Pressure Relief Valves − is there a need when there are EDVs?

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This paper provides a discussion on the need for pressure relief valves (PRVs) if emergency depressurisation valves (EDVs) are designed into a system. The intention of the paper is not to provide an analysis of whether PRVs are required or not, but to pose the question using a risk-based approach. Indeed it may be the case that for certain situations, PRVs and EDVs are required to act as independent systems with appropriate redundancy, even with initial relief from a pressure control valve (PCV). However, it may be the case that there are certain situations where the risk is considered as low as reasonably practicable (ALARP) for EDVs alone, particularly for modern systems where there may be significant improvements in the reliability of equipment. This requires a different way of thinking when designing plant. Where the 'traditional' method was to always include PRVs without further though as to there requirement, this may be replaced by design techniques using risk-based approaches.

Keywords: Emergency Depressurisation, Blowdown, Pressure Relief, Reliability, Redundancy.

Introduction

With the increase in Emergency Depressurisation Valves (EDVs), are Pressure Relief Valves (PRVs) required in certain situations or it is simply prescription and history that are driving their inclusion? Is it the 'traditional' way of designing plants that results in the inclusion of PRVs, i.e. blowing the dust of an old design, rather than starting from scratch.

Modern designs often include blowdown systems, applying API 521 (Ref. 1) design principles, such that there is a reduction in pressure to 6.9 barg (100 psig) or 50% of the design pressure of the system (whichever is lower) within 15 minutes, for each sectionalised area of the process, including pipe sections. This is the principle applied for a vessel subjected to a pool fire which is normally considered as the worst case rapid pressure generating case. Generally, redundancy is provided within the design to meet reliability requirements, such that there are 2 x 100% EDVs on any one system that may require blowdown.

It may often be the case that the same system will also include PRVs. There is generally redundancy within the design for the PRVs as well, i.e. at least 2 x 100%. However, with the improvement in reliability of EDV systems, might it be the case that the PRVs are virtually redundant, particularly if there is already a pressure control valve (PCV) with discharge to the flare, as shown in Figure 1.

There is also an added issue that should be discussed with regard to the operation of such systems. If there are PRVs designed into a system, could there be the potential to consider these as a 'back-up' for the EDVs, rather than two independent systems. If EDVs are built into a system, these will always be the primary means of depressurisation. The PRVs could be considered as an independent back-up if the EDVs should fail. However, as there is redundancy built into the EDV system, a good safety management system should ensure that there is an appropriate proactive maintenance regime to ensure a high reliability. If the PRVs are considered as an alternative, rather than an independent back-up, there is a higher potential for complacency, with an increased likelihood of unavailability of the EDV system, the primary safety system.

Furthermore, if it is considered that PRVs are no longer required because EDVs are available for a system, there will be reduced CAPEX and OPEX.

The paper discusses the pros and cons of the removal of PRVs from a system if EDVs are already present. It opens the debate for future projects with the emphasis on ensuring that the optimal system is available for pressure relief.

Reasons for Overpressure

Process equipment is designed to contain the system pressure (Ref. 1), with the design based on:

a) the normal operating pressure at operating temperatures;

b) the effect of any combination of process upsets that are likely to occur;

c) the differential between the operating, and set pressures of the pressure-relieving device;

d) the effect of any combination of supplemental loadings such as earthquake and wind.

The maximum operating pressure is defined in any system to prevent the pressure in any piece of equipment from exceeding the design pressure (with the operating set at a safe level below the design pressure). However, overpressure of the equipment may occur, and has occurred on many occasions in the past. The principal causes of overpressure are defined in API 521 (Ref. 1):

- Closed outlets on vessels
- Inadvertent valve opening
- Check valve leakage or failure
- Utility failure
- Electrical or mechanical failure
- Loss of fans
- Loss of heat
- Loss of instrument air or electric instrument power
- Reflux failure
- Abnormal heat input from reboilers
- Heat exchanger tube failure
- Transient pressure surges
- Plant fires.

