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PRESSURE / SAFETY RELIEF VALVE SELECTION, SIZING AND TROUBLESHOOTING

(ENGINEERING DESIGN GUIDELINES)</td>
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INTRODUCTION

Scope

Safety is the most important factor in designing a process system. Some undesired conditions might happen leading to damage in a system. Control systems might be installed to prevent such conditions, but a second safety device is also needed. One kind of safety device which is commonly used in the processing industry is the relief valve. A relief valve is a type of valve to control or limit the pressure in a system by allowing the pressurised fluid to flow out from the system.

The pressure in a system can build up by a process upset, instrument or equipment failure, or fire. When considering safety factors to minimizing the damage in industrial plant, it is important to properly select the pressure relief valve to be utilized. This design guideline covers the sizing and selection methods of pressure relief valves used in the typical process industries. It assist engineers and operations personnel to understand the basic design of the different types of pressure relief valves and rupture disks, and increase their knowledge in selection and sizing.

Pressure relief valves controls the pressurised fluid by direct contact; hence it should be designed with materials compatible with the process fluids. There are some codes and standards to govern the design and use of pressure relief valves, but there are also some additional parameters used to select the design in a typical process.

In material selection, some important parameters are based on fluid properties and process requirements; such as temperature, pressure, chemical attack by process fluid, or corrosiveness.

There are many available guidelines developed to aid engineers in selecting and sizing the relief valves, but mostly these guidelines are developed by certain companies and might only be suitable for the application of the valves provided by their own companies. Hence, it is important to obtain a general understanding of pressure relief valve sizing and selection first. Later, whenever changes are needed in a process system, this basic knowledge is still applicable. This guideline is made to provide that fundamental knowledge and a step by step guideline; which is applicable to properly select and size pressure relief valves in a correct manner.

INTRODUCTION

General Consideration

Important of Pressure Relief System

In the daily operation of chemical processing plant, overpressure may happen due to incidents like inadvertent blocked discharge, fire exposure, tube rupture, check valve failure, thermal expansion at a heat exchanger, and utility failures. This may lead to major incident in a plant if the pressure relief system is not in place or not functional.

Is very important to properly select the size and the location and to maintain the pressure relief system to prevent or minimize the losses from major incident like a fire. The pressure relief system is used to protect piping and equipment against excessive over-pressure and insure personnel safety. Pressure relief systems consist of the pressure relief device, the flare piping system, flare separation drum and flare system. A pressure relief device is designed to open and relieve the excess pressure and then it recloses after normal conditions have been restored to prevent the further flow of fluid.

Pressure Relief Devices Design Consideration

Several things have to be considered to design a pressure relief valve such as cause of overpressure (to determine the maximum or minimum required valve in such conditions), valid codes and standards, and general cases of individual relieving rates.

(A) Cause of overpressure

Overpressure incidents in chemical plants and refinery plants have to be reviewed and studied. This is important in preliminary step of pressure relief system design. It helps the designer to understand the causes of overpressure and to minimize the effect. Overpressure is the result of an unbalance or disruption of the normal flows of material and energy that causes the material or energy, or both, to build up in some part of the system. (1)

(I) Blocked Discharge

Blocked discharge can be defined as any vessel, pump, compressor, fired heater, or other equipment item in which the closure of block valve at outlet either by mechanical failure or human error. This will expose the vessel to a pressure that may exceed the maximum allowable working pressure (MAWP), and a pressure relief device is required unless administrative procedures to control valve closure such as car seals or locks are in place.

(II) Fire Exposure

Fire may occur in an oil and gas processing facility, and create relieving requirements. All vessels must be protected from overpressure with protected by pressure relief valves, except as bellow

(i) A vessel which normally contains no liquid, since failure of the shell from overheating would probably occur even if a pressure relief valve were provided.

(ii) Vessel (drums or towers) with 2 ft or less in diameter, constructed of pipe, pipe fittings or equivalent, may not require pressure relief valves for protection against fire, unless these are stamped as coded vessels.

