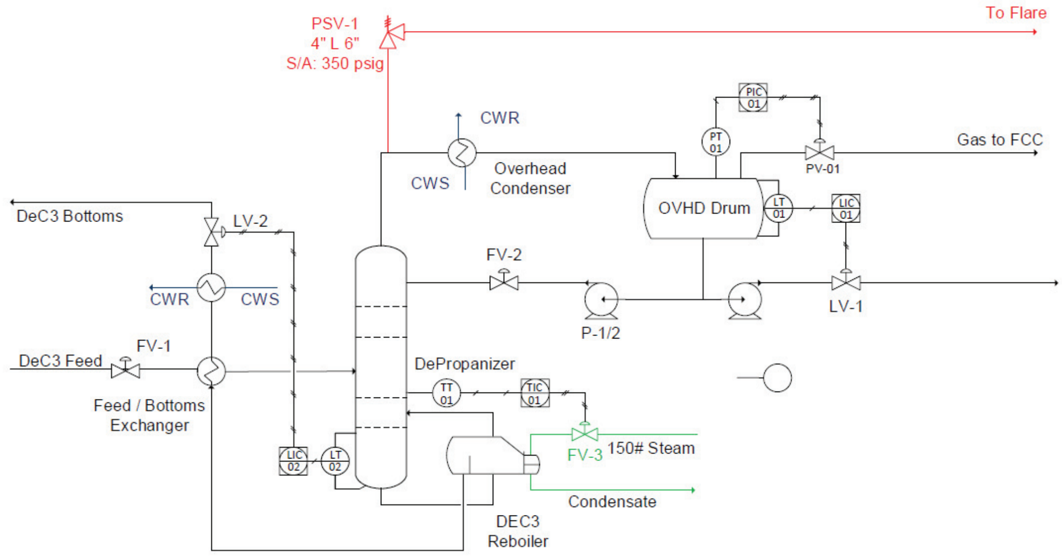

Figure 1: *Illustration of a typical Depropanizer tower system*

It is not the position of the authors that relief devices be sized assuming any of the potential load reduction factors listed above; the purpose is to illustrate how a relief system design for anything but the simplest of systems will always have the potential to be oversized (even for the largest relief scenario). Furthermore, the likely relief scenarios include one or more of the load reductions occurring, while the least likely relief scenario is the worst-case scenario where none of the load reductions occur. ***<u>Therefore, for most installed relief devices on typical process equipment, the expected release is likely to be a fraction of the design load.</u>***

As shown in the previous example for a typical column system, for a single scenario, Top Tower Reflux Failure, the design relief rate is the worst-case scenario assuming a single failure with no basic process control system (BPCS) mitigation. *If this event were to occur, the relief rate seen by PSV-1 could range from nothing (the control systems works) to the full relief rate, and everything in between.* This is only one scenario for this system, and many more may be applicable and result in relief (power failure, cooling water failure, external fire, etc.). Thus, in a practical sense, the concept of being able to design a system to avoid oversized relief devices is nonsensical for most installations. Furthermore, since the design case is the worst case, and the BPCS is more reliable than not, it is the least likely case to occur in the future.

Another event that can lead to oversized relief devices is minor over-pressurization due to small fluctuations in the process. When this happens, the oversized relief valve opens at its set pressure to drop the system pressure; however, the event is generally a “burp” as the oversized relief valve opens, relieves the overpressure and shuts.

Taking these points into consideration, in the authors' opinion, using the design required relief rates as the basis for determining if a relief device is oversized or for stability calculations is inherently flawed.

Oversized Relief Valves:

In most cases, oversized relief valves result in relief valve cycling (low frequency, < 10Hz). In addition to the research done by Smith & Burgess, others have tested relief devices and shown that, when properly installed, will cycle rather than chatter at extremely low required flow rates relative to the relief device capacities (low "demand capacity"). Restated, oversized relief devices installed properly are found to exhibit cycling behavior [1][3]. The following test (Figure 2) shows observed low frequency cycling for a significantly oversized relief device on a small volume system. Subsequent tests show that, as the required relief rate increases, the oscillations will increase until a large enough relief rate is obtained and the valve remains open for the duration of the overpressure event.

