SECTION 5

Relief Systems

This section is concerned with the design and operation of pressure relieving systems for gas processing plants. The principal elements of pressure relief systems are the individual pressure relief devices, the flare piping system, the flare separator drum, and the flare — including igniters, tips, sealing devices, purg,e and steam injection for smokeless burning. Application of relief devices must comply with appropriate ASME Vessel Codes. Design of relief systems must also comply with applicable state and federal codes and laws as well as the requirements of the insurance underwriter covering the plant or installation. State and federal regulations not only cover safety but also environmental considerations such as air and water pollution and noise abatement. This section presents a convenient summary of relief system information obtained from API and other sources, abridged and modified for this data book. Final design work should be consistent with the full scope of API, ASME, and other code and specification requirements.

FIG. 5-1

Nomenclature

a = sonic velocity, ft/sec
A = required discharge area of the valve, sq in. Use valve with the next larger standard orifice size/area
A_B = bellows area, sq in.
A' = discharge area of the valve, sq in., for valve with next standard size larger than required discharge area
A_D = disk area, sq in.
A_N = nozzle seat area, sq in.
A_P = piston area, sq in.
A_w = total wetted surface area of vessel, sq ft
A_3 = vessel area exposed to fire, sq ft
B = liquid expansion coefficient, 1/°F, at relieving temperature [or (Vol/Vol)/°F]
C = drag coefficient
C_p = specific heat at constant pressure, BTU/(lb · °F)
C_v = specific heat at constant volume, BTU/(lb · °F)
C_1 = coefficient determined by the ratio of specific heats of the gas or vapor at standard conditions
d = flare tip diameter, inches
D = particle diameter, ft
f = correction factor based on the ratio of specific heats
F = environment factor (see Fig. 5-16)
F' = relief valve factor, dimensionless
F^* = fraction of heat radiated
F_2 = coefficient for subcritical flow (Fig. 5-12)
F_S = spring force, pounds
gpm = flow rate, gallons per minute at flowing temperature and pressure
g = acceleration due to gravity, 32.2 ft/sec^2
g_c = gravitational constant, 32.2 (ft · lbm)/(lbf · sec^2)
G = specific gravity of gas referred to air = 1.00 at 60°F and 14.696 psia; or, if liquid, the specific gravity of liquid at flowing temperature referred to water = 1.00 at 60°F
h_{L1} = enthalpy of saturated liquid at upstream pressure, Btu/lb
h_{L2} = enthalpy of saturated liquid at downstream pressure, Btu/lb
h_{G2} = enthalpy of vapor at downstream pressure, Btu/lb
H = height of vapor space of vessel, ft
H_l = latent heat of the liquid exposed to fire, Btu/lb
H_S = flare stack height, ft
I = radiation intensity at point X, Btu/(hr · ft^2)
k = specific heat ratio, Cp/Cv (see Section 13)
K_b = capacity correction factor due to back pressure
K_c = combination correction for rupture disk = 0.9
= 1.0 no rupture disk installed
K_d = coefficient of discharge
K_n = correction factor for Napier steam equation
K_{sh} = correction factor due to the amount of superheat in the stream
K_v = capacity correction factor due to viscosity for liquid phase pressure relief
K_w = capacity correction factor due to back pressure for balanced bellows pressure relief valves in liquid service (Fig. 5-14)
L = drum length, ft
L/D = length to diameter ratio of pipe
L_f = length of flame, ft
M = Mach number at pipe outlet
MW = molecular weight of gas or vapor
MABP = maximum allowable back pressure, psig
NHV = net heating value of flare gas, Btu/lb
P = set pressure, psig
P_{CF} = critical-flow pressure, psia
P_n = normal operating gas pressure, psia
P_1 = upstream relieving pressure, psia. This is the set pressure plus the allowable overpressure plus the atmospheric pressure
P_{1g} = upstream relieving pressure, psig. This is the set pressure plus the allowable overpressure
P_2 = downstream pressure at the valve outlet, psia
P_b = back pressure, psig
ΔP = pressure drop, psi
ΔP_w = pressure drop, in. of water
Q = heat input, Btu/hr
Q_r = heat released, Btu/hr
Q_v = flow through valve, scfm

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

FIG. 5-1 (Cont'd)

Nomenclature

r = ratio of downstream pressure to upstream pressure, P_2 / P_1
R = distance from flame center to point X, ft
Re = Reynolds number (dimensionless)
R_o = universal gas constant (10.73) $\frac{\text{psia} \cdot \text{ft}^3}{\text{lb mole} \cdot °\text{R}}$
S = specific heat, Btu/(lb · °F)
t = temperature, °F
T = absolute temperature of the inlet vapor, °R
T_n = normal operating gas temperature, °R
T_1 = gas temperature, °R, at the upstream pressure
T_w = vessel wall temperature, °R
U_d = maximum allowable vapor velocity for vertical vessel, ft/sec
V = gas velocity, ft/sec
V_{ex} = exit velocity, ft/sec
V_w = wind velocity, ft/sec (= 1.47 V_w')
V_w' = wind velocity, mph
W = flow, lb/hr
W_{hc} = hydrocarbon flow, lb/hr
W_{stm} = steam flow, lb/hr
W_f = flare gas flow rate, lb/hr
W_r = vapor rate to be relieved by the relief valve, lb/hr
x_i = weight fraction of component i in total stream
X = distance from the base of the stack to another point at the same elevation, ft
X_c = dimensional reference for sizing a flare stack (Fig. 5-19)
Y_c = dimensional reference for sizing a flare stack (Fig. 5-19)
Z = compressibility factor at flowing conditions

