Introduction to Reliefs

Introduction

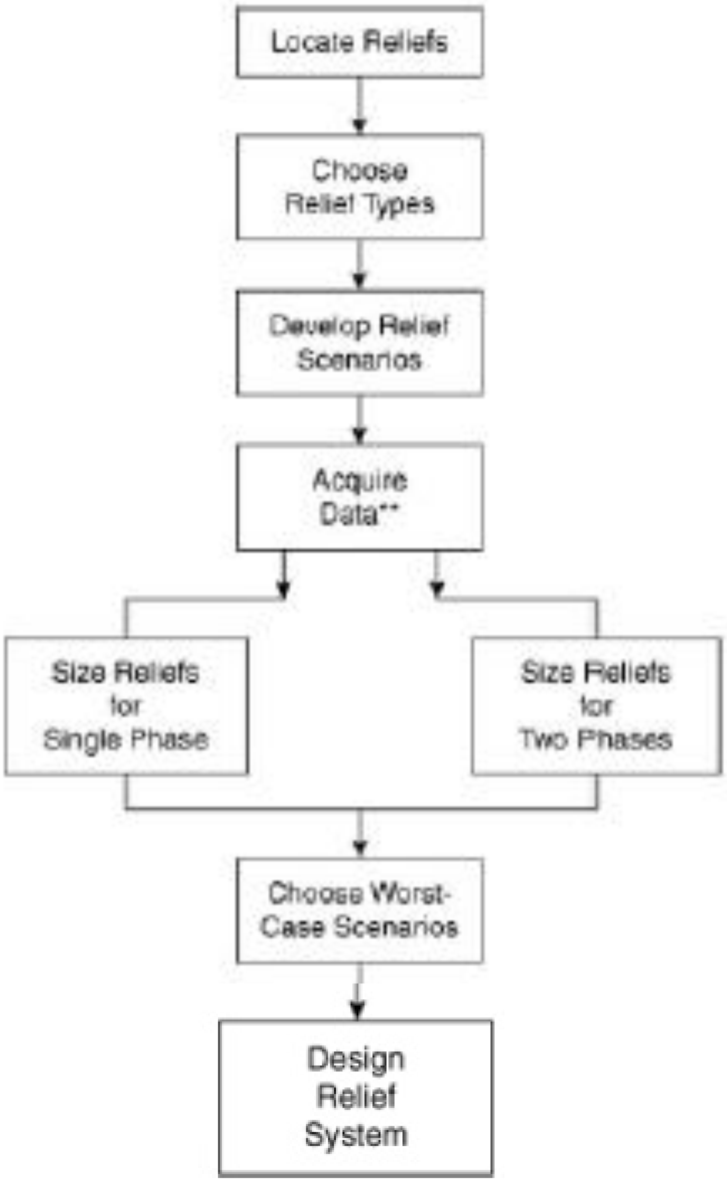
- Despite many safety precautions within chemical plants, equipment failures or operator errors can cause increases in process pressures beyond safe levels.
- If pressures rise too high, they may exceed the maximum strength of pipelines and vessels.
- This can result in rupturing of process equipment, causing major releases of toxic or flammable chemicals.
- The defence against this type of accident is to prevent the accident in the first place.
- Inherent safety, is the first line of defence.
- The second line of defence is better process control.
- A major effort is always directed toward controlling the process within safe operating regions.

- Dangerous high-pressure excursions must be prevented or minimized.
- The third line of defence against excessive pressures is to install relief systems
- Relieve liquids or gases before excessive pressures are developed.
- The relief system is composed of the relief device and the associated downstream process equipment to safely handle the material ejected.

The method used for the safe installation of pressure relief devices

- The first step in the procedure is to specify where relief devices must be installed.
  Second, the appropriate relief device type must be selected
- The type depends mostly on the nature of the material relieved and the relief characteristics required.
- Third, scenarios are developed that describe the various ways in which a relief can occur.
- The motivation is to determine the material mass flow rate through the relief and the physical state of the material (liquid, vapor, or two phases).
- Next, data are collected on the relief process, including physical properties of the ejected material, and the relief is sized.
- Finally, the worst-case scenario is selected and the final relief design is achieved

