8-0 PRESSURE RELIEF AND VENTING

8.1 AN INTRODUCTION TO RELIEFS

Equipment failures or operator errors may cause increases in process pressures beyond safe levels - they may exceed the maximum strength of pipelines and vessels thus rupturing process equipment causing major releases of toxic or flammable chemicals.

The first line of defence - better process control
The second line of defence - install relief system

The relief system comprises the relief device and the associated downstream process equipment to safely handle the material ejected. The methodology adopted for the safe installation of pressure relief devices is shown in Figure 8.1.

- Specify where relief devices must be installed.
- Selection of the appropriate relief device type.
- Scenarios are developed for describing the ways in which a relief can occur
  - determine mass flow and flow quality (liquid, gas, two-phase).
- Size reliefs for various flow types (gas, liquid, two phase).
- Choose worst case scenario and the final relief design is sized.
**FIGURE 8.1**

A METHODOLOGY FOR RELIEFS

---

**Diagram Description:**

1. **Locate Reliefs**
2. **Choose Relief Types**
3. **Develop Relief Scenarios**
4. **Acquire Data**
   - Size Reliefs for Single Phase
   - Size Reliefs for Two Phases
5. **Choose Worst Case Scenarios**
6. **Design Relief System**

---

*"Data may be simple physical properties or sophisticated calorimeter data to characterize two phase flow (including gassy systems and/or high viscosity laminar flow systems)."*
Relief System Philosophy

This section contains a brief summary of the relief systems design method, starting with a list of the contingencies that can cause overpressure and a reference to the methods that can be used to calculate the required relief rate for each contingency. The ruling contingency or contingencies can then be identified, followed by the selection and specification of the relief device and containment system.

Causes of Relief Situations

The causes of overpressure may be classified as follows:
- External fire
- Ambient heat
- Operator errors
- Instrument failures
- Valve failures
- Equipment failures
- Utility failures
- Blocked vent
- Thermal expansion
- Uncontrolled heats
- Uncontrolled reaction
- Other effects
- Double jeopardy

The causes of overpressure are discussed in more details.
CAUSES OF RELIEF

EXTERNAL FIRE
External fire is frequently the ruling contingency for the maximum relief rate of a vessel owing to the unlimited energy that is available for heat transfer. The limiting factor is the heat transfer surface area and any fireproof insulation that has been applied.

AMBIENT EFFECTS
Generally low in intensity, although solar radiation and changes in atmospheric temperature and pressure can produce overpressure and hence relief devices are required. The rate of vapour venting in low pressure storage tanks is particularly applicable.

OPERATOR ERRORS
In this context operator errors are confined to valve operation. Inadvertent valve opening or closure could lead to:
- an overpressure or a vacuum creation e.g. blocked vent
- the addition of wrong material to a reactor
- the setting of an incorrect opening/closing rate
- the mistiming of an intermittent operation such as blowdown or regeneration

INSTRUMENT FAILURES AND VALVE FAILURES
Examples include:
- failure of an automatic control loop e.g. pressure, temperature
- loss of level control in a vessel

Control valves should fail safe by design but the fail safe mechanism cannot always be guaranteed.

The failure of a non-return valve can permit flow in the reverse direction and create overpressure upstream of the valve.

EQUIPMENT FAILURES
Failures can be classified as failures of rotating equipment or of heat exchangers and fired heaters. Such failures can create overpressure either directly or by uncontrolled temperature excursion.
UTILITY FAILURE
Utility failures include electric power, cooling water, instrument air, computer, steam, fuel supply and inert gas.

OTHER EFFECTS
- Uncontrolled chemical reaction or internal explosion
- Hydraulic pressure surge
- Contamination of a heavy material with a lower boiling component
- Rollover in refrigerated storage tanks caused by temperature stratification followed by rapid convection movement and vapourisation.

