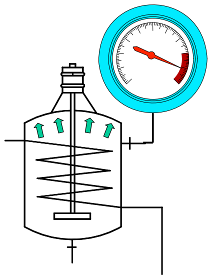
Chemical Process Safety

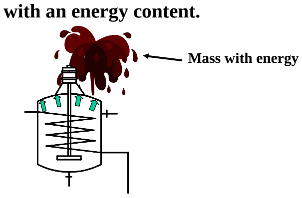
Chapter 8: Relief Systems



Introduction

What: A relief system protects the process from the damaging effects of high or low pressure.

How: A relief system removes energy from a process by discharging mass with an energy content.



How Can High Pressures Develop?

- Overheat
- Over Pump
- Over Fill
- Failure of Regulator
- External Fire
- Runaway Reaction
- Combustion of gases / dusts
- Freezing
- Thermal Expansion
- Loss of mixing
- Many others!

Relief Design Procedure

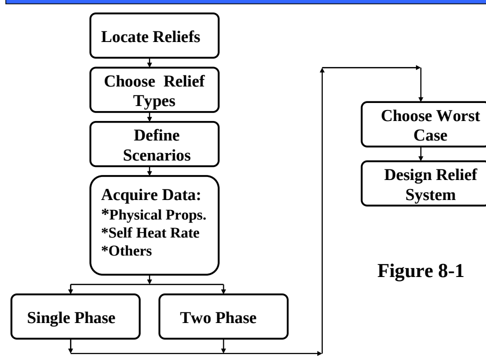


Figure 8-1

Definitions - 1

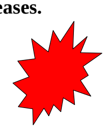
Set Pressure: Pressure at which the relief device begins to open.

Maximum Allowable Working Pressure (MAWP): Maximum design pressure at the top of a vessel for a designated temperature.

As T increases, MAWP decreases.

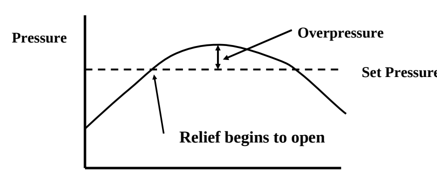
As T decreases, MAWP decreases.

Vessel fails at 4 to 5 times MAWP.



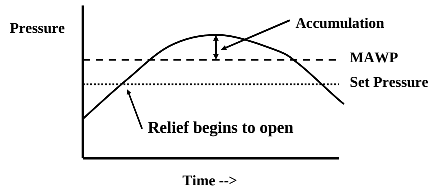
Definitions - 2

Overpressure: Pressure increase over set pressure during relieving. Expressed as % of set pressure. Must be specified prior to relief design. Typically 10%



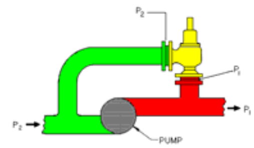
Definitions - 3

Accumulation: **The pressure increase over the MAWP of the vessel during the relief process. Expressed as % of MAWP.**



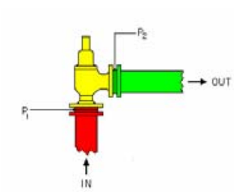
Backpressure: **The pressure downstream of the relief device during the relieving process.**

Backpressure - Superimposed



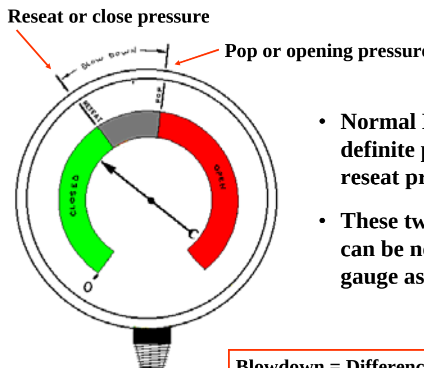
- Pressure in discharge header before valve opens
- Can be constant or variable

Backpressure – Built-up



- Pressure in discharge header due to frictional losses after valve opens

•Total Backpressure = Superimposed + Built-up

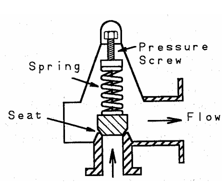


- **Normal PRV has definite pop and reseat pressures**
- **These two pressures can be noted on a gauge as shown.**