Relief method



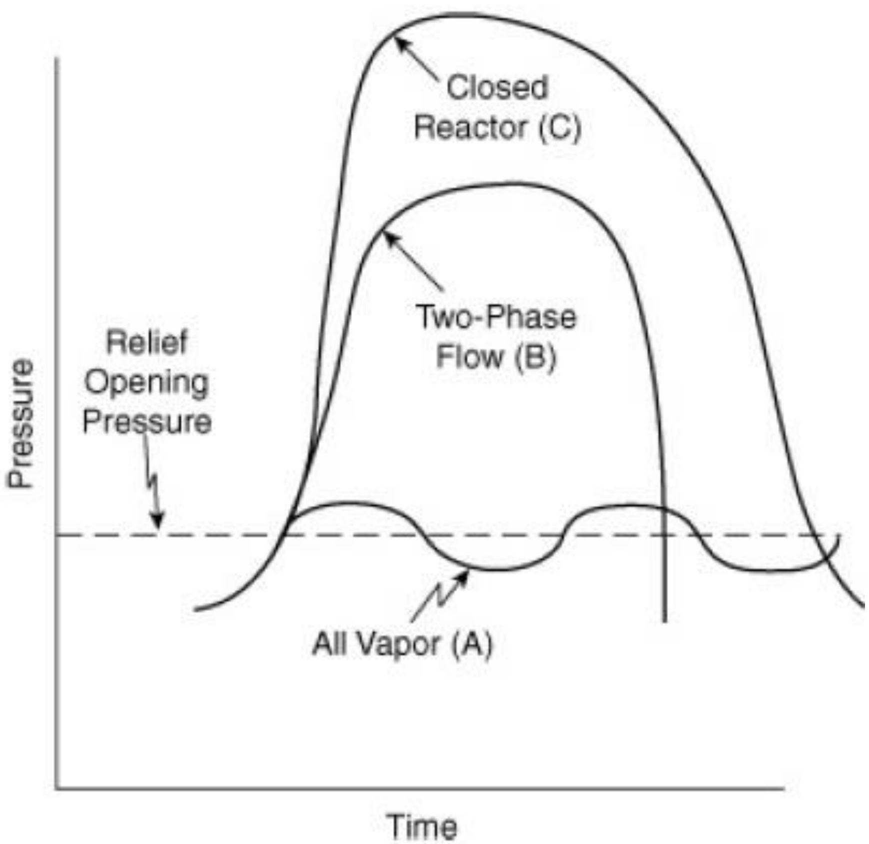
In this chapter we introduce relief fundamentals and the steps in the relief design procedure.

Relief Concepts

- To protect personnel from the dangers of over pressurizing equipment
- To minimize chemical losses during pressure upsets
- To prevent damage to equipment
- To prevent damage to adjoining property
- To reduce insurance premiums
- To comply with governmental regulations

Pressure versus time for runaway reactions

Assume that an exothermic reaction is occurring within a reactor.
If cooling is lost because of a loss of cooling water supply,
failure of a valve, or other scenario,
then the reactor temperature will rise.



- As the temperature rises,
- Reaction rate increases,
- Leading to an increase in heat production.

(A) Relieving vapor,
(B) Relieving froth (two-phase flow)
(C) Closed reaction vessel

- Reaction runaways for large commercial reactors can occur in minutes,
- Temperature and pressure increases of several hundred degrees per minute
- Several hundred psi per minute, respectively
- If the reactor has no relief system, the pressure and temperature continue to rise until the reactants are completely consumed, as shown by curve C
- If the reactor has a relief device, the pressure response depends on the relief device (curve A)

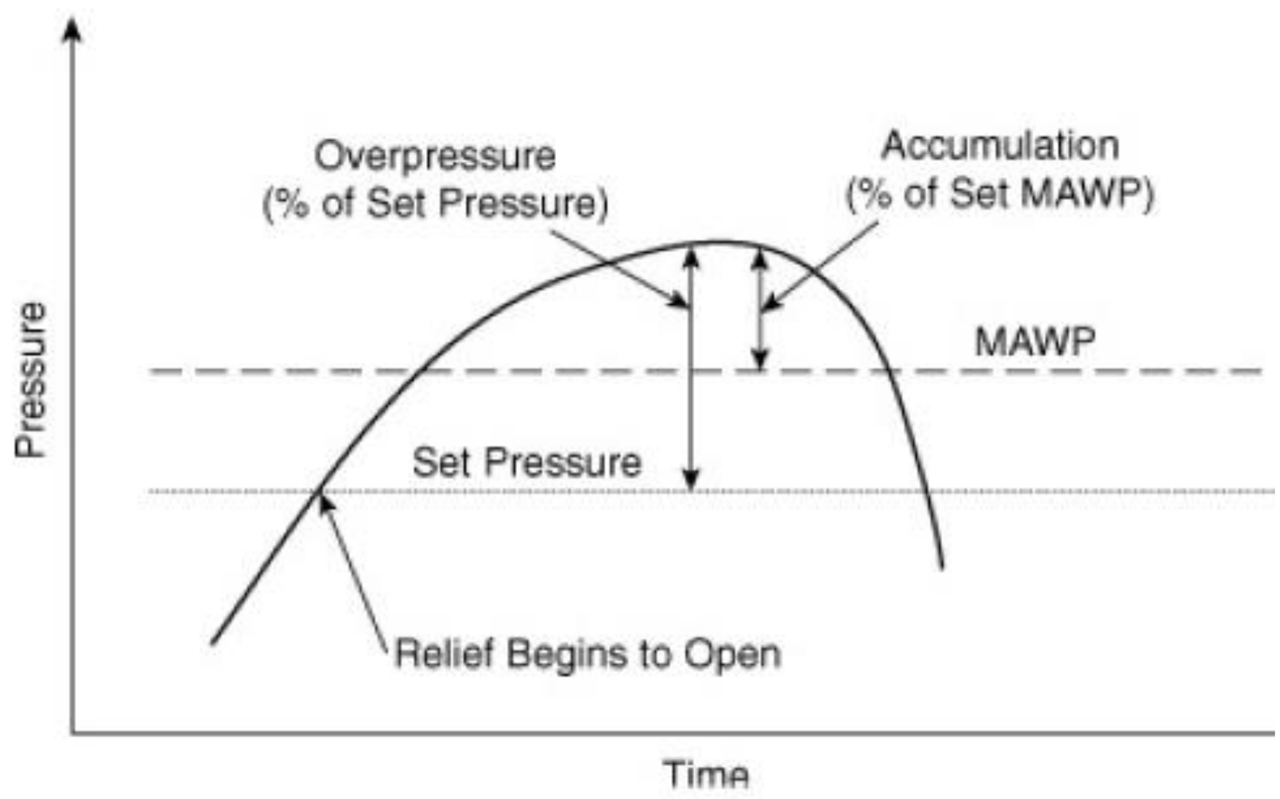
Definitions that are commonly used within the chemical industry

