Will It Really Make that Much of a Difference?
Broad Effects of Operational Changes on Relief System Design

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Abstract

Throughout the life of an operating facility, changes to the process are inevitable and potentially affect the systems that keep personnel and equipment safe. The Management of Change (MOC) process is intended to evaluate proposed changes prior to implementation to assess and address any risks that might be introduced as a result of this change. The MOC process typically includes a process hazards analysis (e.g. Hazard and Operability Study, Layer of Protection Analysis), which evaluates safeguards and independent protection layers (IPLs) for the proposed changes.

Of the many IPLs, pressure relief devices are often overlooked and a re-evaluation of the relief system design basis is sometimes not performed. The authors have observed that personnel do not always recognize the operational change may affect the relief system.

In this paper, the authors explore what types of changes should trigger a relief system design review, exploring why minor modifications may have major ramifications. They also provide specific examples of the most common changes that demonstrate how the relief system design can be affected.

The target audience for this paper is anyone whose responsibilities include (1) pressure relief analysis, (2) process safety management, (3) management of an operating facility, (4) process engineering, and (5) process safety information management.

1. Background and Purpose

All operational changes potentially affect relief system design. Some changes have a minor or negligible affect while others can change the entire relief system design basis.

In theory, a facility's relief system design basis should be reviewed before any operational change occurs. However, this is not a practical approach as change is an ever-present aspect of an operating facility. Not all operational changes require a full relief system design review. Within any facility, operational variation is present and the relief system should be designed to account for small variations in operating pressure, operating temperature, and normal vessel liquid levels.

The Management of Change (MOC) process should include a review of affected relief system to assess the adequacy of the design basis or bases. Will the proposed change result in a new credible overpressure scenario or an undersized relief device? What effect might the change have on downstream relief devices? These are questions that should be asked during the MOC process before a change is implemented. These are also questions that will be asked in a Process Hazards Analysis (PHA). Without a good understanding of how changes can affect the relief system, the resulting risk level may be higher if the relief device can no longer be considered an Independent Protection Layer (IPL).

Sometimes the relief system design basis may be reviewed, but the documentation and any required calculations are not updated; thereby, giving the appearance that no review was performed. Two outcomes are possible when documentation is not updated. One outcome could be that the relief device is adequately sized for the operational change, but not documented and not included as an IPL; therefore, the perceived risk is greater than the actual risk. The second outcome could be that the change results in an additional overpressure scenario, for which the relief device is not sized or is undersized. With no documentation, though, the relief device is counted as an IPL and the perceived risk is less than the actual risk.

2. Exploring Operational Changes

There are many operational changes that can occur in a facility. Due to the inherent interconnectivity of all the components and equipment at a facility, sometimes an operational change to one part of the process will result in another operational change to a different part. A throughput change may require modifications to equipment. An equipment re-rate may require an operating envelope change. Accordingly, the total effects of a relatively minor change to a system may be larger than originally anticipated.

These operational changes can affect relief valve sizing in different ways, and some calculations are more susceptible to operational change than others. They can result in the addition or elimination of an overpressure scenario, or a change to the current sizing of the relief device.

In the sections that follow, the authors will provide details for the most common operational changes: throughput change, equipment change, equipment re-rate, feedstock (compositional) change, and operating envelope change. Each section will (1) outline the impact each type of change may have on an affected pressure relief system, focusing on the addition of credible scenarios and increases in the sizing of the relief device, and (2) examine correlations between the magnitude of operational change and resultant change to relief device sizing.

The information provided is not all-inclusive, nor is it absolute. Exceptions always exist, but in the authors' experience the descriptions and guidance are what normally occurs.

Even if the controlling overpressure scenario and relief device size does not change, the relief system design documentation should be updated to reflect the current system configuration.

3. Throughput Change

3.1 Throughput Change

A throughput change describes a change in the rate of material entering the facility or unit. Changes could be for increased or decreased production, or as a result of a change in another part of the process. To simplify things, we will only consider throughput increases as throughput decreases tend to be short-term in nature and rarely result in a higher required relief rate.