Greek

Δ = prefix, indicates finite increment
ε = fraction of heat radiated
ρ_L = density of liquid, lb/cu ft
ρ_v = density of vapor, lb/cu ft
θ = angle of flare flame from vertical, degrees
μ = viscosity at flowing temperature (centipoise)
μ_S = viscosity at flowing temperature, Saybolt Universal Seconds (SSU)

DOCUMENTATION

A facility's documentation allows the user to determine that the facility was designed in accordance with relevant codes and standards. The relief system design documentation is one facet of the overall facility documentation, which helps demonstrate that the process can be operated in a safe manner. Any equipment modifications, or changes made to process parameters, or operating procedures, can have a direct impact on the relief system, and should therefore be documented as part of a facility management of change (MOC) process.

The relief system documentation should demonstrate that all pressure-containing equipment has been identified and that the overpressure protection has been analyzed. Documentation based on the individual protected systems can facilitate ensuring that all systems requiring pressure protection have been identified. The documentation should show that potential causes of overpressure have been identified, rationale has been provided as to whether a scenario is or is not credible, and credible causes of overpressure have been evaluated. The design basis of the disposal system, including all assumptions made in the determination of controlling load(s), and calculated back pressure at each relief device should be documented. A detailed list of documentation requirements is presented in ISO 23251 (API Std 521).

HAZARD REVIEWS

Appropriate hazard reviews, as a part of a Process Safety Management Program, are required by U.S. OSHA-29 CFR Part 1910 in the United States, and by similar regulations in most other localities in the world. These reviews are conducted during the design phase, prior to operation, and periodically during operation. The relief device sizing, and relief and disposal system design, are critical components of this review. Typical steps in this process are:

- Preliminary hazard review using process flow diagrams and a preliminary layout, to identify hazards in the process, with the proposed facility location, and layout, and with storage and handling of feed materials or intermediate and final products.
- Early engineering hazard review with more advanced work products.
- Detailed hazards review using one of several possible techniques sanctioned by local authorities (e.g., HAZOP, Hazard and Operability Analysis, What-if, Quantitative Risk Evaluation), utilizing process and instrumentation diagrams, plot plan, and other detailed design deliverables.
- Safety Integrity Level (SIL) Review.
- Engineering management of change (MOC) process.
- Facility management of change (MOC) process.
- Pre-start-up detailed hazard review.
- Periodic detailed hazard review.

CAUSES OF OVERPRESSURE

Pressure relief valves or other relieving devices are used to protect piping and equipment against excessive over-pressure. Proper selection, use, location, and maintenance of relief devices are essential to protect personnel and equipment as well as to comply with codes and laws.

Determination of the maximum relief requirements may be difficult. Loads for complex systems are determined by conservative assumptions and detailed analysis. By general assumption, two *unrelated* emergency conditions caused by unrelated equipment failures or operator error will not occur simulta-

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

neously (no double jeopardy). The relationship and sequence of events must be considered. ISO 23251 (API Std 521) provides further guidance on these issues.

The development of relief loads requires the engineer to be familiar with overall process design, including the type of pump drives used, cooling water source, spares provided, plant layout, instrumentation, and emergency shutdown philosophy. The design of the proper relieving device must take into consideration, as a minimum, all of the following upset conditions for the individual equipment item if such upset can occur. Each upset condition must be carefully evaluated to determine the "worst case" condition which will dictate the relieving device capacity.

The following provides guidance for some common overpressure scenarios. It must be recognized that it does not and cannot address all potential overpressure scenarios that may be relevant for a specific piece of process equipment. The designer should employ the Hazard Reviews discussed above to ensure that all credible overpressure scenarios have been incorporated into a facility's design.

SUMMARY OF COMMON RELIEF SCENARIOS

Blocked Discharge

The outlet of almost any vessel, pump, compressor, fired heater, or other equipment item can be blocked by mechanical failure or human error. The relief load for many cases is the maximum flow into the system, at relief conditions, but must be carefully analyzed for each contingency.

Fire Exposure

Fire is one of the least predictable events which may occur in a gas processing facility, but is a condition that may create the greatest relieving requirements. If fire can occur on a plant-wide basis, this condition may dictate the sizing of the entire relief system; however, since equipment may be dispersed geographically, the effect of fire exposure on the relief system may be limited to a specific plot area. Various empirical equations have been developed to determine relief loads from vessels exposed to fire. Formula selection varies with the system and fluid considered. Fire conditions may overpressure vapor-filled, liquid-filled, or mixed-phase systems. See the discussion on Sizing of Relief Devices, for details and relief load calculation methods.