- **Set pressure:** The pressure at which the relief device begins to activate

- **Maximum allowable working pressure (MAWP):**
- This is sometimes called the design pressure.
- Gauge pressure permissible at the top of a vessel for a designated temperature
- Operating temperature increases, the MAWP decreases
- Operating temperature decreases, the MAWP decreases
- Vessel failure typically occurs at 4 or 5 times the MAWP
- Deformation may occur at as low as twice the MAWP

Description of overpressure and accumulation

- **Operating pressure:** The gauge pressure during normal service, usually 10% below the MAWP



Definitions

- **Accumulation:** The pressure increase over the MAWP of a vessel during the relief process.

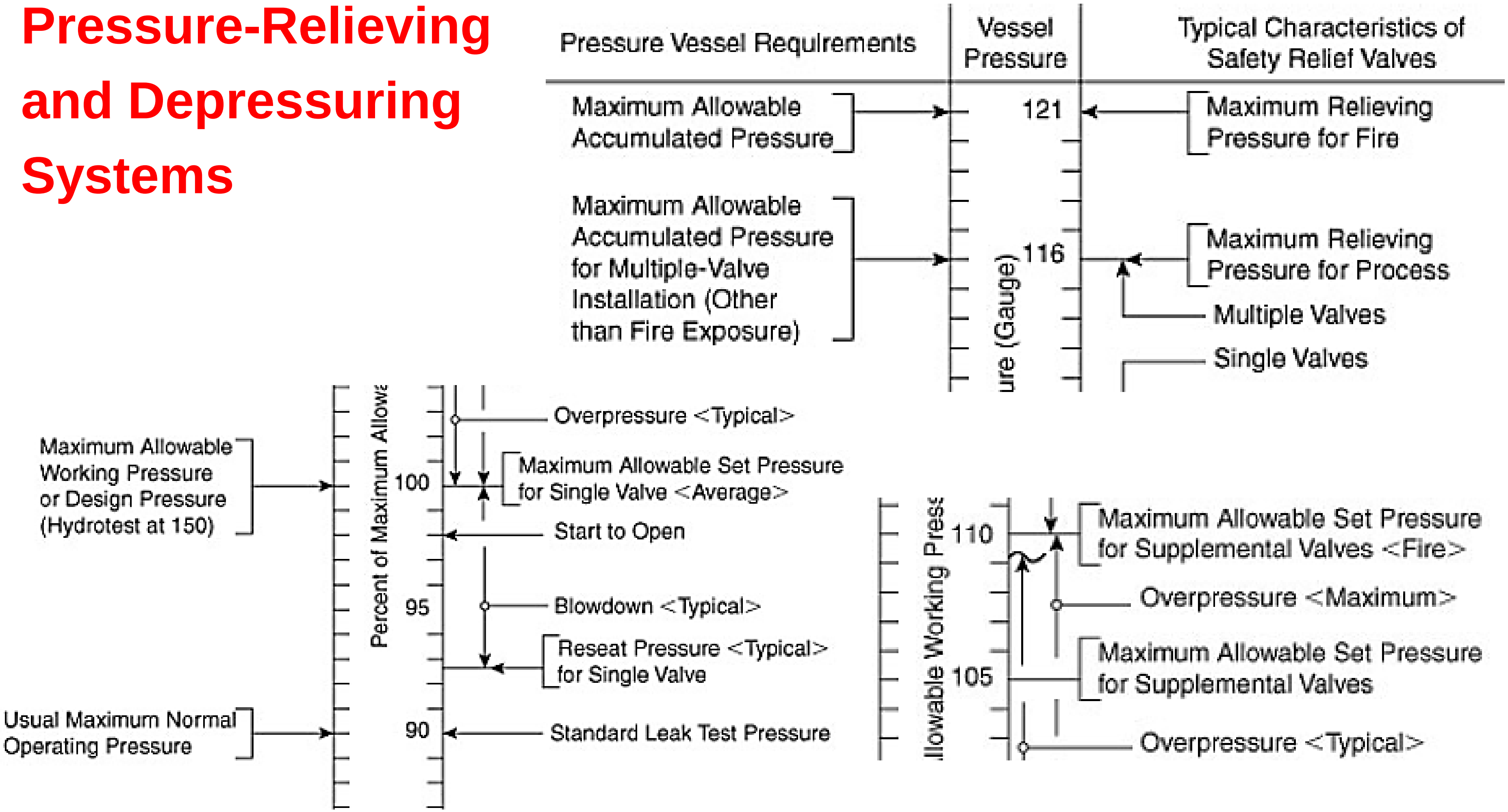
  It is expressed as a percentage of the MAWP.
- **Overpressure:** The pressure increase in the vessel over the set pressure during the
- **Relieving process.** Overpressure is equivalent to the accumulation when the set pressure is at the MAWP. It is expressed as a percentage of the set pressure.
- **Backpressure:** The pressure at the outlet of the relief device during the relief process resulting from pressure in the discharge system.