(iii) Heat exchangers may not need a separate pressure relief valve for protection against fire exposure since they are usually protected by pressure relief valves in interconnected equipment or have an open escape path to atmosphere via a cooling tower or tank.

(iv) Vessels filled with both a liquid and a solid (such as molecular sieves or catalysts) may not require pressure relief valve for protection against fire exposure. In this case, the behavior of the vessel contents normally precludes the cooling effect of liquid boiling. Hence rupture discs, fireproofing and de-pressuring should be considered as alternatives to protection by pressure relief valves.

(III) Check Valve Failure

Check valve is normally located at a pump outlet. Malfunction of the check valve can lead to overpressure in vessel. When a fluid is pumped into a process system that contains gas or vapor at significantly higher pressures than the design rating of equipment upstream of the pump, failure of the check valve from this system will cause reversal of the liquid flow back to pump. When the liquid has been displaced into a suction system and high-pressure fluid enters, serious overpressure may result.

(IV)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, or changes in atmospheric temperature can necessitate thermal protection. Flashing across the relief valve needs to be considered.

(V)Utility Failure

Failure of the utility supplies to processing plant will result in emergency conditions with potential for overpressure the process equipments. Utilities failure event are included, electric power failure, cooling water failure, steam supplier failure, instrument air or instrument power system failure.

Electric power failure normally causes failure of operation of the electrical drive equipment. The failure of electrical drive equipment like electric pump, air cooler fan drive will cause the reflux to fractionator immediate loss and lead to the overpressure at the overhead drum.

Cooling Water failure may occur when there is no cool water supply to cooler or condenser. Same as electric power failure it will cause immediate loss of the reflux to fractionator and vapor vaporized from the bottom fractionator accumulated at overhead drum will lead to overpressure.

Loss of supply of instrument air to control valve will cause control loop interruptions and may lead to overpressure in process vessel. To prevent instrument air supply failure multiple air compressors with different drivers and automatic cut-in of the spare machine is require and consideration of the instrument air the pressure relief valve should be proper located.

(B) Application of Codes, Standard, and Guidelines

Designed pressure relieving devices should be certified and approved under Code,

1. ASME- Boiler and Pressure Vessel Code Section I, Power Boilers, and Section VIII, Pressure Vessels.

2. ASME- Performance Test Code PTC-25, Safety and Relief Valves.

3. ANSI B31.3, Code for Petroleum Refinery Piping.

API are recommended practices for the use of Safety Relief Valves in the petroleum and chemical industries are:

1. API Recommended Practice 520 Part I - Sizing and selection of components for pressure relief systems in Refineries.

2. API Recommended Practice 520 Part II – Installation of pressure relief systems in Refineries.

3. API Recommended Practice 521 – Guide for Pressure-Relieving and Depressuring Systems.

4. API Standard 526 - Flanged Steel Pressure Relief Valves

5. API Recommended Practice 527 - Seat Tightness of Pressure Relief Valves

6. API Standard 2000 - Venting Atmospheric and Low-Pressure Storage Tanks: Nonrefrigerated and Refrigerated

7. API Standard 2001- Fire Protection in Refineries.

(C) Determination of individual relieving rates [1]