Tube Rupture

The tubes of shell and tube heat exchangers are subject to failure from a number of causes; including corrosion, thermal shock, and vibration. In the event of such a failure, it is possibile that the high-pressure stream can overpressure the equipment and piping connected to the low pressure side of the exchanger. A tube rupture can also cause short duration hydraulic pressure shock, due to the rapid acceleration of the fluid on the low pressure side at the time of rupture.

An internal failure can vary from a leaking tube or tube sheet to a complete tube rupture where a sharp break occurs in one tube. The loss of containment of the low-pressure side to atmosphere is unlikely to result from a tube rupture, if the resulting pressure on the low-pressure side, including upstream and downstream systems, does not exceed the corrected hydrostatic test pressure.

Appropriate design options to be considered for protecting the low pressure side equipment and piping from potential tube rupture are: 1) Install a relief device (pressure relief valve or rupture disk) on, or close to, the low pressure side of the heat exchanger, 2) ensure there is an adequate open relief path, so that the low pressure side will not be over-pressured by a tube rupture, or 3) design the low pressure side of the heat exchanger, and the piping and equipment in the associated systems, such that the corrected hydro-static test pressure of the low pressure system exceeds the high pressure side design pressure (in some cases maximum upstream side operating pressure may be used instead of design pressure). The best option for each application is a function of the operating and design pressure for each side, fluid phase on each side, fluid type and service corrosion history, and the heat exchanger design. Systems with gas, two phases, or a liquid which will flash across the tube rupture, on the high pressure side, and a liquid on the low pressure side, should be thoroughly reviewed, since a relief valve may be less effective in preventing surges in these circumstances. See ISO 23251 (API Std 521) for the definition of corrected hydro-static test pressure and detailed guidance on this subject.

Relief protection for tube rupture is not required for double pipe heat exchangers, if the internal parts are constructed of schedule pipe.

Control Failure

The failure positions of instruments and control valves must be carefully evaluated. In practice, the control valve may not fail in the desired position. A valve may stick in the wrong position, or a control loop may fail. Relief protection for these factors must be provided. Relief valve sizing requirements for these conditions should be based on flow coefficients (manufacturer data) and pressure differentials for the specific control valves and the facility involved. Credit can be taken for some downstream flow paths, if ensured to be open throughout the relief event. No favorable control valve action may be assumed. In addition, the relief load determination should take into account that the liquid level in the upstream vessel may be lost, causing gas blow-by through the open control valve.

ISO 23251 (API Std 521) describes several relief scenarios that consider the position of a control valve and its bypass valve. If during operation, the bypass valve may be opened to provide additional flow, then the total maximum flow (control valve wide open, plus bypass valve at some position, depending on the service and facility practices, must be considered when determining the relief load. If the bypass is opened only during maintenance, when the control valve is blocked in after switchover, then a design based on the maximum flow through either the control valve, or the bypass valve, whichever is greater, may be considered. In this case the system must be evaluated during the facility hazard review to ensure that the proper administrative controls are in place to prevent a situation in which both the control valve and the bypass are open simultaneously.

Thermal Expansion

If isolation of a process line on the cold side of an exchanger can result in excess pressure due to heat input from the warm side, then the line or cold side of the exchanger should be protected by a relief valve. If any equipment item or line can be isolated while full of liquid, a relief valve should be provided for thermal expansion of the contained liquid. Low process temperatures, solar radiation, heat tracing, or changes in atmospheric temperature can necessitate thermal overpressure protection. Flashing across the relief valve needs to be consid-

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

ered. Administrative controls for block valves around heat exchanger are discussed in ASME Section VIII, Appendix M.

As a practical manner, thermal relief valves are not installed in all instances where piping systems may be blocked in by two valves. The decision to install a thermal relief valve for piping systems is typically based on the following factors: length and size of piping, vapor pressure of the fluid at the elevated temperature possible, volatility and/or toxicity of the fluid, potential for valve leakage (metal vs. soft seated valves), and the presence of automatic shut down valves in the system. It is common to provide thermal relief valves for cryogenic liquid applications. Guidance for when to specify thermal relief and for sizing of the valve are provided in ISO 23251 (API Std 521). A sizing equation for a simple thermal relief valve is given later in this chapter. A ¾ in × 1 in relief valve is commonly used for liquid filled, non-flashing piping systems containing non-cryogenic liquids.

Utility Failure

Loss of cooling water may occur on an area-wide or plant-wide basis. Commonly affected are fractionating columns and other equipment utilizing water cooling. Cooling water failure must be considered for individual relief devices. In addition it is often the governing case in sizing flare systems.

Electric power failure, similar to cooling water failure, may occur on an area-wide or plant-wide basis and may have a variety of effects. Since electric pump and air cooler fan drives are often employed in process units, a power failure may cause the immediate loss of reflux to fractionators. Motor driven compressors will also shut down. Power failures may result in major device and flare system relief loads.