Definitions

- **Blowdown:** 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 and the allowable accumulation.
- **Relief system:** The network of components around a relief device, including the pipe to the relief, the relief device, discharge pipelines, knockout drum, scrubber, flare, or other types of equipment that assist in the safe relief process.

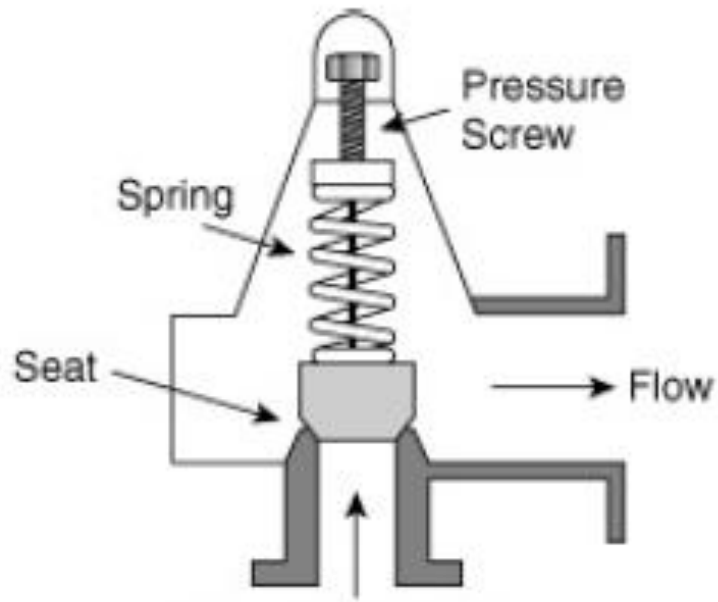
Guidelines for relief pressures. Adapted from API RP 521,

Pressure-Relieving and Depressuring Systems

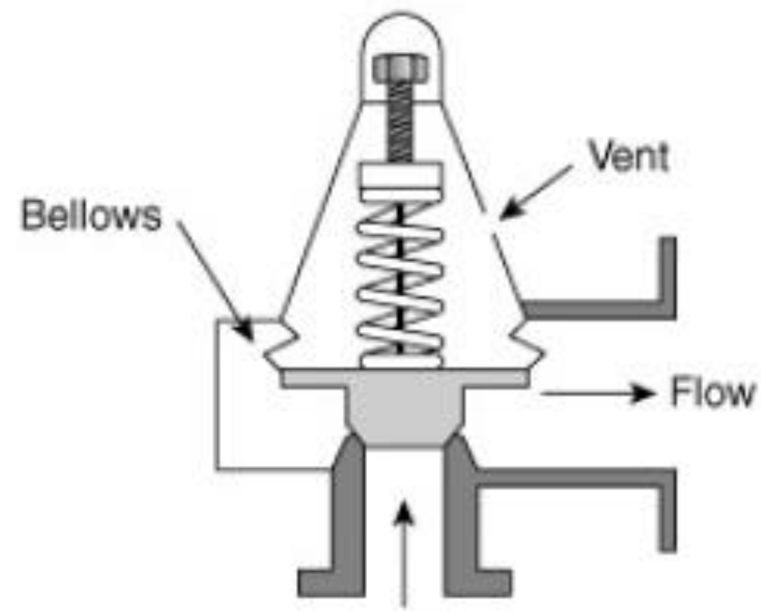


Relief Types and Characteristics

Specific types of relief devices are chosen for specific applications.
There are two general categories of relief devices (spring-operated and rupture discs)
two major types of spring-operated valves (conventional and balanced-bellows)



Conventional Spring-Operated Valve



Balanced Bellows

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.

conventional spring-operated relief

- the valve opens based on the pressure drop across the valve seat; that is, the set pressure is proportional to the pressure drop across the seat.