Table 1: Determination of individual relieving rates

Item	Condition	Pressure Relief Device (Liquid Relief)	Pressure Relief Device (Vapor Relief)
1	Closed outlet on vessels	Maximum liquid pump-in rate	Total incoming steam and vapor plus that generated therein at relieving conditions
2	Cooling water failure to condenser	-	Total vapor to condenser at relieving condition
3	Top-tower reflux failure	-	Total incoming steam and vapor plus that generated therein at relieving condition less vapor condensed by sidestream reflux
4	Sidestream reflux failure	-	Difference between vapor entering and leaving section at relieving conditions
5	Lean oil failure to absorber	-	None, normally
6	Accumulation of non-condensable	-	Same effect in towers as found for Item 2; in other vessels, same effect as found for Item 1
7	Entrance of highly volatile material Water into hot oil Light hydrocarbons into hot oil	 - -	 For towers usually not predictable For heat exchangers, assume an area twice the internal cross-sectional area of one tube to provide fro the vapor generated by the entrance of the volatile fluid due to tube rupture
8	Overfilling storage or surge vessel	Maximum liquid pump-in rate	-
9	Failure of automatic control	-	Must be analyzed on a case-by case basis
10	Abnormal heat or vapor input	-	Estimated maximum vapor generation including non-condensable from overheating
11	Split exchanger tube	-	Steam or vapor entering from twice the cross-sectional area of one tube; also same effects found in Item 7 for exchangers
12	Internal explosions	-	Not controlled by conventional relief devices but by avoidance of circumstance
13	Chemical reaction	-	Estimated vapor generation from both normal and uncontrolled conditions
14	Power failure (steam, electric, or other)	-	Study the installation to determine the effect of power failure; size the relief valve for the worst condition that can occur
15	Fractionators	-	All pumps could be down, with the result that reflux and cooling water would fail

16	Reactors	-	Consider failure of agitation or stirring, quench or retarding steam; size the valves for vapor generation from a run-away reaction
17	Air-cooled exchangers	-	Fans would fail; size valves for the difference between normal and emergency duty
18	Surge vessels	Maximum liquid inlet rate	-

Design Procedure

General procedure in the design of protection against overpressure as below,

(i) Consideration of contingencies: all conditions which will result in process equipment overpressure is considered; the resulting overpressure is evaluated and the appropriately increased design pressure; and each possibility should be analyzed and the relief flow determined for the worse case.

(ii) Selection of pressure relief device: the appropriate type for pressure relief device for each item of equipment should be proper selection based on the service require.

(iii) Pressure relief device specification: standard calculation procedures for each type of pressure relief device should be applied to determine the size of the specific pressure relief device.

(iv) Pressure relief device installation: installation of the pressure relief valve should be at the correct location, used the correct size of inlet and outlet piping, and with valves and drainage.

DEFINITION

Accumulation- A pressure increase over the set pressure of a pressure relief valve, expressed as a percentage of the set pressure.

Back Pressure - Is the pressure on the discharge side of a pressure relief valve. Total back pressure is the sum of superimposed and built-up back pressures.

Balanced Pressure Relief Valve- Is a spring loaded pressure relief valve that incorporates a bellows or other means for minimizing the effect of back pressure on the operational characteristics of the valve.

Built-Up Back Pressure- Is the increase pressure at the outlet of a pressure relief device that develops as a result of flow after the pressure relief device opens.

Burst Pressure – Inlet static pressure at which a rupture disc device functions.

Chatter, simmer or flutter - Abnormal, rapid reciprocating motion of the movable parts of a pressure relief valve in which the disc makes rapid contacts with the seat. This results in audible and/or visible escape of compressible fluid between the seat and the disc at an inlet static pressure around the set pressure and at no measurable capacity, damaging the valve rapidly.

Conventional Pressure Relief Valve- Is a spring loaded pressure relief valve which directly affected by changes in back pressure.

Maximum Allowable Working Pressure (MAWP) - Is the maximum (gauge) pressure permissible at the top of a vessel in its normal operating position at the designated coincident temperature and liquid level specified for that pressure.

Disc – Movable element in the pressure relief valve which effects closure.

Effective Discharge Area – A nominal area or computed area of flow through a pressure relief valve, differing from the actual discharge area, for use in recognized flow formulas with coefficient factors to determine the capacity of a pressure relief valve.

Nozzle – A pressure containing element which constitutes the inlet flow passage and includes the fixed portion of the seat closure.

Operating Pressure- The operating pressure is the gauge pressure to which the equipment is normally subjected in service.

Overpressure- Overpressure is the pressure increase over the set pressure of the relieving device during discharge, expressed as a percentage of set pressure.

Pilot Operated Pressure Relief Valve- Is a pressure relief valve in which the major relieving device or main valve is combined with and controlled b a self actuated auxiliary pressure relief valve (called pilot). This type of valve does not utilize an external source of energy and is balanced if the auxiliary pressure relief valve is vented to the atmosphere.