Instrument air system failure, whether related to electric power failure or not, must be considered in sizing of the flare system since pneumatic control loops will be interrupted. Also control valves will assume the position as specified on "loss of air" and the resulting effect on the flare system must be considered.

Fans on air cooled heat exchangers or cooling towers occasionally become inoperative because of a loss of power or a mechanical breakdown. On cooling towers and on air cooled exchangers where independent operation of the louvers can be maintained, credit may be taken for the cooling effect obtained by convection and radiation in still air at ambient conditions.

Check Valve Failure

Failure of a check valve to close must be considered. A single check valve is not an effective means for preventing overpressure by reverse flow from a high-pressure source. In most cases, focus should be on prevention of reverse flow. It is important to note that, in addition to overpressure of the upstream system, reverse flow through machinery can destroy rotating equipment, causing loss of containment. If this hazard is of concern, additional means of backflow prevention should be provided (i.e. emergency shut down inter-lock and valve).

For relief purposes, a single check valve is treated as if it is not there, unless specific maintenance and inspection practices are adhered to. Two check valves in series reduce the likelihood, and potential magnitude of reverse flow, but over-pressuring of the low pressure side can still take place due to even small check valve leaks, assuming the pressure is high enough. ISO 23251 (API Std 521) provides specific guidance both on how to treat check valve failure as a relief scenario, maintenance/inspection practices for critical check valves, when relief protection is required, and recommended practices for determining the controlling relief rate.

Reflux Failure and/or Loss of Overhead Cooling For Fractionators

The failure of electrical or mechanical equipment that provides cooling or condensation in process streams can cause overpressure in fractionators and process vessels. The evaluation of relief scenarios for towers, in order to determine the appropriate load for the relief device, is complex. Various simplified approaches have been used in the past, however the most common method used today is a modified steady state material balance at relief conditions, as described by Nezami.[11] Dynamic simulation may also be applied to evaluate the tower relief load vs. time. Care should be exercised when using the dynamic approach since the results can be highly dependent on the specific assumptions used, and may not be conservative.

Abnormal Heat Input

Reboilers and other process heating equipment are designed with a specified heat input. When they are new or recently cleaned, and/or due to loss of control, additional heat input above the normal design can occur. In the event of a failure of temperature control, vapor generation can exceed the process system's ability to condense or otherwise absorb the build-up of pressure, which may include non-condensables generated by overheating. The system should be evaluated at the relief condition using a modified material balance approach.

Process Upset

The source of a process upset can vary depending of the application. Therefore this contingency must be analyzed individually based on the specific circumstances. For example, guidance for fractionation towers is included in reference 11.

Liquid Overfilling of a Vessel

Vessels are subject to overfilling and must be protected from overpressure from that source. The cause can be an loss of control on the inlet, or a failure of the controls or pump on the outlet.

Transients

Transient pressure surges can occur as a result of liquid hammer, steam hammer, or steam condensate induced hammer, A pressure relief valve is normally not effective as a protective device for these causes of overpressure, so the focus should be on avoiding transient pressure surges through design and operation, and/or the use of a surge suppressor device.

Vacuum Protection

Vessels may be subject to (partial) vacuum from liquid pump out, condensation of volatiles, or other causes. Typically, industry practices for vessels containing hydrocarbons is to design for the maximum possible vacuum. In some services (i.e., very large low design pressure vessels) alternate vacuum protection is generally necessary.

Relief Scenarios For Specific Equipment Types

The following equipment considerations should be followed for relief system design.

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

Centrifugal Compressors — Centrifugal compressor systems should be analyzed in order to properly understand the maximum pressure that can occur, and required relief protection (if any) for each part of the system, during operation (normal and upset), start-up, and at shutdown, based on the normal and maximum suction, and/or discharge conditions. The maximum settle out pressure for each portion of the system should be calculated based on the configuration of the recycle valves, check valve, seal balance line, and the volumes of the drums, piping and coolers. At compressor shutdown, the pressure in one portion of the system may temporarily rise to a higher pressure than the overall final settle out pressure.

Reciprocating Compressors — Each positive displacement compressor must have a relief valve on the discharge upstream of the block and check valves in order to protect the compressor and downstream equipment. Commonly, relief valves are also provided on each individual stage to protect the interstage equipment. Reciprocating compressor systems should be analyzed in order to properly understand the maximum pressure that can occur, and required relief protection for each part of the system, during operation (normal and upset), start-up, and at shutdown, based on the normal and maximum suction, and/or discharge conditions.

Fired Heaters — General best practice is to design fired heaters such that the process side cannot be blocked in. Typically, the heater control system will shut down the heater in case of loss of flow on the process side, but the safety integrity level (SIL) may be inadequate to avoid overpressure. If there is a possibility that the process side of a fired heater may be blocked in, then a relief valve should be provided to protect the heater. The relief valve should be installed on the downstream of the heater to help ensure flow through the heater upon blocked outlet.