balanced-bellows

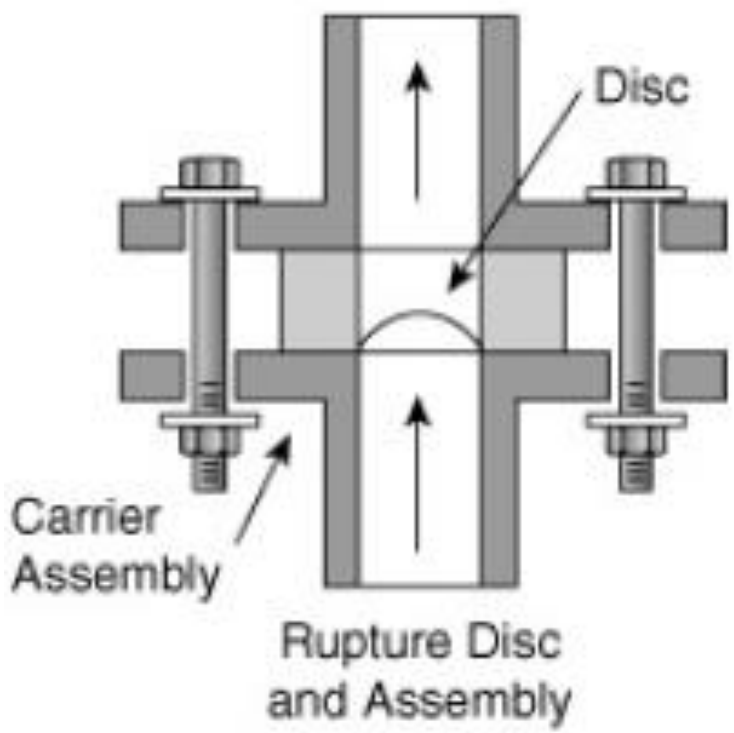
- design the bellows on the backside of the valve seat ensures that the pressure on that side of the seat is always atmospheric.
- Therefore the flow is reduced as the backpressure increases

There are three subcategory types of spring-loaded pressure reliefs:

- **1**. 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.
- **2.** The *safety valve* is for gas service. Safety valves pop open when the pressure exceeds the set pressure. pressure, the valve reseats at approximately 4% below the set pressure; the valve has a 4% blowdown.
- The *safety relief valve* is used for liquid and gas service.

Major types of relief devices

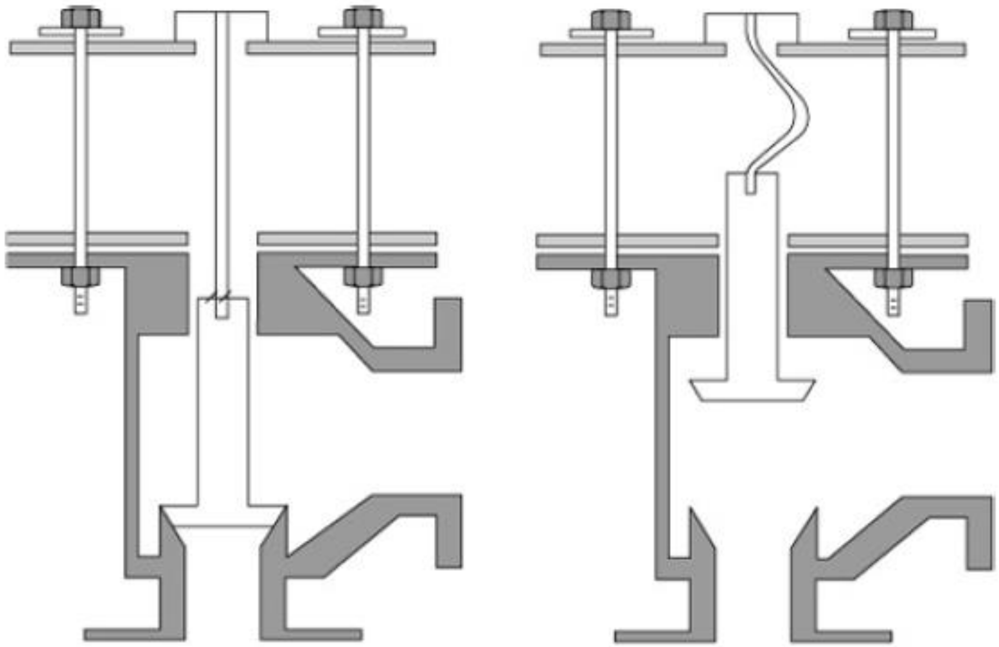
Rupture discs are specially designed to rupture at a specified relief set pressure. They usually consist of a calibrated sheet of metal designed to rupture at a well-specified pressure



Type of relief valve	Advantages	Disadvantages
Spring-operated (conventional)	Very reliable Used in many services Reseats at pressures 4% below set pressure	Relief pressure affected by backpressure Can chatter with high backpressures
Spring-operated (balanced bellows)	Relief pressure not affected by backpressure Handles higher buildup backpressures Protects spring from corrosion	Bellows may fatigue/rupture Flow is function of backpressure May release flammables/toxics to atmosphere
Rupture discs	No fugitive emissions; i.e., no seal leakage Low cost and easy to replace Good for high-volume releases Less fouling or plugging Good for second relief requiring large relief area	Stay open after relief Burst pressure can't be tested Require periodic replacement Sensitive to mechanical damage Greater problems with high temperatures Fatigue problems with pressure cycling

Buckling-Pin Reliefs

- A buckling-pin relief is similar to a rupture disc; that is, when the pressure buckles the pin, the valve opens fully.