Blowdown = Difference between pop and reseat pressure

Spring-loaded Reliefs

Fig. 8-7



CONVENTIONAL SPRING

– Setpressure $\propto (P_{PROCESS} - P_{DOWNSTREAM})$

– Flow $\propto (P_{PROCESS} - P_{DOWNSTREAM})$

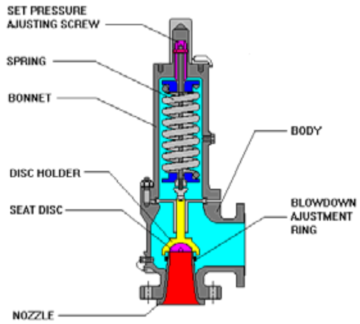
– Setpressure and flow affected by backpressure:

Setpressure increases

Flow decreases

Spring-loaded Reliefs

Spring-loaded Reliefs



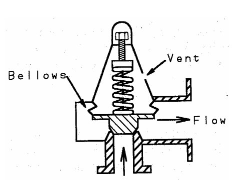
Spring-Loaded Relief Installed on Vessel

Spring-Loaded Relief Installed in Plant

Advantages / Disadvantages Conventional Valve

- Advantages
  - \+ Most reliable type if properly sized and operated
  - \+ Versatile -- can be used in many services
- Disadvantages
  - – Relieving pressure affected by back pressure
  - – Susceptible to chatter if built-up back pressure is too high

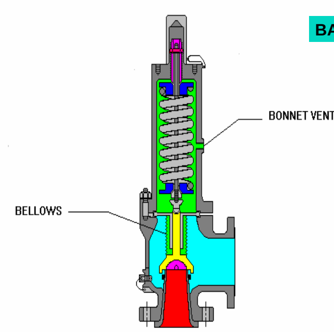
Spring-loaded Reliefs



BALANCED BELLOWS

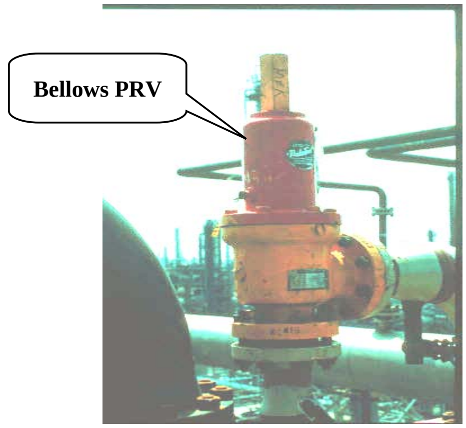
–Setpressure $\propto (P_{PROCESS} - P_{AMBIENT})$
–Flow $\propto (P_{PROCESS} - P_{DOWNSTREAM})$
–Setpressure not affected by backpressure.
–Flow decreases with backpressure.

BALANCED BELLOWS



Advantages / Disadvantages Balanced Bellows Valve

- Advantages
  - + Relieving pressure not affected by back pressure
  - + Can handle higher built-up back pressure
  - + Protects spring from corrosion
- Disadvantages
  - – Bellows susceptible to fatigue/rupture
  - – Flow thru valve is affected by back pressure



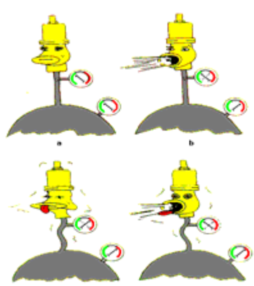
Chatter

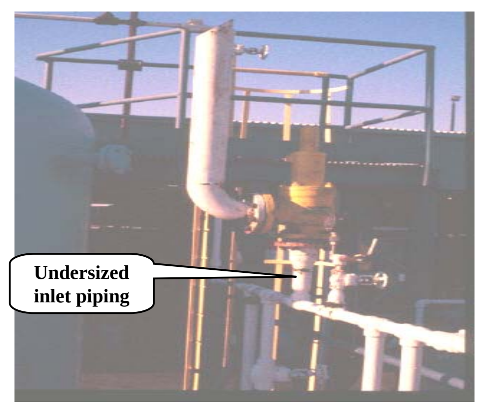
- Chattering is the rapid, alternating opening and closing of a PR Valve.
- Resulting vibration may cause misalignment, valve seat damage and, if prolonged, can cause mechanical failure of valve internals and associated piping.
- Chatter may occur in either liquid or vapor services