Pumps — Relief valves are required on the discharge of each positive displacement pump. Normally, these relief valves are piped back to the source vessel. In some instances, the relief device discharge can be returned to the suction line, depending on the service and extent of heat up due to recycle. In either installation, the pressure present at the discharge of the pressure relief valve must be considered in determining the set pressure of a conventional pressure relief valve. Isolation valves around the pressure relief valves may not be required, if the recycle is to the suction line and the pump itself can be isolated for maintenance. Many small metering pumps will have built-in internal relief protection. As these internal reliefs are typically not identified in facility documentation (e.g., P&IDs, critical device lists, etc.), they are typically not tested or maintained. For this reason, they generally should not be relied upon as a means to prevent overpressure.

Atmospheric Storage Tanks, and Low Pressure Tanks — Atmospheric storage tanks are typically protected against overpressure and vacuum due to process conditions and atmospheric changes. In addition, relief protection for fire and other upset conditions is required. Tanks are commonly protected by weighted or spring loaded pallet operated relief devices (conservation vents). A pilot-operated pressure relief can also be utilized. Storage tanks with diameters of 50 ft or larger may be fitted with a frangible roof (weak roof to shell attachment which will fail upon overpressure); such a roof-to-shell joint serves as emergency pressure relief device in lieu of a separate fire relief valve (See API Std 650). All other tanks require fire overpressure protection by an emergency relief vent.

Pressure relief requirements and relief device sizing for atmospheric tanks and any tanks, vessels, or other equipment designed for less than 15 psig, are covered by ISO 28300 (API Std 2000), which sets thermal breathing rates, and fire relief rules for this equipment. Note that the fire sizing equations for low pressure equipment covered by ISO 28300 (API Std 2000) differ from those in ISO 23251 (API Std 521).

At a minimum, design of overpressure protection for tanks should consider: liquid movement into the tank, tank breathing due to weather changes that heat the tank, inert gas pad and/or purge regulator failure, internal and external heat transfer devices, failure of vent collection systems, utility failure, blowthrough of gas from a higher pressure source, composition changes, cooling failure upstream of the tank, fire, and overfilling.

At a minimum, design of vacuum protection for tanks should consider: liquid movement out of the tank due to pump transfer, liquid movement out of the tank due to opening of a drain valve, tank breathing due to weather changes that cool the tank, failure of inert pads, utility failures.

SPECIAL RELIEF SYSTEM CONSIDERATIONS

Administrative Controls

Administrative controls are procedures that, in combination with mechanical locking elements, are intended to ensure that personnel actions do not compromise the overpressure protection of the equipment. They include, as a minimum, documented operation and maintenance procedures, and training of operator and maintenance personnel in these procedures. [ASME Boiler & Pressure Vessel Code Section VIII, Appendix M]

Block Valves in the Relief Path

ASME Section VIII, Appendix M, provides requirements, including specific administrative controls, for block valves associated with the inlet and outlet of pressure relief devices, block valves around equipment, such as heat exchangers, which may be isolated and drained for maintenance, and block valves between two pieces of equipment protected by a single relief device.

High Integrity Protection Systems (HIPS)

A High Integrity Protection System (HIPS) is an instrumented system that has multiple redundancies to ensure the system is reliable and will react with desired effects as close to 100% of the time as possible. As part of this, the instruments and valves, and the safeguarding system, are rated and maintained to a stricter standard than most instruments. These systems are even on a different control system. The instruments have a Safety Instrument Level (SIL); the higher the level the more reliable the system. HIPS are typically used to mitigate flare loads that otherwise would become excessively large, or where a pressure relief valve would not adequately protect the system. See Section 4 of the Data Book for more information on High Integrity Protection Systems (HIPS).

In some very limited instances (i.e. loss of control for an inlet valve downstream of a large packed pipeline upstream of a treating facility, or protection against runaway reaction,) a High Integrity Protection System may be considered to replace the requirement for a pressure relief device. This is now recognized by ASME Section VIII, Division 1 (UG-140),[15] with a number of requirements including:

- The user shall ensure that the MAWP of the vessel is greater than the highest pressure that can reasonably be expected to be achieved by the system. The user shall conduct a detailed analysis of all credible overpressure scenarios.

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

- This analysis shall utilize an organized, systematic process safety analysis approach such as: a Hazards and Operability (HAZOP) review; a failure modes, effects and criticality analysis (FMECA); fault tree analysis; event tree analysis; what-if analysis, or other similar methodology.
- Instrumentation associated with a HIPS shall be tested at regular intervals to ensure it functions per design.
- Documentation of the HIPS system design and testing shall be developed and maintained.

The user shall consult ASME Section VIII, Division 1 (UG-140) for the complete set of requirements for the use of HIPS as a means of overpressure protection.

Emergency Depressuring

Emergency depressuring system are commonly used in natural gas facilities. The system can be automatically actuated or operator actuated, on emergency shutdown of a piece of equipment, a process unit, or an entire facility. The purpose of the depressurization system is one or more of the following: 1) minimize risk of loss of containment due to fire/runaway reaction for pressure vessels, 2) minimize risk of fire, explosion, or release of toxic gas due to partial loss of containment (e.g., piping or flange leak), or 3) minimize risk of fire, explosion, or release of toxic gas due to partial or total seal/packing failure of rotating equipment.

