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Safe Design Consideration for Overpressure Protection via Depressuring Valves

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Abstract

Depressuring valves are used in the oil and gas industry to release fluid in a controlled manner in the event of an overpressure, upset, or shutdown of a plant. API 521 provides guidance on how and when to utilize depressuring valves but do not clearly indicate cases where a plant might prefer to configure multiple depressuring valves instead of a single depressuring valve. Refining and offshore oil explorations are two areas where knowing a reasonably optimum configuration of the number and set point of the valves could meet the constraints of operation while meeting the safety requirements and disposal system design limitations. This paper provides basic guidelines for consideration and highlights the theory behind depressuring through valves, so that practitioners can make preliminary safe design assessments. In addition, the impact of depressuring valves design on disposal system, such as flare header system, is presented.

Emergency Depressuring Applications

Pressure vessels and other equipment require relief devices to prevent loss of containment due to overpressure that may cause serious injuries to personnel, costly mechanical damages, loss of production, and environmental hazardous releases. The proper sizing, selection, and installation of pressure relief systems are necessary elements to ensure adequate protection and to reduce hazards in the event pressure system discharges.

Often, pressure relief valves and rupture desks are not suitable to provide protection from pressure system mechanical failure; rupture or leakage, resulted from overheating scenarios, such as exothermic runaway reaction or external fire. For such scenarios, when the temperature of a metal is increased, a stress rupture can develop. This can occur even though the system pressure has not necessarily exceeded the maximum allowable working pressure. As a result, system rapid emergency depressuring is required.

Emergency depressuring is an operation to reduce the internal pressure within a pressured system to a specified target pressure within a specified time interval. While the ultimate goal of depressuring is to prevent loss of containment due to overpressure, it is important to note that the primary concern is the reduction in vessel wall strength due to the increase in temperature within the system rather than the potential for the increase in internal pressure. In addition, depressuring will help prevent fire escalation, for cases where external fire is the depressuring trigger.

Emergency depressuring is typically identified for exothermic runaway reaction and external fire contingencies; however, it still can be utilized to mitigate overpressure concerns associated with other process upset scenarios.

Factors impacting the emergency depressuring design and operation

There are several factors to be considered when designing and operating emergency depressuring systems. Many of these factors are described in the American Petroleum Institute Pressure-relieving and Depressuring Systems Standard (API 521, sixth edition) [1].

The following describe the key factors that should be carefully evaluated.

1. Depressuring system need and initiation mechanism

   Although the general criteria to utilize a depressuring system has been driven by the need to de-inventory a pressure system impacted by high temperature contingencies to avoid vessel stress rupture; however, over the time, process operators have defined more specific requirements to define the need to install depressuring systems. Most of the times these requirements have been based on operators' own experience:

- Pressure system with large inventory of flammable or toxic material
- High-pressure and reaction sections of hydroprocessing units
- Compressor circuit that can be isolated by shutdown valves in case of fire, leakage, or seal failure

   API 521 provides key considerations to determine the initiation mechanism of depressuring system operation.

2. Process equipment mechanical and operation specifications:

Stress and brittle failure characteristics are among the key pressure system (vessels and piping) specifications that need to be assessed as part of designing and operating depressuring system, specifically to determine the depressuring rate and duration. In addition, mechanical and operating specifications, such as total depressured systems volume, inventory, composition, internal components (trays, packing, etc.), and associated control systems accessibility during fire contingency.

3. Depressuring pressure and temperature targets:

   API 521 specifies that equipment pressure shall be reduced from its initial conditions to a level equivalent to 50% of the vessel's design pressure within approximately 15 minutes so the stress rupture is not of an immediate concern based on the vessel-wall temperature versus the stress that is required to rupture.

   This depressuring operation pressure target is specific to carbon-steel vessels with a wall thickness of approximately 1 in. or more. Vessels with thinner walls generally require a somewhat faster depressurizing rate. API 521 provides additional guidance to determine criterion specific to pool and jet fire scenarios.

   Depressuring light hydrocarbon may result in dropping the fluid temperature to below vessel minimum design temperature. This may lead to permanent damage or brittle failure. To some extent, the fluid minimum temperature targets are determined based on controlling the depressuring rate. Generally, calculating the depressuring rate and the minimum discharged temperature is an iterative process, until an optimized depressuring orifice size is calculated. Multiple staggered depressuring valves may be an option to consider meeting both depressuring rate and minimum temperature requirements.

4. Depressuring rate determination:

   Upon defining the target pressure of the depressuring operation, as described in 3 above, the depressuring rate and minimum discharge temperature can be calculated. Depressured system typically includes each piece of equipment and pipe component that will be in open communication at the time depressuring is initiated. The system can typically be identified by the presence of emergency shutdown valves located on the inlet and outlet lines to and from the system and manual valves are generally considered to remain open.

   API 521 provides detailed approach to determine the vapor depressuring rate for vaporizing and flashing liquid in addition to expanding vapor. To improve the accuracy of the depressuring rates and minimum temperature, it is recommended that non-equilibrium modeling techniques are used, as the vapor and liquid phases in the depressured system shouldn't be assumed to be at thermodynamic equilibrium.

   The depressuring rates and temperatures from each vessel and piping component are best to be calculated separately and then mixed assuming adiabatically. This will result in more accurate depressuring rate compared to assume the entire depressured system to be at same composition, temperature, and pressure conditions.

The depressuring rate and the minimum relief temperature can be optimized through an iterative process by changing the size of the depressuring valve and the number of depressuring valves to reach the targeted depressuring time, pressure and minimum temperature.

5. Flare system adequacy:

   The flare system consists of piping component (laterals, sub-headers, headers,) knock-out drum, seal drum, and flare tip should be assessed for adequacy during emergency depressuring operation. Total loads from all simultaneously discharging depressuring valves to the flare system should be considered for this evaluation. In addition, load from other sources (such as relief valves, control valves, bleeder valves, Emergency Shutdown (ESD) systems, etc.) should also be considered, if discharging simultaneously with depressuring valves. The flare system adequacy evaluation should at minimum address the following:

a. Backpressure limits – To ensure that the relief capacities for individual sources will remain adequate despite the pressures built-up in the disposal system.

b. Header velocities – To ensure that there are no localized areas of high velocity in the flare network that could cause mechanical problems due to excessive momentum forces or acoustically induced vibrations.

c. Flare equipment sizing – To ensure satisfactory performance of all relevant flare equipment such as liquid knockout pots (for vapor-liquid separation), flare seals (including seal height evaluation), flare tip performance (in terms of flare radiation, noise, flame stability, etc.), vaporizers/heaters, etc.

d. Mechanical limits of the header – To ensure that the flare header itself can adequately handle the expected operating requirements. Special attention should be given to scenarios where the discharged stream temperature is below flare piping minimum allowable working temperature. Brittle fracture assessment of impacted flare piping segments should be conducted to assess piping segment fitness-for-service.

e. Liquid removal facilities – To ensure that the integrated flare loads will not result in excessive mechanical stress due to undesirable flow patterns (such as high-velocity liquid slugs).

Conclusions:

Depressuring valves are critical components to provide protection from pressure vessel and piping component stress failure when pressure relief valves and rupture desks are not suitable for this service. Several interrelated factors are considered when designing and operating depressuring valves. API 521 provides guidance on how and when to utilize depressuring valves but process operator needs to fully understand the significant of these factors to ensure safe operation. The accurate depressuring rate and minimum temperature calculation, an iterative exercise, to meet depressuring criterion is the most critical step.

Reference

[1] API 521, Pressure-relieving and Depressuring Systems, American Petroleum Institute, Sixth Edition, 2014.

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