Pop action - An opening and closing characteristic of an safety relief valve in which the valve immediately snaps open into high lift and closes with equal abruptness.

Pressure Relief Valve – This is a generic term applying to relief valves, safety valves or safety relief valves. Is designed to relief the excess pressure and to recluse and prevent the further flow of fluid after normal conditions have been restored.

Relief Valve - Is a spring loaded pressure relief valve actuated by the static pressure upstream of the valve. Opening of the valve is proportion to the pressure increase over the opening pressure. Relief valve is used for incompressible fluids / liquid services.

Rupture Disk Device – Is a non-reclosing pressure relief device actuated by static differential pressure between the inlet and outlet of the device and designed to function by the bursting of a rupture disk.

Rupture Disk Holder- The structure used to enclose and clamps the rupture disc in position.

Relieving Pressure- The pressure obtains by adding the set pressure plus overpressure/accumulation.

Safety Valve- Pressure relief valve with spring loaded and actuated by the static pressure upstream of the valve and characterized by rapid opening or pop action. A safety valve is normally used for compressible fluids /gas services.

Safety Relief Valve- Is a spring loaded pressure relief valve. Can be used either as a safety or relief valve depending of application.

Set Pressure- Is the inlet pressure at which the pressure relief valve is adjusted to open under service conditions.

Superimposed Back Pressure- The static pressure from discharge system of other sources which exist at the outlet of a pressure relief device at the time the device is required to operate.

Variable Back Pressure – A superimposed back pressure which vary with time.

NOMENCLATURE

A	Effective discharge area relief valve, in^2
A_D	Disk area
A_N	Nozzle seat area
A_{wet}	Total wetted surface of the equipment, ft^2
B	Effective liquid level angle, degrees
c	Specific heat, kJ/kg·K
C_1	Critical flow coefficient, dimensionless
E	Effective liquid level, ft
F	Environmental factor
F_2	Coefficient of subcritical flow, dimensionless
Fs	Spring force
G	Specific gravity of the liquid at the flowing temperature referred to water at standard conditions, dimensionless
k	Ratio of the specific heats
K	Effective height liquid level
K_b	Capacity correction factor due to back pressure, dimensionless
Kc	Combination correction factor for installations with a rupture disk upstream of the pressure relief valve, dimensionless
K_d	Effective coefficient of discharge, dimensionless
K_N	Correction factor for Napier equation, dimensionless
K_p	Correction factor due to overpressure, dimensionless
K_{SH}	Superheat steam correction factor, dimensionless
K_w	Correction factor due to back pressure, dimensionless
K_v	Correction factor due to viscosity, dimensionless
M_W	Molecular weight for gas or vapor at inlet relieving conditions.
Q	Flow rate, US.gpm
q	Heat input to vessel due to external fire, BTU/hr
P	Set pressure, psig
P_1	Upstream relieving pressure, psia
P_2	Total back pressure, psia
P_b	Total back pressure, psig
P_{cf}	Critical flow Pressure, psia
P_V	Vessel gauge pressure, psig

r	Ratio of back pressure to upstream relieving pressure, P_2/P_1
R	Reynold's number, dimensionless
T_1	Relieving temperature of the inlet gas or vapor, R (°F+460)
V_o	Specific volume of the two-phase system inlet (ft^3/lb)
W	Flow through the device, lb/hr
x_o	Vapor mass fraction (quality) inlet.
Z	Compressibility factor for gas, dimensionless

Greek letters

μ	Absolute viscosity at the flowing temperature, centipoise
λ	Heat absorbed per unit mass of vapor generated at relieving conditions, BTU/lb (as latent heat)
ρ_L	Liquid density at relief conditions, lb/ft^3
ρ_V	Vapor density at relief conditions, lb/ft^3
ϕ	Total heat input to system, Btu/h
α_V	Cubic expansion coefficient of liquid, dimensionless
χ	Isothermal compressibility coefficient of liquid, dimensionless
η_c	Critical flow ratio