Depressurization systems are often used to prevent potential stress rupture of a vessel when the metal temperature is raised above the design temperature due to an abnormal heat source. This source is usually from a fire, but could also be from a runaway exothermic reaction or other source of heat. This type of rupture can occur before a vessel reaches the set pressure of relief devices on the vessel. A general guideline is that a depressurization system should be able to reduce the pressure in the vessel to 50% of the design pressure in 15 minutes in the event of a pool fire. However, the required depressurization time is dependent on the vessel material and wall thickness. A detailed discussion of emergency depressurization design basis is provided in ISO 23251 (API Std 521).

Another application for a depressurization system is to reduce the consequences of a leak by quickly reducing the pressure of the system/plant/compressor. By reducing the equipment pressure, both the leak rate and the total inventory of fluid leaked can be reduced. A general criterion for system depressurization is to reduce the pressure in the system to 100 psig in fifteen minutes or less.

For compressors, the depressurization time is partially a function of the location of the machine, and de-pressurization times of less than 15 minutes is often used. For compressors located in buildings, a depressurization time of 3–5 minutes to near atmospheric pressure are not uncommon.

For each application, the designer must verify that all components (especially vessel internals and machinery elastomer seals) can withstand the chosen de-pressurization rate. In addition, cold metal temperatures can be developed both in the source vessel and the flare system during de-pressuring. Both systems must be designed for these conditions.

Note that the ASME Pressure Vessel Section VIII code requires a pressure relief device or HIPS to be installed to protect the vessel even if a depressuring system is used.

Low Temperature Flaring

Natural gas plants frequently have more than one flare system. (i.e. high pressure flare, low pressure flare, cryogenic flare). The segregation of flare systems should be carefully evaluated, based on the fluid compositions, temperatures, and allowable back pressures in the relief header. Several incidents have raised industry awareness on the need to properly consider segregation of flare headers and systems.

When low temperature streams are relieved, the flare system piping and equipment exposed to cryogenic temperature may require stainless steel or other acceptable alloys. The system should be designed for the coldest process stream to be relieved including the cooling effect of the expanding fluid (Joule-Thomson effect). Materials selection should be made according to applicable code recommendations.

Industry experience has shown that formation of limited quantity of hydrates at a relief valve outlet can typically be handled safely. However, relieving large amounts of hydrates, or solid CO_2/ H_2S/ methane solids to a closed flare system should be avoided. Industry experience has shown that pure CO_2 can be safely vented to the atmosphere, utilizing proper design practices.

SET PRESSURE FOR PRESSURE RELIEF VALVES

Fig. 5-2, extracted from ISO 23251 (API Std 521), shows the characteristics of safety relief valves for vessel protection. It can be used as a general guide in determining the proper set pressure of a pressure relief valve, for a protected system. Refer to the Standard for further guidance on setting single or multiple pressure relief valves.

RELIEVING DEVICES

Several pressure relief devices are certified and approved under Section VIII of the ASME Boiler and Pressure Vessel Code covering unfired pressure vessels. They include spring loaded direct-acting pressure relief valves, pilot operated pressure relief valves, and rupture disks and shearing pin devices. When the governing code is ANSI B31.3 or ANSI B31.8, other types of pressure relieving devices such as monitoring regulators, series regulators, weight-loaded relief valves, liquid seals, etc. are permitted. The discussion below is limited to ASME, Section VIII, devices. The devices must be compatible with the service and the overall design of the system. See ASME, Section I, for fired boiler relieving criteria.

Conventional Pressure Relief Valves

In a conventional pressure relief valve, the inlet pressure to the valve is directly opposed by a spring. Tension on the spring is set to keep the valve shut at normal operating pressure but allow the valve to open when the pressure reaches relieving conditions. This is a differential pressure valve. Most conventional safety-relief valves available to the petroleum industry have disks which have a greater area, A_D, than the nozzle seat area, A_N. The effect of back pressure on such valves is illustrated in Fig. 5-3b. If the bonnet is vented to atmospheric pressure, the back pressure acts with the vessel pressure so as to overcome the spring force, F_S, thus making the relieving pressure less than when set with atmospheric pressure on the outlet. However, if the spring bonnet is vented to the valve discharge rather than to the atmosphere, the back pressure acts with the

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

spring pressure so as to increase the opening pressure. If the back pressure were constant, it could be taken into account in adjusting the set pressure. In operation the back pressure is not constant when a number of valves discharge into a manifold.

A cut-away of a conventional relief valve is shown in Fig. 5-3a. Materials of construction for relief valves vary by service.

Balanced Pressure Relief Valves

Balanced safety-relief valves incorporate means for minimizing the effect of back pressure on the performance characteristics — opening pressure, closing pressure, lift, and relieving capacity.