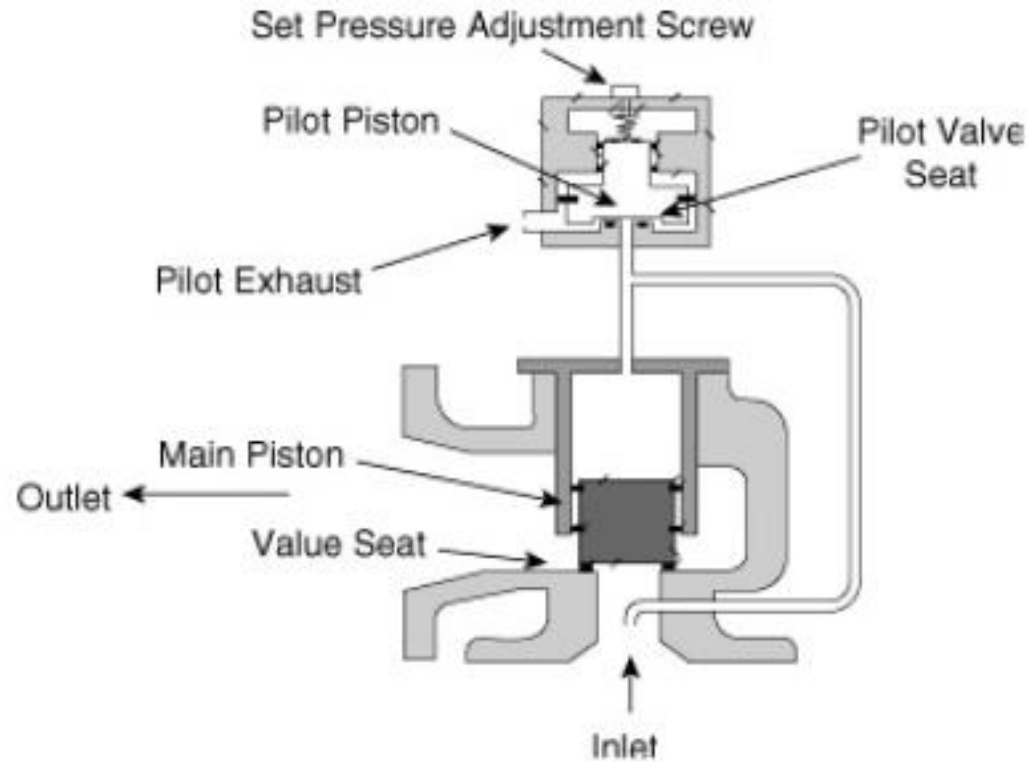


Closed
Pressure below Set Pressure

Full Open
Pressure at or above Set Pressure

(Buckles in Milliseconds at a Precise Set Pressure)

Pilot-Operated Reliefs



The main valve of a pilot-operated relief valve is controlled by a smaller pilot valve that is a spring-operated relief valve. The pilot and main valves reseat when the inlet pressure drops below the set pressure.

Buckling-pin	No fatigue problems Relief pressures are more accurate than conventional devices Set pressure is not sensitive to operating temperature Replacing pins is very easy and not expensive	Elastomer seals limit temperature to about 450°F Initial cost is greater than for rupture discs
Pilot-operated	Relief pressure is not affected by backpressure Can operate at pressures up to 98% of set pressure Seals tightly even at pressures approaching set pressure Main valve snaps fully open at low overpressures Less susceptible to chatter Chattering due to backpressure is not possible	Pilot is susceptible to plugging Limited to the chemical and temperature constraints of the seals Condensation and liquid accumulated above the main piston may cause problems Potential for backflow

- Pilot-operated valves are frequently chosen when operating pressures are within 5% of set pressures.

Chatter

- In general, relief systems must be designed appropriately to prevent unwanted and dangerous problems.
- Included in this design are the sizing of the relief and also the mechanical piping details
- Chattering is the rapid opening and closing of a relief valve that can cause valve seat damage or the mechanical failure of the internals.
- The major cause of valve chatter is an oversized relief valve.
- In this case the valve opens a short time to reduce the pressure and the pressure then rises rapidly to open the valve again.
- This pulsating action can be very destructive.
- The major causes of chatter are excessive inlet pressure drop, high backpressures, and oversized valves.

Relief Scenarios

- A relief scenario is a description of one specific relief event.
- Usually each relief has more than one relief event.
- Largest relief vent area.
- Examples of relief events are

  1. A pump is dead-headed; the pump relief is sized to handle the full pump capacity at its rated pressure.

  2. The same pump relief is in a line with a nitrogen regulator; the relief is sized to

  handle the nitrogen if the regulator fails.

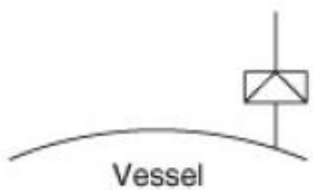
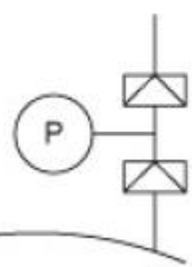
  3. The same pump is connected to a heat exchanger with live steam; the relief is sized
- This is a list of scenarios for one specific relief.
- The worst-case scenarios are identified later by means of the computed maximum relief area for each scenario and relief.
- Only three reliefs have multiple scenarios that require the comparative calculations to establish the worst cases.