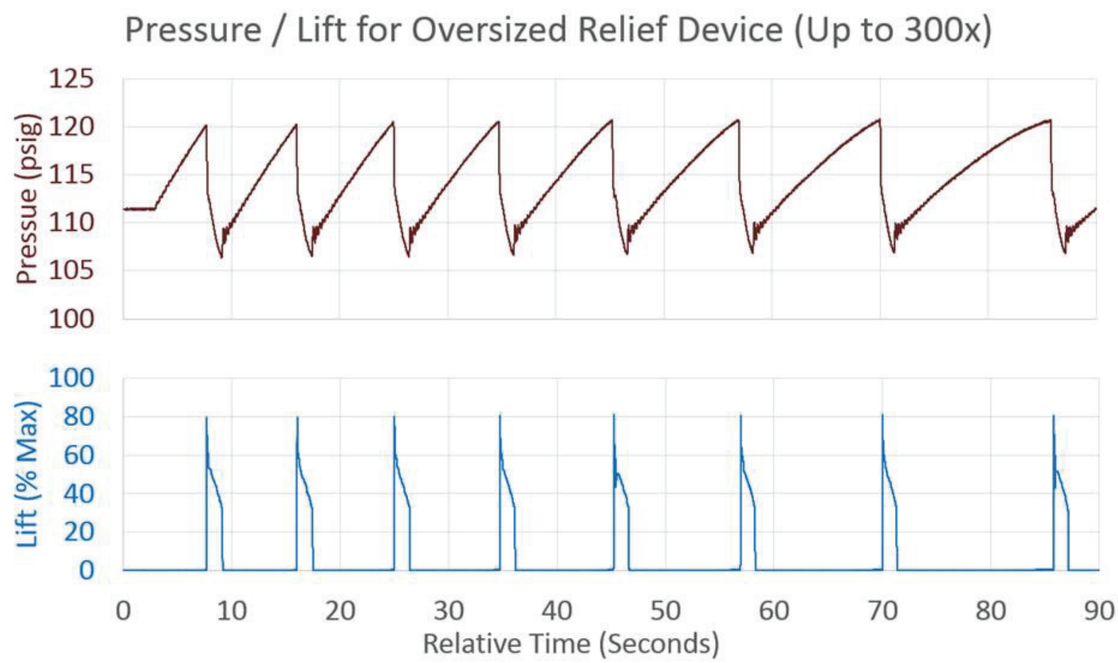

Figure 2: The Oversized Relief Valve with a 24" long inlet pipe opens at 121 psi but due to being oversized, the valve begins to immediately close after opening. An initial cycling rate of 1 discharge every 8 seconds (or about 0.125 Hz) is observed. Due to the reduction in the relief rate, the frequency can be observed increasing to once opening every 15 seconds. Note that the closing pressure is 106 psi, which is approximately 12.4% blowdown.

Relief valves in vapor or liquid service can also acoustically couple with standing waves in the inlet piping and result in the relief valve chattering (with a frequency of >10 Hz).

It should be noted that in reference [3], "*A Review of Stability Concerns*" that the author includes a graphic example from test data that shows an oversized valve (a 3L4 spring loaded relief valve set at 142 psi opening pressure and relieving at 6% PRV capacity while mounted on a constant diameter 72" long inlet pipe) experienced a one-second long chatter event. During this chatter event, the closing pressure was approximately 70 psi (or 51% blowdown). It should be noted that this same valve was stable on a 24" pipe segment. This suggests stability is dictated by the installation more than the required relief rate (although, as shown by Paul et al., relief valve demand capacity has a minor effect on stability compared to the inlet pipe length).