These valves are of two types, the piston type and the bellows type. A cross section drawing of a balanced (bellows) relief valve is shown in Fig. 5-4a. In the piston type, of which several variations are manufactured, the guide is vented so that the back pressure on opposing faces of the valve disk cancels itself; the top face of the piston, which has the same area, A_P, as the nozzle seat area, A_N, is subjected to atmospheric pressure by venting the bonnet. The bonnet-vented gases from balanced piston-type valves should be disposed of with a minimum restriction and in a safe manner.

In the bellows type of balanced valve, the effective bellows area, A_B, is the same as the nozzle seat area, A_N, and, by attachment to the valve body, excludes the back pressure from acting on the top side of that area of the disk. The disk area extending beyond the bellows and seat area cancel, so that there are no unbalanced forces under any downstream pressure. The bellows covers the disk guide so as to exclude the working fluid from the bonnet. To provide for a possible bellows failure or leak, the bonnet must be vented separately from the discharge. The balanced safety-relief valve makes higher pressures in the relief discharge manifolds possible. Balanced-type valves should have bonnet vents large enough to assure no appreciable back pressure during design flow conditions. If the valve is in a location in which atmospheric venting (usually not a large amount) presents a hazard, the vent should be piped to a safe location independent of the valve discharge system. The user should obtain performance data on the specific type of valve being considered. A diagram of the force balance for piston and bellows balanced pressure relief valves is shown in Fig. 5-4b.

Pilot Operated Pressure Relief Valves

A pilot operated pressure relief valve consists of two principal parts, a main valve and a pilot. The valve utilizes a piston instead of a shaft. Inlet pressure is directed to the top of the main valve piston. More area is exposed to pressure on the top of the piston than on the bottom so pressure, instead of a spring, holds the main valve closed. At the set pressure, the pilot opens, reducing the pressure on top of the piston thereby allowing the main valve to open fully. For some applications, pilot-operated relief valves are available in minimum friction, light-weight diaphragm construction (in place of heavy pistons).

Pilot operated valves can allow backflow if downstream pressure exceeds set points. Backflow prevention is required on valves, connected to common relief headers, where protected equipment can be depressured and isolated while connected to an active flare header, where a vacuum could occur at the inlet, or where the downstream is connected to a system or vessel where the pressure could exceed the inlet pressure.

A check valve, split piston type valve, or backflow preventer in the pilot line can be used.

A typical pilot operated relief valve is shown in Fig. 5-5. Pilot operated valves may be used in liquid or vapor services. These valves contain nonmetallic components (elastomers), therefore fluid pressure and temperature, fluid characteristics, polymerization, fouling, solids, and corrosion can limit their use.

Pilot operated valves are available with snap-action or modulating action. The modulating type relieves only the amount of fluid required to control the overpressure.

When specifying pilot operated pressure relief valves, the elastomers chosen for the o-rings, and seals should be carefully considered. Temperature (maximum and minimum), chemical compatibility (for the principle and trace components, and for potential liquid carryover), and resistance to explosive de-compression, are all factors in the choice of elastomers.

Seat Leakage, and Resilient Pressure Seat Relief Valves

Some leakage can be expected through the seats of with metal-to-metal seated, conventional or balanced type relief valves, when the operating pressure rises too close to the set pressure. Allowable seat leakage rates are specified in API Std 527.[16] Resilient seat pressure relief valves (see Fig. 5-6), with either an O-ring seat seal or a plastic seat, can provide seat integrities which are significantly higher than metal seated valves. API Std 527[16] specifies that, soft seated, pressure relief valves shall have zero bubbles/minute leakage at the same test pressures as metal seated valves. This can allow bubble tight operation to 90%, of the set pressure, or higher. Proper elastomer choice is critical for resilient seat pressure relief valves.

Vapor Trim vs. Liquid Trim For Pressure Relief Valves

Pressure relief valves handling gas or vapor are supplied with vapor trim. Valves which releive liquid, two-phase, or potentially two-phase fluids, require a liquid trim. It is important that the supplier is properly informed of the full range of expected operation when procuring pressure relief valves. In addition, liquid trim pressure relief valves have a significantly higher blowdown as compared to vapor trim. In these applications the designer must be prudent to allow sufficient pressure margin between the operating pressure and the relief valve set pressure to ensure reclosure of the valve following a relief event.

Rupture Disks

A rupture disk consists of a thin diaphragm held between flanges. The disk is designed to rupture and relieve pressure within tolerances established by ASME Code Section VIII. Rupture disks can be used in gas processing plants, upstream of relief valves, to reduce minor leakage and valve deterioration. In these installations, the pressure in the cavity between the rupture disk and the relief valve should be monitored to detect a ruptured or leaking disk. In some applications a rupture disk with a higher pressure rating is installed in parallel to a relief valve.

Rupture disks should be used as the primary relieving device only if using a pressure relief valve is not practical. Some examples of such situations are:

(a) Rapid rates of pressure rise. A pressure relief valve system does not react fast enough or cannot be made large enough to prevent overpressure (e.g., an exchanger ruptured tube case or a runaway reaction in a vessel).