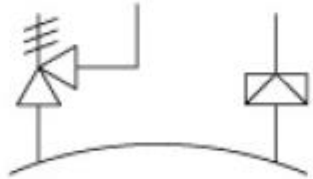
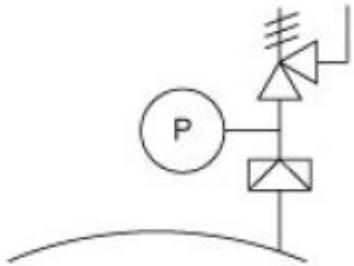
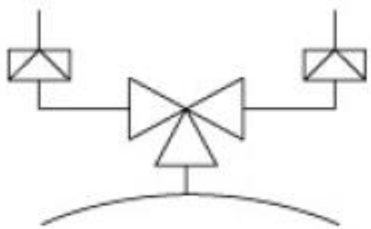
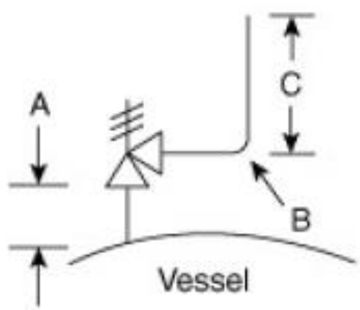
Relief identifications	Scenarios
PSV-1a and PSV-1b	(a) Vessel full of liquid and pump P-1 is accidentally actuated. (b) Cooling coil is broken and water enters at 200 gpm and 50 psig. (c) Nitrogen regulator fails, giving critical flow through 1-in line. (d) Loss of cooling during reaction (runaway).
PSV-2	V-1 is accidentally closed; system needs relief for 100 gpm at 50 psig.
PSV-3	Confined water line is heated with 125-psig steam.
PSV-4	(a) Nitrogen regulator fails, giving critical flow through 0.5-in line. (b) Note: The other R-1 scenarios will be relieved via PSV-1.
PSV-5	Water blocked inside coil, and heat of reaction causes thermal expansion.

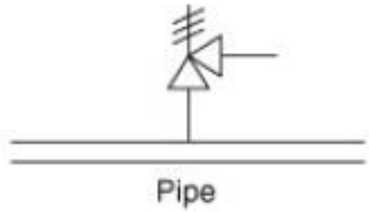
Relief Installation Practices

- Regardless of how carefully the relief is sized, specified, and tested, a poor installation can result in completely unsatisfactory relief performance.

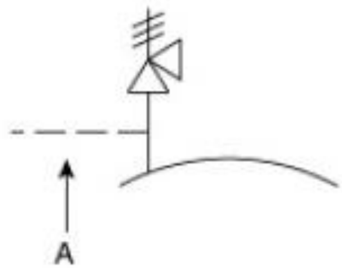
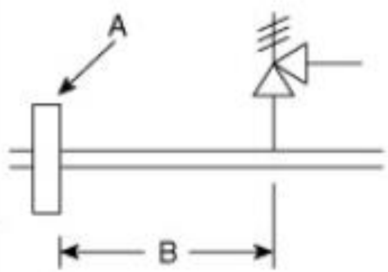
Some installation guidelines are illustrated

System	Recommendations
	• Rupture disc in corrosive service. • Or for highly toxic materials where spring-loaded valve may weep.
	• Two rupture discs in extremely corrosive service. The 1st may periodically need to be replaced.

	• Rupture disc and spring-loaded relief. Normal relief may go through spring-loaded device, and rupture disc is backup for larger reliefs.
	• Two reliefs in series. The rupture disc protects against toxicity and corrosion. The spring-loaded relief closes and minimizes losses.
	• Two rupture discs with special valve which keeps one valve always directly connected to vessel. This type of design is good for polymerization reactors where periodic cleaning is necessary.
	A. Pressure drop not more than 3% of set pressure B. Long radius elbow C. If distance is greater than 10 feet, weight and reaction forces should be supported below the long radius elbow.

<table>
<tr>
<td>
</td>
<td>

- Orifice area of a single safety relief in vapor service, should not exceed 2% of the cross-sectional area of the protected line.
- Multiple values with staggered settings may be required.

</td>
</tr>
<tr>
<td>
</td>
<td>A. Process lines should not be connected to safety valve inlet piping.</td>
</tr>
<tr>
<td>
</td>
<td>A. Turbulence-causing device
B. Dimension (B) shown below:
<table>
<tr><th>Device causing turbulence</th><th>Minimum number of straight pipe diameters</th></tr>
<tr><td>Regulator or valve:</td><td>25</td></tr>
<tr><td>2 ells or bends not in same plane:</td><td>20</td></tr>
<tr><td>2 ells or bends in same plane:</td><td>15</td></tr>
<tr><td>1 ell or bend:</td><td>10</td></tr>
<tr><td>Pulsation damper:</td><td>10</td></tr>
</table>
</td>
</tr>
</table>