Pressure-relieving systems are designed into plant to prevent an overpressure from such causes that will result in a loss of containment. Depending upon the level of risk, multiple independent systems may be used (with the example shown in Figure 1 of a pressure control valve, an EDV and 2 x 100% PSVs). There may still be an issue with common cause failures, although in the case of the independent systems shown in Figure 1, common cause failure is reduced, particularly as EDVs are fail-open and PSVs are not reliant on control systems. The common cause failure in this case would be a lack of a good safety management system, such that all pressure-relieving systems were poorly maintained, or taken out of service.

Pressure Systems Safety Regulations

The Pressure Systems Safety Regulations 2000 state in Regulation 4(5): "*The pressure system shall be provided with such protective devices as may be necessary for preventing danger; and any such device designed to release contents shall do so safely, so far as is practicable*" (Ref. 2).

Guidance is provided in the Approved Code of Practice (Ref. 2), which states in Paragraph 64: *"Every plant item in which the pressure can exceed the safe operating limit (i.e. those which have not been designed to withstand the maximum pressure which can be generated within the system) should be protected, whenever operational, by at least one pressure-relieving or pressure-limiting device. The device should be suitable for its intended duty and should be fitted as close as practicable to the plant item it is designed to protect. Sufficient devices should be fitted at other points to ensure that the pressures inside the system do not exceed the safe operating limits. In the event of a pressure relief device operating, the design should enable the contents to be released in as safe a manner as is practicable"*.

Paragraph 70 states: *"The devices and associated inlet and outlet pipework should have an adequate discharge capacity in order to limit pressure to within the safe operating limits. It should reach full discharge capacity within a set limit of overpressure (accumulation). The normal operating pressure of the system should be sufficiently below the setting of the protective device to prevent its premature operation"*.

One of the key points here is that the guidance document states that at least *one pressure-relieving device* should be fitted. Although the number of pressure-relieving devices is not stipulated for a specific system, one would expect that a system that may produce high consequences upon failure and where the operating limits may give reason to predict a relatively high frequency of failure would be expected to have multiple protection. Regulation 4(5) stated above uses the term *so far as is practicable*. It is expected that this refers to the ALARP philosophy.

Pressure Control (Relief)

The diagram in Figure 1 is a simplified P&ID showing a vessel for oil and gas separation, with difference systems for pressure relief:

- PCV
- EDV
- PSVs.

Pressure Control Valves

The initial pressure relief may be through a pressure control valve, for example that is set to a pressure above the pressure control valve on the gas discharge from a liquid / gas separator, as shown in Figure 1. The operator would also be alerted to the fact that there is a high pressure in the system by a high pressure alarm. The Digital Control System (DCS) would highlight to the operator that this valve has been opened to relieve pressure to the flare system.

Emergency Shutdown and Emergency Depressurising Systems

The function of an ESD and associated emergency depressurising (blowdown) systems is to isolate equipment into sections and, if necessary, depressurise those sections under controlled conditions to the flare system.

An ESD system ensures safe isolation and shutdown of equipment under fault, process upset, leak or fire conditions. An ESD system activates pre-programmed actions automatically on detection of abnormal process or safety conditions, or by manual activation.

An ESD system is interfaced with the Fire & Gas (F&G) system so that hazardous conditions detected by the F&G system triggers the appropriate ESD actions. The ESD system is also interfaced with the DCS, to provide complete status, alarm information overviews, alarm management, and operational and maintenance overrides.

The severity and scale of a trip or detected hazard condition determines the levels of ESD shutdown, for example offshore:

- ESD 0 (the highest level) is Abandon Platform. Abandon Platform is initiated only by push button prior to evacuation. ESD 0 initiates the Prepare to Abandon Platform Alarm (PAPA);
- ESD 1 is total facility shut down and the automatic activation (or permissive for manual activation) of the plant automatic blowdown sequence;
- ESD 2 is production shutdown plus blowdown of the area affected by a confirmed gas / fire detection. ESD 2 blowdown is activated after a time delay of 30 sec, during which operator interruption is permitted. (The operator has the facility to interrupt the auto blowdown, if required, via the 30 second timer interrupt button. Single area depressurization push button is inhibited when any auto blowdown sequence is activated. The permissive configuration allows only one area to be blown down at any one time; on completion of blowdown of that one area, the permissive configuration will allow another one area to be blow down);
- ESD 3 is total production shutdown (or process shutdown).