DOUBLE JEROPARDY
An important aspect in determining relief rates is the consideration of two or more coincident events causing overpressure. If the events are entirely unrelated it is considered unlikely that two or more events will coincide, e.g. the failure of a heat exchanger tube and the inadvertent closure of an outlet valve. However, if two or more events can be related to a common cause, the combined effect must be considered e.g.

- Power failure causing loss of cooling water and loss of pumparound
- Instrument air failure causing two or more control valves to move simultaneously

Identification of cases of double jeopardy are best identified using hazop and hazan techniques.

8.2 SCOPE AND DEFINITIONS
Scope
Pressure relief systems are needed for the following reasons:
- Protect personnel from the dangers of overpressurizing equipment.
- Prevent damage to equipment.
- Prevent damage to adjoining property.
- Minimise chemical losses during pressure upsets.
- Reduce insurance premiums.

Figure 8.2 shows typical pressure versus time curves for runaway reactions.
Assuming an exothermic reaction is occurring within a reaction, if cooling is lost:
- loss of cooling water supply
- failure of a valve
If there is no relief system the pressure and temperature rise until the reactants are completely consumed, C. After this the reactor .cools. Curve C assumes the reactor can withstand the full pressure.

If the reactor has a relief device, the pressure response depends on the relief device and fluid properties at the relief discharge. Curve A shows vapour relief and curve B two phase flow relief. When a froth is discharged as in B the pressure continues to rise as the relief valve opens. For vapour relief, as in curve A, the pressure drops at once until the relief valve closes. Because of these different characteristics, it is important to know the nature of the relieved material to design a proper relief.
Pressure versus time for runaway reaction: (A) relieving vapor, (B) relieving froth, (C) closed reaction vessel. (Adapted from Dieter Gartner, Hartmut Giesbrecht, and Wolfgang Leuckel, "Thermodynamics and Fluid-dynamic Effects in Emergency Blow-Downs of Chemical Reactors,"

**Definitions**

It is necessary to define the pressure terms and pressure limits for the relief system. The relationships are shown in Figure 8.3.

**SET PRESSURE (Ps)**

The pressure at which the relief device begins to operate.

**MAXIMUM ALLOWABLE WORKING PRESSURE (MAWP)**

The maximum gauge pressure permissible at the top of a vessel for a designated temperature. This is sometimes called the DESIGN PRESSURE.

**OPERATING PRESSURE**

The pressure during normal service, usually 10% below MAWP.

**ACCUMULATION**
The pressure increase over the maximum allowable working pressure of a vessel during the relief process. It is expressed as a percentage of the MAWP.

OVERPRESSURE
The pressure increase in the vessel over the set pressure during the relieving process. Overpressure is equivalent to the accumulation when the set pressure is at the MAWP. It is expressed as a percentage of set pressure.

BACK PRESSURE
The pressure at the outlet of the relief device during the relief process due to pressure in the discharge system.

BLOW DOWN
The pressure difference between the relief set pressure and the relief reseating pressure. It is expressed as a percentage of the set pressure.

MAXIMUM ALLOWABLE ACCUMULATED PRESSURE
The sum of the MAWP plus the allowable accumulation.
**FIGURE 8.3**

GUIDELINES FOR PRESSURE RELIEF VALVES

<table>
<thead>
<tr>
<th>Pressure Vessel Requirements</th>
<th>Vessel Pressure</th>
<th>Typical Characteristics of Pressure Relief Valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum allowable pressure (fire exposure only)</td>
<td>121 130</td>
<td>Maximum relieving pressure for fire sizing</td>
</tr>
<tr>
<td>Maximum allowable accumulated pressure for multiple-ware installation (other than fire exposure)</td>
<td>116 115</td>
<td>Multiple valves maximum relieving pressure for process sizing</td>
</tr>
<tr>
<td>Maximum allowable accumulated pressure for single-ware installation (other than fire exposure)</td>
<td>110</td>
<td>Single valve maximum relieving pressure for process sizing</td>
</tr>
<tr>
<td>Maximum allowable set pressure for supplemental valves (fire exposure)</td>
<td>Overpressure (maximum)</td>
<td>Maximum allowable set pressure for additional valves (process)</td>
</tr>
<tr>
<td>Maximum allowable working pressure or design pressure</td>
<td>100</td>
<td>Simmer (typical) maximum allowable set pressure for single valve</td>
</tr>
<tr>
<td>Maximum expected operating pressure (see Notes 3 and 6)</td>
<td>90</td>
<td>Start to open blowdown (typical) (see Note 8)</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>Closing pressure for a single valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leak test pressure (typical)</td>
</tr>
</tbody>
</table>