Documents
Document Sharing Hub
Full document details: GPSA E05 2012

(b) Large relieving area required. Because of extremely high flow rates and/or low relieving pressure, providing the required relieving area with a pressure relief valve system is not practical.

(c) A pressure relief valve system is susceptible to being plugged, and thus inoperable, during service.

All rupture disks have a manufacturing design range (MDR), which essentially specifies the user's tolerancefor variations in the burst pressure. Furthermore, disk temperature can have a significant affect on the pressure at which the disk will open. Therefore, it is essential that the designer communicate the desired MDR and the full range of expected operating and relief temperatures when specifying requirements for a rupture disk. This will help ensure that the disk ruptures and provides relief flow at the desired pressure rather than at a pressure higher or lower than the stamped pressure.

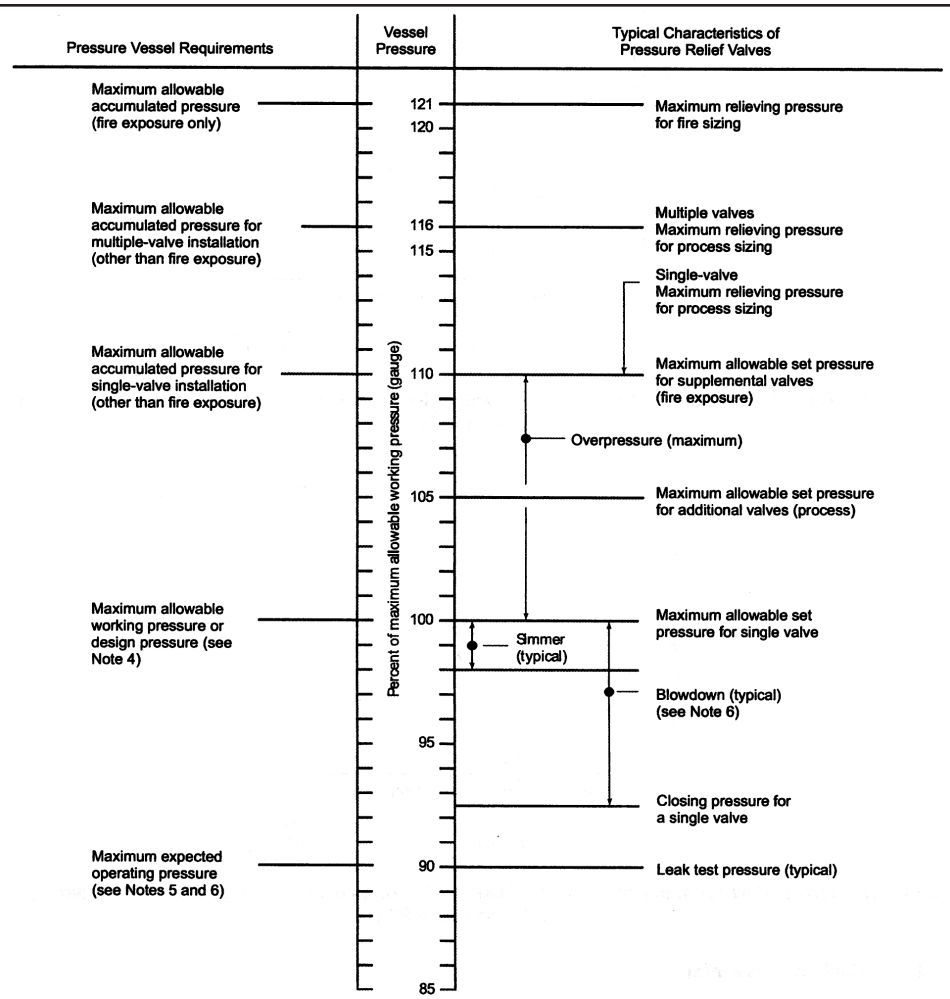
A rupture disk is subject to fatigue failure due to operating pressure cycles. To establish recommended replacement intervals, consult rupture disk suppliers.

Shearing Pin Device (Rupture Pin)

A shearing pin device is a non-closing pressure relief-device actuated by differential pressure, or static inlet pressure, designed to function by the shearing of a load-carrying member that supports a pressure-containing member. The devices are sanctioned by ASME Section VIII, and may be used for circumstances where rupture disks may also be appropriate. They have the advantage that the pin can be replaced without removing a piping flange.

FIG. 5-2

Pressure Level Relationships for Pressure Relief Valves[14]



NOTES
1. This figure conforms with the requirements of Section VIII of the ASME *Boiler and Pressure Vessel Code* for MAWPs greater than 30 psig.
2. The pressure conditions shown are for pressure relief valves installed on a pressure vessel.
3. Allowable set-pressure tolerances will be in accordance with the applicable codes.
4. The maximum allowable working pressure is equal to or greater than the design pressure for a coincident design temperature.
5. The operating pressure may be higher or lower than 90 %.
6. Section VIII, Division 1, Appendix M of the ASME Code should be referred to for guidance on blowdown and pressure differentials.

Courtesy American Petroleum Institute

Documents
Document Sharing Hub
Full document details: GPSA E05 2012