The primary emergency depressurisation (blowdown) function is to provide equipment with a means of pressure reduction when loss of containment is unacceptable, for instance in a fire scenario. The secondary function is to reduce local loss of containment arising from a leak, which may otherwise lead to escalation and the risk of catastrophic

After isolation via ESD valves the blowdown system is via emergency depressurisation valves (EDVs). The EDVs evacuate gaseous inventory under controlled conditions (blowdown sequences) to the flare system. EDVs are 'fail open' and supplied with dedicated instrument air volume tanks to maintain air pressure. This keeps them in the closed position and prevents simultaneous blowdown of an entire complex in case of loss of instrument air.

According to API 521 (Ref. 1): "*In the case of protecting vessels exposed to fire, a vapor depressuring system should have adequate capacity to permit reduction of the vessel stress to a level at which stress rupture is not of immediate concern. For pool fire exposure, this generally involves reducing the equipment pressure from initial conditions to a level equivalent to 50 % of the vessel's design pressure within approximately 15 minutes.*"

"Depressuring to a gauge pressure of 690 kPa (100 psi) in 15 min is commonly considered when the depressuring system is designed to reduce the consequences from a vessel leak or failure. This criterion is also commonly applied for both fire and leak scenarios. Controlled depressuring also guards against the potential of adding fuel to the fire should the vessel rupture, thereby reducing the fire duration or severity. The reduced pressure permits somewhat more rapid control of the situation in which the source of fire is the leakage of flammable materials from the equipment being depressurized. The fire scenario results in a higher depressurization rate than the non-fire case, whereas the non-fire case could result in the need for materials suitable for lower temperatures. If vapour depressuring is required for fire, leakage, and/or process reasons, the larger requirement usually governs the size of the depressuring facilities."

"Depressuring criteria other than those given above can be used depending upon the specific circumstances and user-defined requirements. For example, if there is a reactive hazard or other exceptional hazard that can cause loss of containment due to over temperature, emergency depressuring can be appropriate for equipment designed for a wider range of pressures than that noted above."

Pressure Relief Valves

PRVs provide the means for overpressure protection of hydrocarbon inventories in a process upset or under fire condition. This may be for cases where the emergency shutdown systems (ESD valves and EDVs) do not react within sufficient time to contain pressure within the design envelope.

Discussion

With the design of past, present and future pressure relief systems, there may be two major questions to ask:

- What was / is in the designers' heads?

- Has this / will this be carried through into Operations?

Nothing is 100% reliable. Even SIL-4 systems, which are very high integrity, may fail. This is a key reason why designers will often include PRVs into a system that is already protected by ESVs and EDVs. However, is this 'safety factor' simply to include a level of safety that is not required, due to an already high reliability, or could this actually be detrimental if complacency sets in by the consideration of double protection? It is important to remember that when a Project has been handed over to Operations, what was "in the designers' heads" may be lost. Also, the system may be operated for 40 to 50 years, with a significant turnover of staff. Hence, the upkeep of a good safety management system in operation is vitally important to ensure that a high level of reliability is maintained.

Design Perspective

Is it the 'traditional' way of designing plants that results in the inclusion of PRVs, i.e. blowing the dust of an old design, rather than starting from scratch? Certainly PRVs have become a traditional part of process, often in a 2 x 100% arrangement. When design engineers are designing a process vessel, for example, one of the first levels of instrumentation would often be a system of PRVs. In the first instance this may be taken from another design with the PRVs already designed into the system.

Where a system that includes ESVs to sectionalise the process and EDVs for each of the sections is designed this is generally as the system contains high hazard materials, for example sour gas systems. The EDVs can have two major functions in design:

- If the pressure becomes critical, i.e. above the high-high level set by the DCS, the EDVs will open to relieve the pressure by sending the fluid to the high pressure flare system;
- If there is a leak of fluid, the ESVs will close and the EDVs will blowdown the system. (The whole system may be blown down sequentially.)