Overpressure scenarios can be classified as rate dependent or non-rate dependent. For the purposes of this paper, a rate dependent overpressure scenario will be defined as any calculation which changes based on the amount of fluid passing through the system. Rate dependent cases typically involve specifying the relief rate instead of calculating a relief rate. Calculations which are based on a pressure differential (e.g. flow across a control valve, orifice flow), or which depend on a vaporization rate (e.g. external fire), are considered to be non-rate dependent. Throughput changes directly affect rate dependent overpressure scenarios, the most common of which are blocked outlet and loss of cooling/reflux.

On the surface, a throughput change can seem straightforward, and one might expect it to be easy to check relief valve sizing. As the throughput rate increases, the new throughput should be compared to the capacity of the relief device to determine if the capacity is exceeded. This simplified analysis is indeed effective in systems where boiling or chemical reaction does not occur (for which a more complex approach should be used).

To illustrate a simple analysis, let us look at a basic liquid/vapor separator and the blocked outlet overpressure scenario on the vapor overhead line. Two-phase feed enters the separator at 10,000 lb/hr and produces 2,415 lb/hr of vapor which corresponds to a required relief area of 0.081 in^2. A debottlenecking project is implemented which increases the feed to 15,000 lb/hr having the same composition and operating conditions. The new feedrate produces 3,623 lb/hr of vapor which corresponds to a required relief area of 0.122 in^2. The vapor flowrate and required area both increased by the same percentage the feed was increased, showing a direct correlation between the throughput increase and the relief rate/area increase.

When looking at how the more complex systems change based on throughput, the best way to perform an analysis is using a simulation to mimic relief conditions. An example of a more complex system is a tower with a loss of cooling to the overhead condenser. Consider a tower designed to separate C4s and lighter from a feed stream. Losing overhead cooling produces a certain amount of relief fluid. When the throughput to the original tower is increased by 15% and all other conditions remain the same, the required orifice area also increases by approximately 15%.

Both of these examples show that when other conditions remain the same, there is a direct correlation between throughput increase and relief area increase. If other factors (e.g. pressure, desired separation) change, then the desired correlation may not hold true.

4. Equipment Change

Another potential pitfall is changes to equipment. This can be something as simple as changing a pump impeller or something as complex as replacing a fractionating column. As a general guide, replacements-in-kind typically will not affect the relief device sizing. Examples of equipment replacements-in-kind include replacing a heat exchanger with a similar size and duty exchanger, replacing a control valve with one having the same size and C_v value, or replacing a tower with one having the same dimensions and number of trays so as to keep the separation the same. If the replacement heat exchanger has a longer shell or thicker tubesheet, it would not be considered a replacement-in-kind, relief device sizing could be affected, and the change may require the relief valve to be resized.

4.1 Pump Impeller Change

Consider a process which requires additional flow through a centrifugal pump. The facility currently has one online pump and one spare and would like to remain with only one pump in operation at a time. The process dictates that pump discharge pressure must remain the same, so the decision is made to install a larger diameter pump impeller to achieve the increased flow. With the larger impeller, the pump curve has changed and the deadhead pressure has increased. This example actually has two items that need to be checked.

First, it must be determined whether the previous deadhead pressure of the pump would overpressure the vessel if the liquid outlet was blocked and the vessel overfilled. A review of the relief device protecting the downstream vessel may show the MAWP of the vessel is greater than the deadhead pressure of the pump. In this example, liquid blocked outlet is not a credible overpressure scenario and no sizing was performed. However, with the *increase* in deadhead pressure, a review of the same relief device may show the deadhead pressure has increased sufficiently to result in overpressure of the vessel in the event of a liquid blocked outlet. Sizing must be performed to determine the adequacy of the relief valve.