Notes:
1. This figure conforms with the requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.
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 given 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.
8.3 LOCATION OF RELIEFS

To specify the location of reliefs requires a review of every unit operation in:
- the process and
- every process operating step

It is necessary to anticipate the potential problems which may result in increased pressures. Pressure relief devices are installed at every point identified as potentially hazardous, that is, at points where upset conditions create pressures that may exceed the maximum allowable working pressure.

Typical review questions include:
- What happens with loss of cooling, heating or agitation?
- What happens if the process is contaminated or has a mischarge of a catalyst or monomer?
- What happens if the operator makes an error?
- What is the consequence of closing valves on vessels or in lines which are filled with liquids and exposed to heat or refrigeration?
- What happens if a line fails, e.g., a failure of a high pressure gas line into a low pressure vessel?
- What happens if the unit operation is engulfed in a fire?
- What conditions cause runaway reactions, and how are relief systems designed to handle the discharge as a result of runaway reactions.

GUIDELINES FOR SPECIFYING RELIEF POSITIONS

- All vessels other than steam generators (which have their own code) need reliefs, including reactors, storage tanks, towers and drums.
- Blocked-in sections of cool liquid-filled lines which are exposed to heat (like the sun) or refrigeration need reliefs.
- Positive displacement pumps, compressors and turbines need reliefs on the discharge side.
- Storage vessels need pressure and vacuum reliefs to protect against pumping in or out of a block-in vessel, or against the generation of a vacuum by condensation.
- Vessel steam jackets are often rated for low pressure steam. Reliefs are installed in jackets to prevent excessive steam pressures due to operator error or regulator failure.
INSTALLATION

In general, the preferred position for the relief device is mounted directly on the pressure vessel or pipe which it is protecting, using a dedicated and properly designed nozzle. A safety valve should be installed in the vertical position with bottom inlet and side outlet. A bursting disc should be installed with the inlet side towards the process and the outlet side towards the vent, as indicated on the bursting disc tag.

There are several possible reasons for not mounting the relief device directly on the vessel: (ASME Code provides some guidelines)

- in the case of a high (or low) temperature service, the relief device can be mounted some distance from the vessel to reduce (increase) the temperature at which it has to operate;
- to improve access to the device;
- if valves are required between the vessel and the device to increase the elevation of the device to improve the drainage of the discharge pipework;
- to avoid pressure fluctuations caused by compressors or fittings;
- to permit the location of a relief device outside insulation.

8.4 CASE STUDY 1

Specify the location of reliefs in the simple polymerisation reactor system illustrated in Figure 8.4. The major steps in this polymerisation process include:

- Pumping 100lb of initiator into the reactor R-1.
- Heating to the reaction temperature of 240°F
- Adding monomer over a period of 3 hours.
- Stripping the residual monomer using a vacuum via valve V-15.

Since the reaction is exothermic, cooling during monomer addition with cooling water is necessary.
FIGURE 8.4 – CASE STUDY 1
POLYMERISATION REACTOR WITHOUT RELIEF VALVES
8.5 Description of Relief Devices

On spring operated valves, the adjustable spring tension offsets the inlet pressure. The relief set pressure is usually specified at 10% above the normal operating pressure. To avoid the possibility of an unauthorised person changing this setting, the adjustable screw is covered with a threaded cap.