If we think about it from a protection point of view is an EDV more appropriate than a PRV? Let's take the case of a jet fire impingement on a vessel. A jet fire can potentially cause structural deformation in less than five minutes. During that period it is unlikely that the overall vessel pressure will rise to a level that would lift a PRV if there is only locally heating at one point. Therefore, having a ESV/EDV system would be preferable as inventory can be isolated, and depressurisation of the affected systems initiated, before the structural failure occurs and there is major escalation of the event. In this case a PRV would be completely redundant and wouldn't from part of the vessel protection system.

In terms of CAPEX, the ESD system including EDVs will have a much higher cost than PRVs that are connected to the flare system. Hence, if cost became an issue in a project, the inclusion of PRVs would not be a high profile item in terms of cuts. In the designers' mind, "why wouldn't one include them in the design' as the cost is relatively low and we've always put them in"?

One last perspective is from the other point of view. If the ESD system with EDVs is designed with high integrity, e.g. SIL-3, then by adding potential extra protection with PRVs, does this suggest that a failure of the EDVs is still a credible outcome? Certainly, reliability data from sources such as OREDA (Ref. 3) may suggest that such failures are credible.

Operations Perspective

From an Operations perspective, one big danger is that the overall reason behind a design of PRVs and EDVs in parallel may be lost over the years, particularly as personnel change. The importance of an understanding of the overall design throughout the life-cycle of a plant cannot be overstated. Of course, as discussed above, the reason that PRVs and EDVs may be included in a design in parallel may simply be because "that is how it has always been done". However, an understanding of the importance of each part of the system is essential for Operations.

Another big danger in Operations is that there is a level of complacency due to the fact that there are two separate systems for pressure relief. The danger is that planned maintenance is not as rigorous for the EDVs, for example, as there is pressure relief back-up from the PRVs. This is an unlikely scenario, but there is always the potential if a well maintained safety management system is not in place. As discussed above, the EDVs are also in place for blowdown of the system if there is a release. The PRVs are not designed for this scenario. Hence, it is vitally important the EDVs are well maintained. If it is felt that the primary system for pressure relief is the EDVs, then it may be the case that the planned maintenance routine is not so strict for the PRVs. Again, this is a dangerous scenario, particularly if the reasons for a back-up of pressure relief are lost.

The adoption of a good safety management system is essential to ensure that all safety critical equipment (SCE) is well maintained throughout the life-cycle of a project. EDVs and PRVs are considered safety critical and would be items under the planned maintenance system to ensure a high level of reliability. Safety management systems have become well established mechanisms to reduce the risk of accidental events at process plant and a system that is well maintained would reduce the likelihood of SCE become unfit for use, thus increasing the risk of escalation should a deviation from normal operating conditions occur.

Bowtie Analysis

Bowtie analyses have become well established mechanisms for defining the threats and consequences for a major accident hazard (top event). One of the critical aspects of the bowtie diagram is the barriers that reduce the likelihood of the threats and the potential impact of the consequences.

This is one area where the difference between EDVs and PRVs can be graphically demonstrated, as shown in Figure 2. Whilst PRVs will only appear on the left-hand side of the bowtie diagram as a barrier against overpressure and potential loss of containment, EDVs will appear on both sides of the bowtie. From a prevention standpoint, EDVs essentially act in the same ways as PRVs as they reduce pressure before a critical level above the design pressure is reached. (The design of the DCS will ensure that EDVs are opened before the PRV set pressure is reached, such that the PRVs are a 'last line of defence'.) Also, EDVs appear on the right-hand side of the bowtie diagram, as upon a loss of containment, the ESD system will be initiated and the EDVs will blowdown the leaking section to the HP flare.

Bowtie diagrams are often used as a mechanism to define the SCEs. The effectiveness and criticality of the barrier can be defined on the bowtie by the assessment team. This may provide a mechanism to determine the relative importance of the EDV and PRV barriers, i.e. the assessment team may define an EDV barrier as more critical than a PRV barrier for the overpressure threat. With the additional barrier on the right-hand side of the bowtie, this certainly increases the effectiveness and criticality of EDVs (compared to the PRVs).