To put it in terms of actual values, originally, the pump deadhead pressure was 195 psig. The downstream vessel has a MAWP of 200 psig and the relief device is set at the same pressure. Since the deadhead pressure did not exceed the MAWP of the vessel, this would not have been considered a credible overpressure scenario and no relief device sizing would have been performed. With the new impeller the deadhead pressure of the pump is 225 psig which now exceeds the MAWP plus allowable accumulation of the vessel which equates to 220 psig. Now this scenario has become a credible overpressure scenario and requires relief device sizing.

Second, if the relief device was initially sized for the liquid blocked outlet overpressure scenario, the device must be checked to determine if the relief device has enough capacity to pass the new flowrate. This would be similar to the throughput increase and the relief rate change would be in direct proportion to the increase in pump flowrate.

4.2 Control Valve Change

A different type of equipment change involves a control valve used to let down pressure. A given process requires an increase in fuel gas to a vessel with an MAWP of 150 psig and relief device set at the same pressure. A control valve is installed on the fuel gas line to let the pressure down from 200 psig to 100 psig before entering the vessel. The existing control valve is not large enough to allow the increased flow and remain at the downstream operating pressure of 100 psig. The facility decides to install a larger control valve to obtain the required flow at the normal operating pressure. The downstream relief device is properly sized for the flow through the control valve currently installed. Though various factors contribute to the amount of flow that passes through a control valve, the C_v value has the greatest impact. The greater the change in wide open C_v value, the greater the increase in required area.

5. Equipment Re-rate

Equipment re-rating can be done to decrease the MAWP of equipment and is often done to extend its life. When equipment is re-rated, it can have an effect not just on the relief device protecting it, but it could also affect additional relief valves that are not as obvious. It could potentially eliminate credible overpressure scenarios in other downstream relief devices or it may add scenarios to other relief devices. For instance, re-rating the low pressure side of a shell-and-tube heat exchanger may result in tube rupture becoming a credible overpressure scenario where it may not have previously been. Re-rating the high pressure side of a shell-and-tube heat exchanger may eliminate a tube rupture scenario for that exchanger.

5.1 Heat Exchanger Re-rate

In the heat exchanger examples mentioned above, let us consider what happens when each side is re-rated. A heat exchanger has a shell-side (high pressure) MAWP of 300 psig. The tube-side (low pressure) has an MAWP of 200 psig and a hydrotest of 1.5 times (300 psig). For this exchanger, the shell-side MAWP does not exceed the tube-side hydrotest pressure and tube rupture is not considered a credible overpressure scenario. If the tube-side is re-rated to 175 psig MAWP and 1.5 times hydrotest (263 psig), the tube-side hydrotest pressure is now less than the shell-side MAWP. This has created a credible overpressure scenario and the tube-side relief valve should be resized to pass tube rupture flow.

A different heat exchanger has a tube-side (high pressure) MAWP of 400 psig. The shell-side (low pressure) MAWP is 250 psig and has a hydrotest of 1.5 times (375 psig). In this exchanger, the shell-side relief valve is sized for a tube rupture overpressure scenario. Downstream of the shell-side of this exchanger is a vessel also with an MAWP of 250 psig but a hydrotest of only 1.3 times (325 psig). The tube-side of the exchanger is re-rated down to 370 psig, which eliminates the tube rupture case in the exchanger. However, the downstream vessel hydrotest pressure is still less than the tube-side MAWP. Now the downstream vessel has a credible tube rupture scenario and the relief valve should be resized for it.

5.2 Vessel Re-rate

Often, an upstream relief valve is used to limit the pressure to downstream equipment (i.e. both vessels have an MAWP of 300 psig and the upstream relief valve is sized for a blocked outlet case so the downstream relief valve is not needed for a blocked outlet). If the downstream vessel is re-rated to 250 psig, the upstream relief valve cannot be used to limit the pressure to the downstream vessel and the lower set pressure relief valve will need to be re-sized for the blocked outlet scenario.

6. Feedstock (Compositional) Change

Composition changes can occur in any part of a facility. They can be changes to feedstock, addition of a new feedstream, changes to chemical additives, or changes in composition within the facility or process unit. Compositional changes may not have the same effect at the end of a facility or process unit as they do at the inlet. The potential for the most change to the relief valve is where the compositional change is introduced. The fluid phase also contributes to how much the composition will affect the relief valve sizing.