Today there are minimal guidelines for dealing with these small over-pressurizations that result in the relief valve continuously cycling. ASME recommends a 10% margin between the operating pressure and the set pressure of a relief device. However, minor process upset can still result in relief device opening, cycling, or chattering. If a relief systems designer is concerned about oversized relief valves or the aggregate problem of sporadic relief events from various systems with large relief valves, one possible design solution could be to add a secondary relief valve that is sized for smaller system disturbances with a slightly lower set pressure than the larger main relief valve. In this way, the system will be protected from both minor and major system disturbances and limit the release of contained fluid and potentially reduce relief valve wear from cycling. *Note that the use of a relief device to control pressure in process requirement is inconsistent with the requirement in ASME pressure vessel code.*

For most systems that can be expected to have real world releases that are significantly lower than the relief device capacity, the relief systems designer should determine the minimum possible inlet line length for the relief valve that meets all other design criteria, as it has been shown that shorter inlet piping has less acoustic power and is less likely to couple with the relief valve and result in a chatter event.

Capacitance:

The frequency of cycling due to a relief valve being oversized is related to the size of the system, the rate of feed to the system, and the capacity of the relief device. As shown in Figure 2, while the relief device is 300 times oversized, it still takes 1 second to depressurize the system. For an oversized relief valve to reach high frequency cycling (chatter) will take the combination of a large relief device with long inlet piping connected to an extremely small system volume (e.g., a piping letdown station). In many cases, the low system pressurization rate which causes the relief device to be oversized results in low cycling frequencies (>1 Hz). While theoretically possible to get the cycling frequencies similar to chatter (> 40 Hz), the practicality of real world systems meeting these requirements is unlikely, but easy for a relief systems designer to verify (for additional information refer to the authors' previous work).

Chatter Effect on Relief Valve Performance:

Chatter can have several negative effects on relief valve performance. Several researchers have identified that chattering relief valves can result in increased blowdown [4][5]. That is, a chattering relief valve closes at a lower pressure than the same valve when chatter does not occur. This is shown in Figure 3.