An important part of any bowtie analysis is from moving from Project to Operations. If bowtie analysis is used for a process, there will generally be analyses conducted at different times, and, as a minimum, it is expected that there would be Design bowties and Operations bowties. As the Operations team is set up and bowties are developed for the Operations phase, this provides a perfect platform to transfer information from Project to Operations. The best starting point for Operations bowties are the Design bowties themselves; the operational aspects would simply be added to the bowties. It is considered essential that personnel from Project are invited to the Operations bowties workshop, such that vital information is noted with regard to all SCEs. This provides the opportunity for Operations to note "what was in the designers' heads" and why, for example, it may be considered essential for there to be parallel pressure relief systems of EDVs and PRVs. The converse is also true. If the designers have not included PRVs, then the Operations bowtie workshop provides the opportunity for a discussion with Operations on why such a design was chosen.

Overall Decision-Making

If EDVs are present in a system, the potential inclusion of PRVs in addition will be down to a number of factors, and the Design Engineers should pose as questions:

- What would be the consequences of a loss of containment due to overpressure, i.e. how significant are the hazards posed by the process materials?
- What is the likelihood of a loss of containment due to overpressure?
- What is the reliability of the emergency depressurisation system; is the SIL level chosen sufficient?
- For the emergency depressurisation system chosen, have any previous failures occurred resulting in overpressure and loss of containment?
- What is the additional cost of PRVs?

With the last question posed, it may be the case that the additional cost of PRVs is not high such that the Design Engineers consider that it is reasonably practicable to include PRVs in the system. Certainly, it is considered necessary that the overall risk of a system without PRVs should be assessed and it should be determined whether this risk could be considered ALARP. The reliability of the EDVs would need to be sufficiently high for a demonstration of ALARP for a system that only includes PRVs.

A question that the Design Engineers are unlikely to pose would be regarding the strength of the maintenance system to ensure a high reliability of the EDVs (and PRVs) and whether there would be a good safety management system behind the planned maintenance activities. These are key questions that should be asked between Project and Operations and a bowtie assessment may provide a good platform. The overall reliability of the EDVs is dependent on the maintenance system, i.e. one can provide a system with a relatively high SIL level (e.g. SIL-3) during Project, but if the planned maintenance activities are not well managed, then the reliability will decrease.

It should also be recognised that the PRVs would be an independent system that provide a last level of defence for pressure relief. The EDV and PRV systems are completely independent and should be treated as such. Hence, if there is the design intent to reduce the risk by the inclusion of the two systems this must be highlighted. In this way, the planned maintenance system will ensure that both systems are well maintained and that there is not the tendency to 'downplay' the importance (reliability) of one system or the other, because an independent system is available.

Conclusion

This paper has asked more questions than provided answers, but this was the intention. It was certainly not the intention to provide an answer to a question that can't be answered simply. The paper's intention is to provide food for thought and to highlight that what may be in the designers' heads must be continued throughout of the operating life of a plant, and well maintained by good safety management systems.

The EDV system is expected to protect a system from overpressure to a high reliability. The EDV system can also reduce the consequences following a loss of containment, such that this provides a level of risk reduction of both sides of a bowtie diagram, threats and consequences. Both EDVs and PRVs would likely be considered SCEs (as may be a PCV for initial depressurisation), but the effectiveness and criticality of an EDV system may be considered higher than PRVs.

If the removal of PRVs was to be considered, this should be looked at from a risk perspective. The risk of the systems including the EDVs would be investigated as a base case and the further reduction in risk from the inclusion of PRVs would also be assessed. The SIL level of the EDV system would be taken into account. Certainly, if high hazards are included in the process, a high SIL level would be expected for the EDV system to ensure that the risk is reduced to a low level. The further reduction from the inclusion of PRVs (2 x 100%) would then be assessed to determine if the risk is ALARP or if PRVs should be included.

One may argue that the inherently safe solution is the inclusion of PRVs in the system anyway, i.e. on top of the PCV and EDV, to provide an independent and final level of protection. However, this can only be true if the overall system including all independent protection mechanisms is well maintained. The danger in operation is that the reason for having several independent levels of protection is lost over the years and the criticality of the EDV system is reduced. If this is the case, one can effectively ask the question would it be better to remove the PRVs? This would certainly be a radical step, but it could mean that the EDV system was always maintained at a very high level of reliability and the overall risk level could even be reduced. Food for thought!