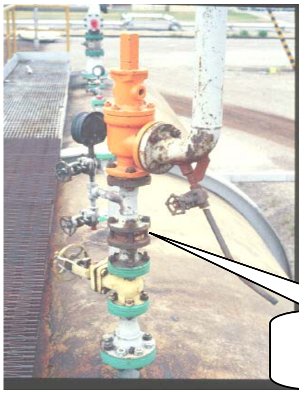
Chatter - Principal Causes

- Excessive inlet pressure drop
- Excessive built-up back pressure
- Oversized valve
- Valve handling widely differing rates

Chatter Mechanism Excessive Inlet Pressure Drop







Consider the pressure drop from all these connections

Rupture Discs

- A rupture disc is a thin diaphragm (generally a solid metal disc) designed to rupture (or burst) at a designated pressure. It is used as a weak element to protect vessels and piping against excessive pressure (positive or negative).

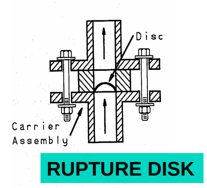
- There are five major types available
  - Conventional tension-loaded rupture disc
  - Pre-scored tension-loaded rupture disc
  - Composite rupture disc
  - Reverse buckling rupture disc with knife blades
  - Pre-scored reverse buckling rupture disc

Rupture Discs

- They are often used as the primary pressure relief device.
  - Very rapid pressure rise situations like runaway reactions.
  - When pressure relief valve cannot respond quick enough.

- They can also be used in conjunction with a pressure relief valve to:
  - Provide corrosion protection for the PRV.
  - Prevent loss of toxic or expensive process materials.
  - Reduce fugitive emissions to meet environmental requirements.

Rupture Disk



*** Calibrated metal disk**
*** Remains open after rupture**
*** Subject to pressure cycling fatigue**

Rupture Disk

Rupture Disk

Rupture Discs Are Well Suited For Some Applications

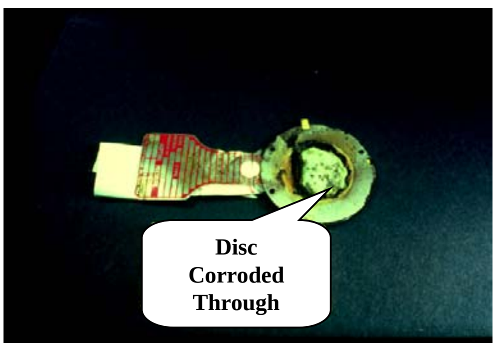
Advantages

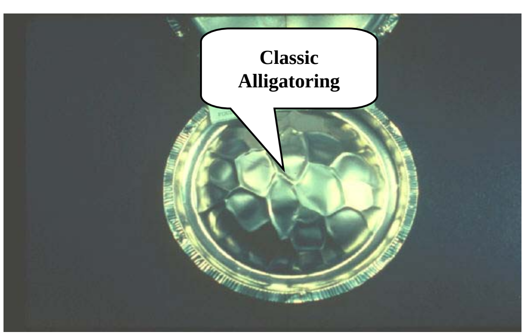
+ Reduced fugitive emissions - no simmering or leakage prior to bursting.
+ Protect against rapid pressure rise cased by heat exchanger tube ruptures or internal deflagrations.
+ Less expensive to provide corrosion resistance.
+ Less tendency to foul or plug.
+ Provide secondary protective device for lower probability contingencies requiring large relief areas.

Rupture Discs Are Less Well Suited For Other Applications

Disadvantages

– Don't reclose after relief.
– Burst pressure cannot be tested.
– Require periodic replacement.
– Greater sensitivity to mechanical damage.
– Greater sensitivity to temperature

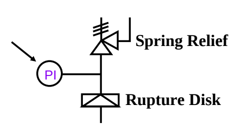




Alligatoring is caused by operating too close to the set pressure.

Rupture Disk

Tell-tale pressure gauge



Protects spring device against corrosion, plugging.