Relief Design Considerations

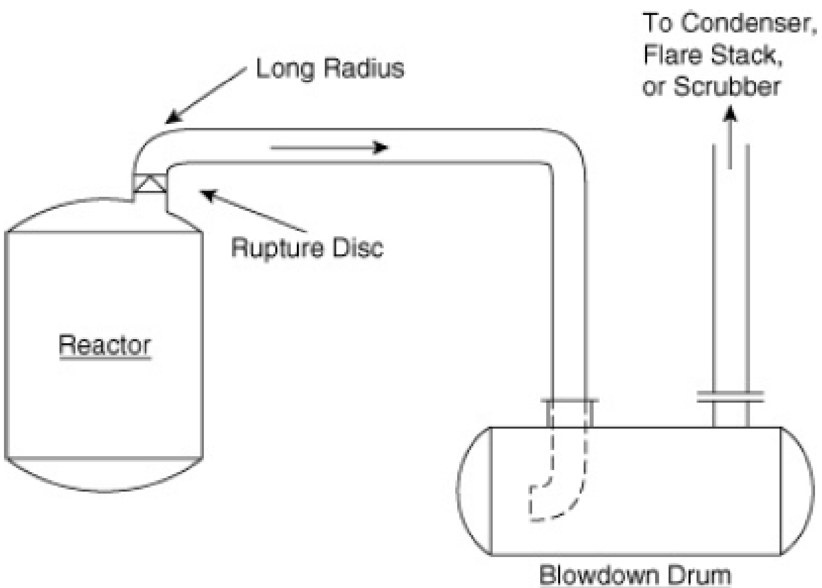
- A designer of relief systems must be familiar with governmental codes, industrial standards, and insurance requirements.
- This is particularly important because local government standards may vary.
- Codes of particular interest are published by the
  - American Society of Mechanical Engineers
  - American Petroleum Institute
  - National Board of Fire Underwriters
- API RP 5207 has some guidelines
- Reliefs are now rarely vented to the atmosphere.
- In most cases a relief is first discharged to a knockout system to separate the liquid from the vapor.

Relief Design Considerations

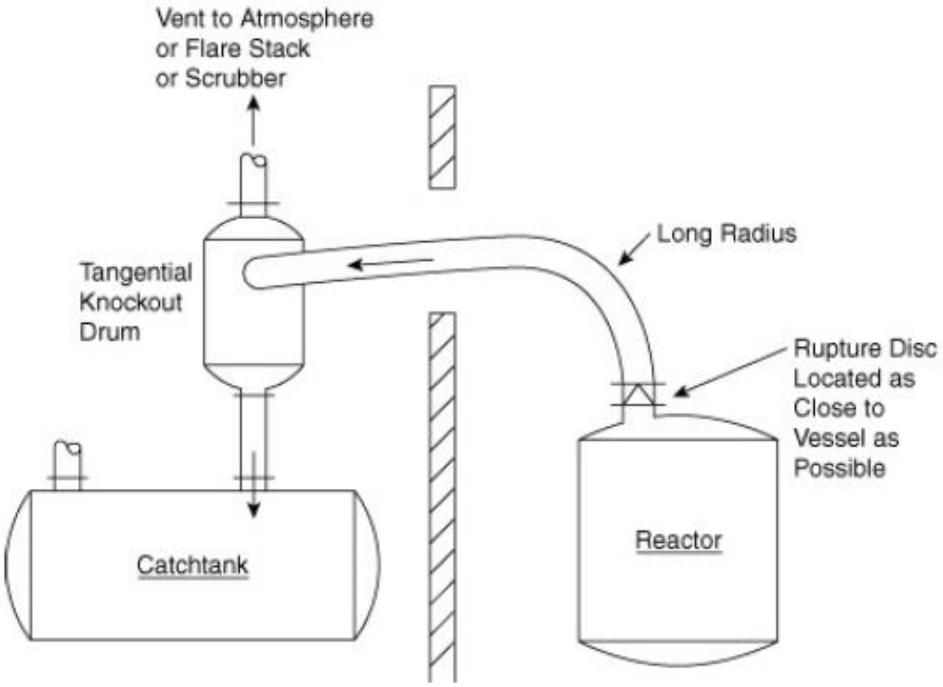
- Here the liquid is collected and the vapor is discharged to another treatment unit.
- This subsequent vapor treatment unit depends on the hazards of the vapor;
- it may include a condenser, scrubber, incinerator, flare, or a combination of them.
- This type of system is called a total containment system.
- Total containment systems are commonly used, and they are becoming an industrial standard.

Relief containment system with blowdown drum

Horizontal Knockout Drum



Tangential inlet knockout drum



When space within a plant is limited, a tangential knockout drum is used

Flares

- The objective of a flare is to burn the combustible or toxic gas to produce combustion products that are neither toxic nor combustible.
- The diameter of the flare must be suitable to maintain a stable flame and to prevent a blowout (when vapor velocities are greater than 20% of the sonic velocity)
- The height of a flare is fixed on the basis of the heat generated and the resulting potential damage to equipment and humans.
- The usual design criterion is that the heat intensity at the base of the stack is not to exceed 1500 $Btu/hr/ft^2$.

- The effects of thermal radiation are shown in the following table

Heat intensity ($Btu/hr/ft^2$)	Effect
2000	Blisters in 20 s
5300	Blisters in 5 s
3000–4000	Vegetation and wood are ignited
350	Solar radiation

Scrubbers

- If the vapors are toxic, a flare (described previously) or a scrubber system may be required.
- Scrubber systems can be packed columns, plate columns, or venturi-type systems.

Condensers

- A simple condenser is another possible alternative for treating exiting vapors.
- This alternative is particularly attractive if the vapors have a relatively high boiling point and if the recovered condensate is valuable.
- This alternative should always be evaluated because it is simple and usually less expensive and because it minimizes the volume of material that may need additional post-treatment.