Vapor streams are affected by changes in molecular weight (MW) which is essentially a specific gravity change. The lower the molecular weight and subsequently specific gravity, the greater the required relief area -- assuming the same temperature, pressure, and flowrate for a given stream. However, the change here is not proportional as it is with a throughput change. Consider a vapor hydrocarbon stream entering a gas plant having a molecular weight of 22.5 lb/lbmol. Gas from a different well is routed to this same gas plant, changing the molecular weight to 21.3 lb/lbmol. This change in composition will have some effect on relief valve sizing but will likely be insignificant. If the gas molecular weight changed from the initial down to 18.8 lb/lbmol, the effect on relief valve sizing will likely be greater.

Liquid streams are also affected by changes in molecular weight and liquid specific gravity. However, changes in molecular weight without a subsequent change in specific gravity have little effect on relief valve sizing. For example, MDEA used for removing H_2S from vapor streams is typically 40% MDEA and 60% water and has a molecular weight of 58.47 lb/lbmol. A stream of pure MDEA has a much higher molecular weight (119.16 lb/lbmol); however, the specific gravities of these two streams are approximately the same at the same conditions. The similar specific gravity indicates relief valve sizing will be similar.

A final feedstock change worth considering pertains to production wells. Over the lifetime of a given subsea gas well, for instance, the production fluid from the well will typically develop higher and higher water to gas ratios. If a relief valve is installed on the flowline upstream of any separation to safeguard against a blocked-in scenario, it would need to relieve the full production fluid -- in this case, a two-phase mixture. The relief installation should be adequately sized to account for all expected flow profiles; however, it is significantly more difficult to generalize the effect different flow qualities will have on relief valve sizing, as sizing of two-phase flow requires a much more rigorous analysis than single phase flow. As such, the recommended approach is to ensure that the relief design is adequate for all extremes of the flow profile for the projected lifetime of the well.

7. Operation Envelope Change

Of all potential operational changes, the operating envelope changes have the potential to be the most severe and seem to be the easiest to overlook in relief device sizing. Operation envelope refers to pressure, temperature, liquid level, and alarm setpoints/interlocks. In the authors' experience, a good practice is to size relief devices such that minor fluctuations in operating conditions will not require resizing of the relief valve. For example, if the controlling case for a valve requires an area of 1.270 in^2, good engineering practice when designing the relief system is to install a K orifice (1.853 in^2) instead of a J orifice (1.287 in^2) to allow for fluctuations in the process.

Required relief rates are typically calculated based on the normal operating conditions at the time of the analysis. If those operating conditions change significantly, the required relief rate and subsequently the relief device sizing may change as well. This is especially important if the change in operating conditions results in additional credible overpressure scenarios.

A pressure or temperature change in an upstream vessel may also result in more than a pressure/temperature change in downstream vessels. For example, look at the cold side of a shell-and-tube heat exchanger. If the operational temperature of the hot side is increased, the result of isolating the cold side could be vaporization of the liquid instead of thermal expansion of the liquid. Additionally, increases to the pressure of the high pressure side could render the installed relief device ineffective due to the response time.

7.1 Pressure Change

Many required relief rate calculations are based on pressure differential. As the pressure increases on the high pressure side, the required relief rate increases and subsequently the relief device required area increases.

One of the most frequently occurring examples of pressure change involves gas blowby from a higher pressure vessel down to a lower pressure vessel by way of a wide open control valve. Consider a separator operating at 400 psig. As a result of a change to the process upstream, the separator must run at a higher operating pressure than normal. The operating pressure needs to increase from 400 psig to 475 psig. The downstream vessel has an MAWP of 250 psig with the relief device set at the same pressure. This creates an increased pressure differential from 125 psi to 200 psi.