Protects spring reliefs: corrosion, plugging

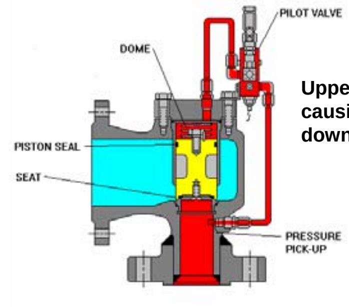
Absolute protection, no weeping: toxicants, flammables

Problem: Piece of rupture disk might break off and plug spring relief

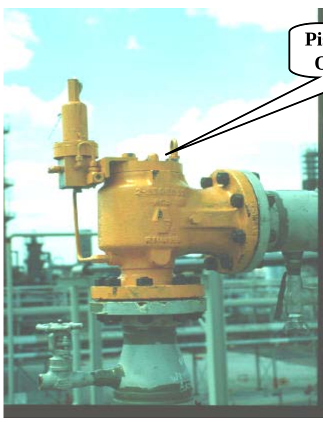
Pressure above RD

Reduced inlet piping

Piston Type Pilot Operated Safety Relief Valve



Upper surface is larger, causing a greater downward pressure.



Piston Type Pilot Operated PRV

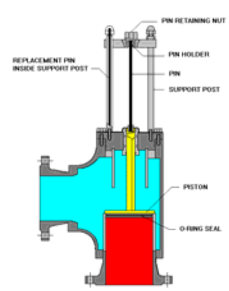
Advantages / Disadvantages Pilot Operated Valve

- Advantages
  - + Relieving pressure not affected by backpressure
  - + Can operate at up to 98% of set pressure
  - + Less susceptible to chatter (some models)
- Disadvantages
  - – Pilot is susceptible to plugging
  - – Limited chemical and high temperature use by “O-ring” seals
  - – Vapor condensation and liquid accumulation above the piston may cause problems
  - – Potential for back flow

Rupture Pins

- A rupture pin is designed to be a non-reclosing pressure relief device, similar to a rupture disc
- A piston is held in the closed position with a buckling pin which will fail at a set pressure according to Euler's Law
- An o-ring on the piston is used to make a bubble tight seal

Conventional Rupture Pin Device



Comparison of Rupture Pins To Rupture Discs

Advantages

+ Not subject to premature failure due to fatigue
+ Can be operated closer to its set point
+ Setpoint is insensitive to operating temperature
+ Available as balanced or unbalanced device
+ Capable of operating as low as 0.1 psig (0.007 barg)
+ Suitable for liquid service
+ Resetting after release usually requires no breaking of flanges
+ Replacement pins are 1/3 to 1/4 the cost of replacement discs

Comparison of Rupture Pins To Rupture Discs

Disadvantages

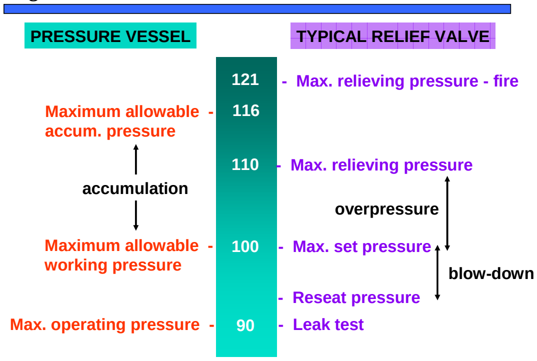
– The elastomer o-ring seal limits the maximum operating temperature to about 450°F (230°C)

– Initial cost of installation is greater than for a rupture disc

* twice as costly for 2” carbon steel
* up to seven times as costly for 8” stainless steel

Figure 8-4

Definitions



Code Requirements

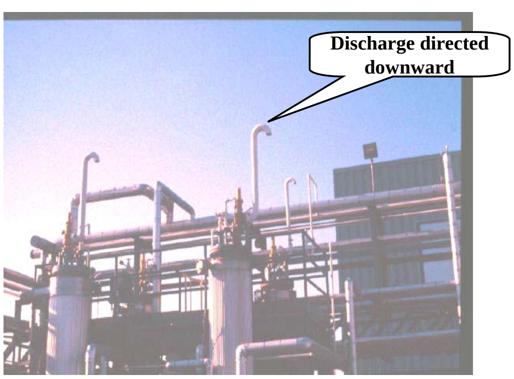
Relieving pressure shall not exceed MAWP (accumulation) by more than:

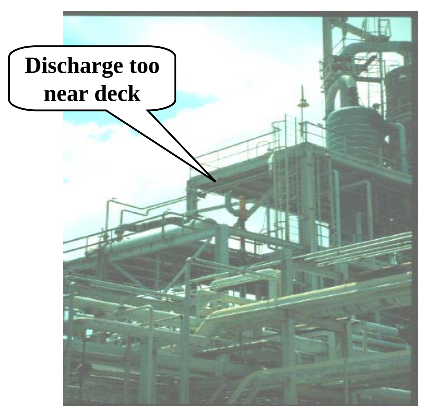
– 3% for fired and unfired steam boilers

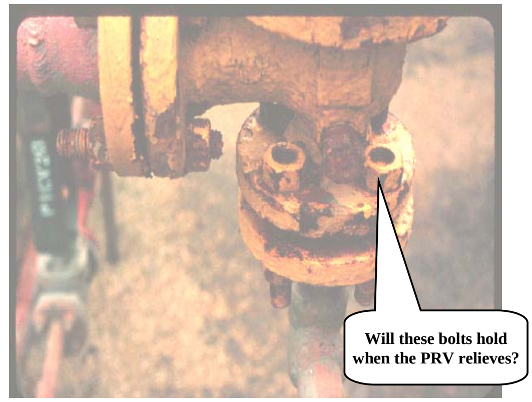
– 10% for vessels equipped with a single pressure relief device

– 16% for vessels equipped with multiple pressure relief devices

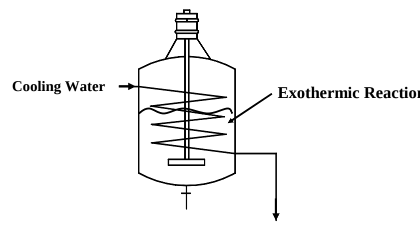
– 21% for fire contingency







Runaway Reactions - 1



Why important: **Common problem with exothermic reactions.**

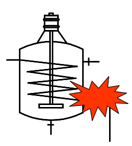
Runaway Reactions - 2

How?

1. Loss of coolant.

2. Increased temperature.

3. Increased energy generation.



High pressure due to: **Vapor pressure of liquid.**

Vapor decomposition products.

Larger vessels respond faster - less heat transfer thru walls!!!

Some chemicals can achieve self heat rates of 100's deg. C/min! **Styrene, Acrylic Acid**

Runaway Reactions - 3

Some ways for runaways to occur:

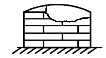
- **Loss of cooling.**
- **Overcharge reactant.**
- **External fire.**
- **Mis-charge reactant.**
- **Low reaction temperature in semi-batch reactor . This is called a sleeping reactor.**
- **Loss of agitation.**

Most reactive runaways result in 2-phase flow thru relief and require a relief area 2 to 10 times larger than single phase relief.

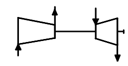
Runaway Reactions - 4

Table 8-1 Relief Locations

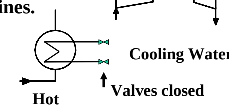
- All process and storage vessels.



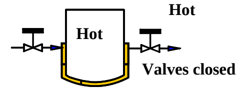
- Pumps (positive displacement), compressors, turbines. Many have internal reliefs.



- Blocked, liquid-filled lines.

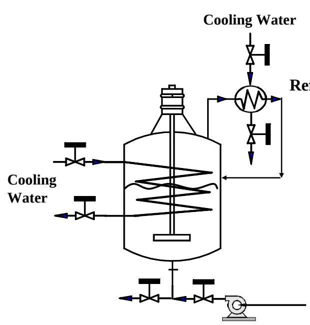


- Jackets on vessels.



- Others

Relief Locations Example



<u>Relief Locations:</u>

1.

2.

3.

4.

Relief Scenarios

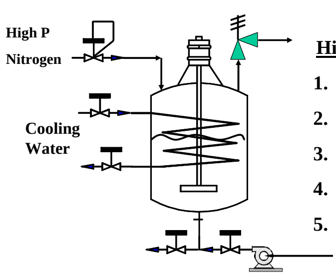
<u>What:</u> Describe situations or sequences of events that result in high pressure.

- Could be dozens of scenarios for a particular piece of equipment, particularly with reactors.
- Select worst case, i.e. case that requires largest relief area.

<u>Generally, worst case is:</u>

- Runaway Reaction.
- External Fire.

Relief Scenarios - Example



<u>High Pressure In Reactor</u>

1.

2.

3.

4.

5.