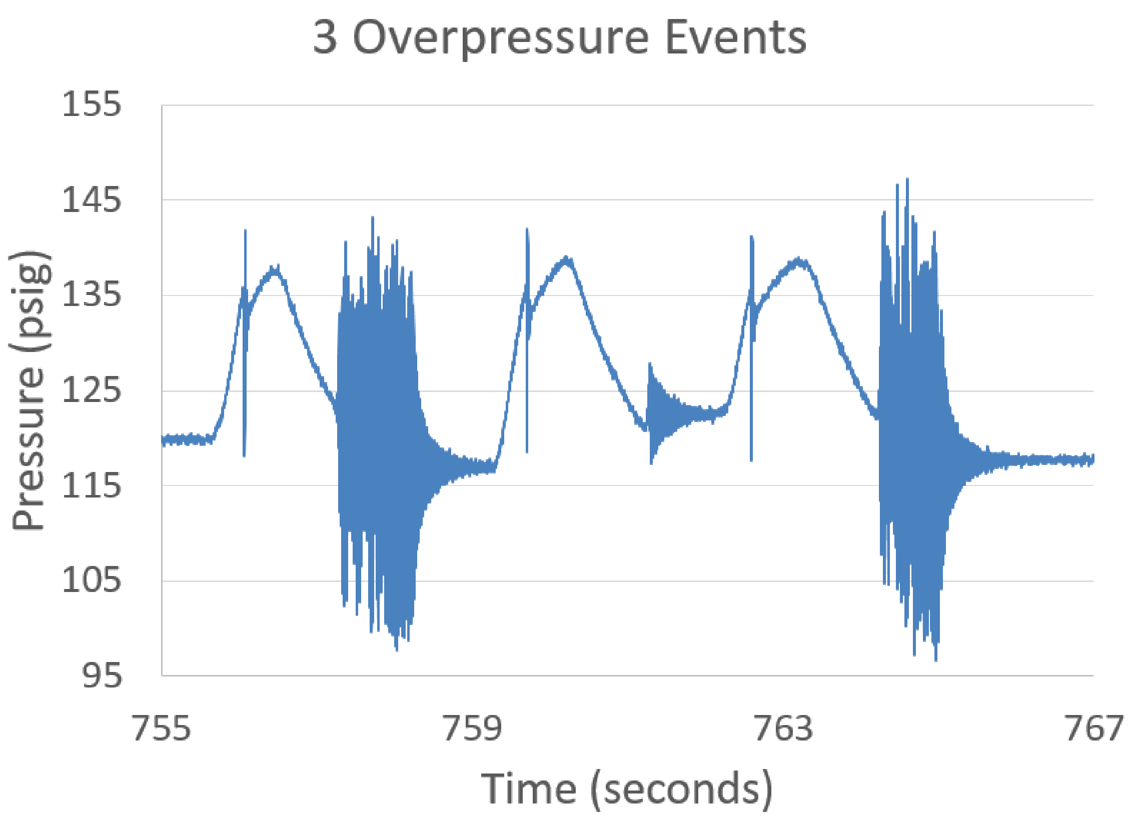

Figure 3: This figure represents the pressure at the inlet of a relief valve for three overpressure events. The Relief Valve is installed on 36" long inlet pipe and opens at ~135 psi. The valve chatters (upon closing) on the first and third overpressures with a blowdown pressure of ~117 psi. The relief valve did not chatter on the second overpressure event and closed at a pressure of 123 psi. Note that chatter reduced the closing pressure of this relief valve by 6 psi, which is approximately 4.4% of the set pressure.

This lower closing pressure may be detrimental to the overall system process. It should also be noted that when a relief valve in liquid service couples with the acoustic standing waves in the inlet piping and begins to chatter, the measured discharge rate of the relief valve drops to approximately 70% of the design relief capacity. Chattering has also been observed to reduce the capacity of a gas system relief device by up to 50% [3][4][5]. Furthermore, in some instances chatter has been observed to accelerate the internal wear of the internal parts of the relief valve (seat, guide, bellows, etc.) and could lead to early replacement or loss of containment in extreme cases [6]. However, it should be noted that in the combined experience of the authors of this paper, significantly less damage was observed to the relief devices tested than has been observed by others.

Conclusions:

Oversized relief valves have been shown to cycle and potentially chatter depending on the specifics of the system installation. While these oversized relief valves tend to cycle when closely connected to their system, it has been observed that oversized valves can facilitate chatter on installations with long inlet lines. Relief valve chatter is most heavily influenced by the coupling of the relief device with the inlet piping (or in some cases system), and, to a much lesser extent, the demand capacity. Thus, the use of long inlet lines combined with oversized relief valves greatly increases the likelihood of relief device chatter.

In the authors' opinion, it is difficult for relief systems designers to predict what relief rate demand any given device will see in the future; as such, the relief device should be designed such that it is:

1. Large enough to pass the worst-case load (consistent with most design standards). This is typically the worst-case design scenario.

2. Installed with a piping system that avoids chatter for a large range of potential flow rates (not just the worst-case design scenario).

References:

1. API Standard 520 Part II, "Sizing, Selection, and Installation of Pressure-relieving Devices: Part II – Installation," American Petroleum Institute, 6th Ed. 2015.
2. API Standard 521, "Pressure-relieving and Depressuring Systems," American Petroleum Institute, 6th ed., 2014.
3. Ken Paul, DIERS Meeting Presentation (Spring 2016) – Houston TX; "Dynamic Behavior of Direct Spring Loaded Pressure Relief Valves – A Review of Stability Concerns"
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5. Hős, C. J., et al. "Dynamic behaviour of direct spring loaded pressure relief valves in gas service: II reduced order modelling." Journal of Loss Prevention in the Process Industries 36 (2015): 1-12.
6. Aldeeb, A. A., Ron Darby, and Scott Arndt. "The dynamic response of pressure relief valves in vapor or gas service. Part II: Experimental investigation." Journal of Loss Prevention in the Process Industries 31 (2014): 127-132.