Operating pressure increases can also affect the stability of the relief device. In order for relief devices to operate properly, a pressure differential must exist between the set pressure of the relief device and the operating pressure of the vessel due to blowdown and tightness requirements. For direct, spring-operated conventional and balanced bellows relief devices, there are general guidelines for the minimum difference.[1]

- 5 psig for set pressures ≤ 70 psig
- 10% for set pressures between 71 psig and 1000 psig
- 7% for set pressures > 1000 psig

Pilot-operated relief valves are a special case as they have different blowdown and tightness requirements and can operate at a much lower differential than spring-loaded valves. The typical differential pressure for pilot-operated valves is 5%. Operating at differentials less than the recommended minimum values may result in chattering or cycling and subsequent damage to the relief valve or failure of the relief valve altogether.

7.2 Temperature Change

Temperature changes do not necessarily have as direct an effect on relief device sizing as pressure changes do. Incompressible fluids are more affected by temperature changes than compressible fluids. Unlike pressure, temperature changes will not create new overpressure scenarios except in the case of thermal expansion due to ambient heating (solar radiation). Temperature has the potential to change the phase of a fluid from all liquid to two-phase or vapor when flashing from higher pressure down to lower pressure. Required relief area is much greater for a two-phase fluid than for a liquid.

For instance, a vessel with a liquid hydrocarbon mixture operates at 250 psig and 180 °F. The liquid flows to a downstream vessel through a control valve to a vessel which has a MAWP of 100 psig. At these upstream conditions, the fluid will remain all liquid as it flows through the control valve and the relief fluid will be all liquid. If the temperature of the upstream fluid is increased to 210 °F, the fluid flashes as it flows through the control valve and the relief fluid becomes two-phase which has a much greater required relief area than liquid.

The other main effect temperature changes have is during a liquid thermal expansion overpressure scenario, specifically thermal expansion in the cold side of a shell-and-tube heat exchanger. This occurs when the cold fluid is isolated while hot fluid continues. The temperature of the hot side fluid determines if the cold fluid remains a liquid or vaporizes at relief pressure. During the initial analysis of a relief device, the temperature of the hot fluid may not have been high enough to vaporize the cold fluid. If the hot fluid temperature is increased, the current analysis may require the relief device to be sized for vaporization of the cold fluid instead of expansion. This could significantly change the sizing of the relief valve.

Another example involves a shell-and-tube heat exchanger having the hot side fluid on the shell-side and cold side fluid on the tube-side. The hot side fluid normally operates at about 250 °F. At this temperature, the colder fluid will remain liquid at relief pressure if the tube side of the exchanger is blocked in while the hot side remains flowing. However, if the temperature of the hot side is raised to 305 °F, the fluid will vaporize when blocked in.

7.3 Liquid Level Change

Vessel liquid levels can be one of the most difficult operational changes to assess against a given relief system design. Liquid levels factor into more than just the required relief rate calculations. They may factor into what types of instrumentation are installed on a vessel and the determination of response time during an upset. A cursory glance through the relief system design may not be enough to understand how a change in liquid level will affect the system.

The most common impact of a liquid level change is on the external fire overpressure scenario. Liquid level affects the wetted surface area calculation, which changes the external fire required relief rate calculation. Since the heat input calculation is based on the wetted area raised to the 0.82 power, it is difficult to determine a correlation between the increase in liquid level and relief valve sizing. Small increases in liquid level are expected to have less effect on relief valve sizing than larger changes.

Another area where adjustments to liquid level can be an issue is in the case of high pressure to low pressure interfaces (e.g. high pressure separator flowing into a low pressure separator) where liquid overfill can occur prior to gas blowby when a bottom level control valve fails open. The liquid levels in both vessels can initially be set such that loss of liquid level in the upstream vessel does not overfill the downstream vessel prior to gas blowby occurring from the upstream vessel. An increase to either the upstream vessel or downstream vessel liquid level may be sufficient that the low pressure vessel will overfill with liquid prior to gas blowby. This liquid full condition can result in the gas displacing the liquid in the vessel and that liquid having to be relieved before the high pressure gas can be relieved.