The conventional relief is affected by the backpressure as illustrated in Figure 7. This type of valve is acceptable only when backpressures increases are minimal because the set pressure increases as the backpressure increases.

The balanced bellows design is used for process situations where substantial backpressures are present. This type of valve keeps atmospheric pressure on the discharge side of the relief. Therefore, the relief opens at the preset relief pressure, regardless of the process backpressure. The flow rate, however, is affected by the magnitude of the backpressure.

Rupture discs are specially designed to rupture at a specified relief set pressure. They usually consist of a calibrated sheet of metal designed to rupture at a well-specified pressure. They are used alone, in series, or in parallel to spring loaded relief devices. They can be made from a variety of materials, including exotic corrosion resistant materials.

Rupture discs are used alone when it is desired to keep the relief line operating after the disc has ruptured. An example of this requirement is the relief of exploding gases or exploding dusts.

Rupture discs are frequently installed in series to a spring loaded relief (a) to protect an expensive spring loaded device from a corrosive environment, (b) to give absolute isolation when handling extremely toxic chemicals (spring loaded relief may weep), (c) to give absolute isolation when handling flammable gases, (d) to protect the relatively complex parts of a spring loaded device from reactive monomer which could cause plugging, and (e) to relieve slurries which may plug spring loaded devices.

When rupture discs are used before a spring loaded relief, a pressure gauge is installed between the two devices. This "tell-tale gauge" is an indicator which shows when the disc ruptures. The failure can be the result of a pressure excursion or the result of a
pin hole due to corrosion. In either case this telltale gauge indicates that the disc needs to be replaced.

There are three subcategory types of spring loaded pressure reliefs.

- The relief valve is primarily for liquid service. The relief valve (liquid only) begins to open at the set pressure. This valve reaches full capacity when the pressure reaches 25% overpressure. The valve closes as the pressure returns to the set pressure.

- The safety valve is for steam, gas and vapor service. Safety valves pop open when the pressure exceeds the set pressure. This is accomplished by using a discharge nozzle that directs high velocity material towards the valve seat. After blowdown of the excess pressure, the valves reseats at approximately 4% below the set pressure; the valve has a 4% blowdown.

- The safety relief valve is used for liquid and vapor service. Safety relief valves function as relief valves for liquids and as safety valves for vapors.

The tolerance/inaccuracy of a bursting disc can vary from 2% to 20% depending on disc type and operating temperature.
FIGURE 8.5
THREE MAIN TYPES OF RELIEF DEVICES
RELIEF SCENARIO

A relief scenario is a description of one specific relief event. Usually each relief has more than one relief event, and the worst case scenario is the scenario or event which requires the largest relief vent area. Examples of relief events are:

A pump is dead headed; the pump relief is sized to handle the full pump capacity at its rated pressure.
The same pump relief is in a line with a nitrogen regulator; the relief is sized to handle the nitrogen if the regulator fails.
The same pump is connected to a heat exchanger with live steam; the relief is sized to handle steam injected into the exchanger under uncontrolled conditions, for example, a steam regulator failure.

This is a list of scenarios for one specific relief. The relief vent area is subsequently computed for each event (scenario) and the worst case scenario is the event requiring the largest relief vent area. The worst cases are a subset of the overall developed scenarios for each relief.

For each specific relief all possible scenarios are identified and catalogued. This step of the relief methodology is extremely important: The identification of the actual worst case scenario frequently has a more significant effect on the relief size compared to the accuracy of relief sizing calculations.

The scenarios developed for the reactor system described in Figure 5 are summarized in Table 1. The worst case scenarios are identified later via the computed maximum relief area for each scenario and relief. In Table 1 only three reliefs have multiple scenarios which require the comparative calculations to establish the worst cases. The other three reliefs have only single scenarios; therefore, they are the worst case scenarios.