References

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Figure 1 Simplified Separator P&ID

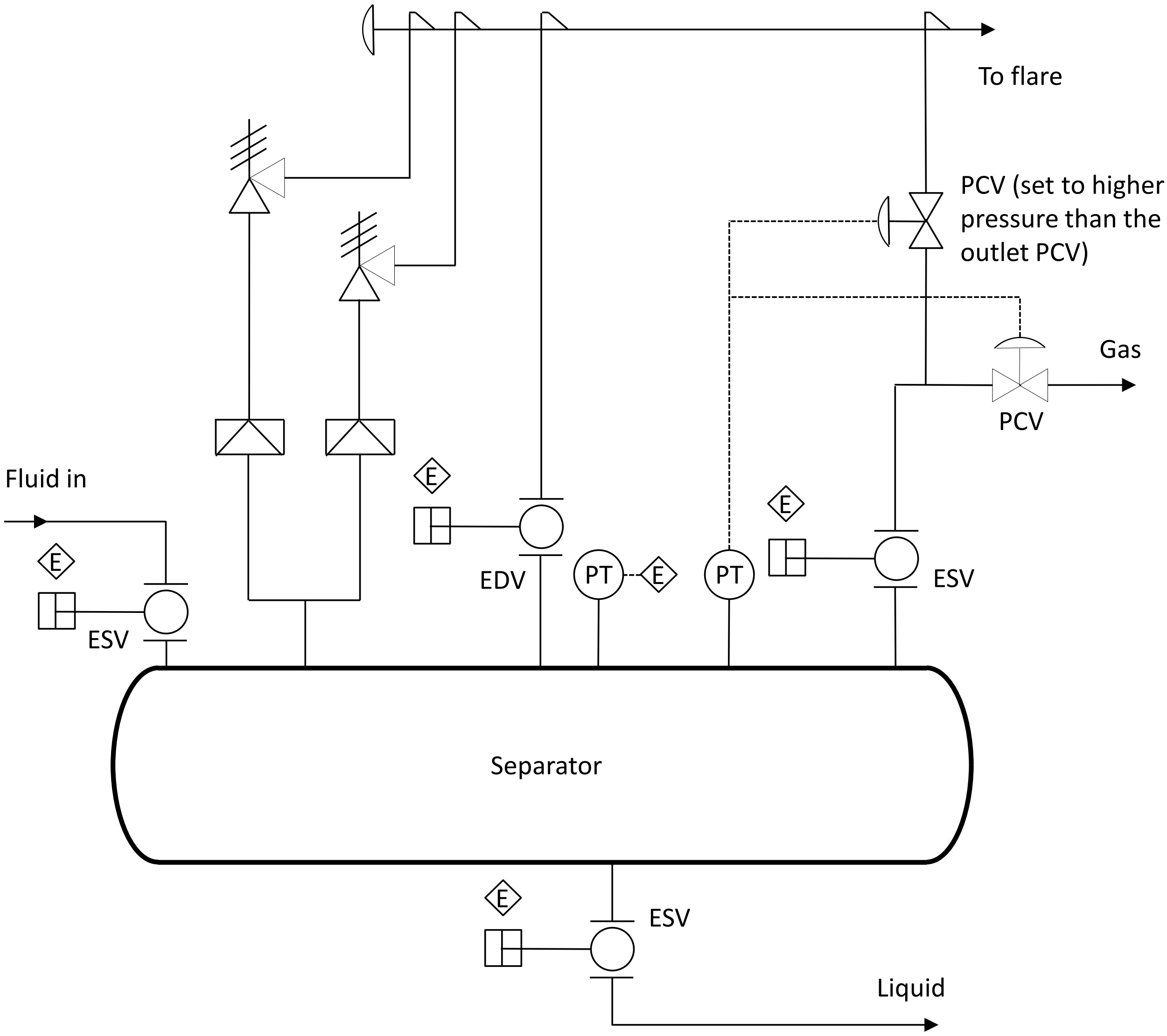

Figure 2 Example Bowtie