8. Additional Considerations

The operational changes described above are the most common and have the greatest impact on relief system design. As mentioned above, any operational change has the potential to result in a relief design basis change. Some additional operational changes are listed below:

- Removal of restriction orifices - if the orifice is used in sizing the relief device, removal of the orifice will require a change in the relief device sizing and probably an increase in the size of the relief device;
- Changes to relief device inlet and outlet piping;
- Changes in alarms or interlock setpoints - a note of caution here, changes in alarm setpoints may not require an MOC but the setpoints may be used in the relief device sizing as an upper or lower limit; and
- Installing or removing check vales - API 521 Section 4.4.9.3[2] provides guidance on taking credit for installed check valves to reduce required relief rates.

9. Guidance

Now that the most common operational changes have been described and specific examples have been detailed, how does that translate into knowing if your change will have a large or small effect on the relief system design? The authors have put together some guidance to follow when evaluating operational changes. As a note, in the authors' experience, if the current required area for the overpressure scenario affected is within 10% of the available area of the relief device, the device should be resized for any change.

While each operational change is unique, there are some commonalities that may provide the engineer a way to evaluate the effect on relief system design.

- Throughput changes generally result in a percent change in relief area proportional to the percent change in flow when all other conditions remain the same.

- Equipment changes are varied, and therefore, more difficult to find commonalities. Changes to rotating equipment tend to follow the same guidelines as throughput changes. For globe style control valves, the percent change in wide open C_v is roughly equal to the percent change in relief device required relief area. Changes to vessels and heat exchangers should be evaluated on a case-by-case basis.

- When re-rating heat exchangers, the tube rupture overpressure scenario is the most critical. If the relief device is already sized for the tube rupture scenario, a pressure differential change of approximately 5% corresponds to a less than 10% change in required relief area; however, the percent change in relief area is not proportional to the change in pressure. Re-rating of a vessel should require the entire relief system to be re-evaluated at the new pressure. Any changes that need to be made should follow the other typical operational changes described.

- Feedstock changes generally have the least effect on relief valve design. When evaluating vapor, as the MW decreases, the required relief area increases. There is difficulty in determining a percentage change since the composition affects other properties. With liquid compositions in the same family (e.g. hydrocarbons), as the molecular weight increases, the density increases as well which in turn increases the required relief area. Generally, the required relief area changes at a rate of 50% of the density change.

- Changes in pressure when evaluating vapor show that at pressures less than 200 psig, the percent change in pressure is greater than the percent change in required relief area. At pressures greater than 200 psig, the percent change in pressure is less than the percent change in required relief area. For liquids, the percent change in pressure corresponds to the percent change in required relief area. Changes in temperature have little to no effect on the required relief area of vapors. For liquids, unless a significant change in specific gravity is associated with the temperature change, the required relief area is minimally changed. Changing a vessel's liquid level by 20% creates a 10% - 15% change in required relief area.

10. Conclusion

Change is an integral part of the long term operation of any production facility. Balancing the need for safety of personnel and equipment with the profitability of a facility can be difficult at times. Knowing where to focus efforts will help streamline that process. Relief system design can be complex and confusing, but understanding how operational changes affect the relief system is beneficial (especially in the broader context of PHAs).

The most common operational changes (throughput change, equipment change, equipment re-rate, feedstock/compositional change, and operating envelope change) were detailed and guidelines were provided based on how the change may affect the required relief area. These changes may show different effects based on fluid phase. While the material presented is not all encompassing, it provides a basis for evaluation. Some changes have little to no effect on the relief device. Others can completely change the relief device design basis. Beginning from a starting point is better than not beginning at all.

11. References

[1] ASME Boiler and Pressure Vessel Code. *Section VII, Division I, Rules for the Construction of Pressure Vessels.* American Society of Mechanical Engineers, New York, NY, 2013.

[2] API Standard 521. *Sixth Edition, Pressure-relieving and Depressuring Systems.* American Petroleum Institute, Washington, DC, 2014.