Module 9.2

Types of Safety Valves

Types of Safety Valves

There is a wide range of safety valves available to meet the many different applications and performance criteria demanded by different industries. Furthermore, national standards define many varying types of safety valve.

The ASME standard I and ASME standard VIII for boiler and pressure vessel applications and the ASME / ANSI PTC 25.3 standard for safety valves and relief valves provide the following definition. These standards set performance characteristics as well as defining the different types of safety valves that are used:

- **ASME I valve -** A safety relief valve conforming to the requirements of Section I of the ASME pressure vessel code for boiler applications which will open within 3% overpressure and close within 4%. It will usually feature two blowdown rings, and is identified by a National Board 'V' stamp.
- **ASME VIII valve -** A safety relief valve conforming to the requirements of Section VIII of the ASME pressure vessel code for pressure vessel applications which will open within 10% overpressure and close within 7%. Identified by a National Board 'UV' stamp.
- **Low lift safety valve -** The actual position of the disc determines the discharge area of the valve.
- **Full lift safety valve -** The discharge area is not determined by the position of the disc.
- **Full bore safety valve -** A safety valve having no protrusions in the bore, and wherein the valve lifts to an extent sufficient for the minimum area at any section, at or below the seat, to become the controlling orifice.
- **Conventional safety relief valve -** The spring housing is vented to the discharge side, hence operational characteristics are directly affected by changes in the backpressure to the valve.
- **Balanced safety relief valve -** A balanced valve incorporates a means of minimising the effect of backpressure on the operational characteristics of the valve.
- **Pilot operated pressure relief valve -** The major relieving device is combined with, and is controlled by, a self-actuated auxiliary pressure relief device.
- **Power-actuated safety relief valve -** A pressure relief valve in which the major pressure relieving device is combined with, and controlled by, a device requiring an external source of energy.

The following types of safety valve are defined in the DIN 3320 standard, which relates to safety valves sold in Germany and other parts of Europe:

- **Standard safety valve -** A valve which, following opening, reaches the degree of lift necessary for the mass flowrate to be discharged within a pressure rise of not more than 10%. (The valve is characterised by a pop type action and is sometimes known as high lift).
- **Full lift (Vollhub) safety valve -** A safety valve which, after commencement of lift, opens rapidly within a 5% pressure rise up to the full lift as limited by the design. The amount of lift up to the rapid opening (proportional range) shall not be more than 20%.
- **Direct loaded safety valve -** A safety valve in which the opening force underneath the valve disc is opposed by a closing force such as a spring or a weight.
- **Proportional safety valve -** A safety valve which opens more or less steadily in relation to the increase in pressure. Sudden opening within a 10% lift range will not occur without pressure increase. Following opening within a pressure of not more than 10%, these safety valves achieve the lift necessary for the mass flow to be discharged.

- **Diaphragm safety valve -** A direct loaded safety valve wherein linear moving and rotating elements and springs are protected against the effects of the fluid by a diaphragm.
- **Bellows safety valve -** A direct loaded safety valve wherein sliding and (partially or fully) rotating elements and springs are protected against the effects of the fluids by a bellows. The bellows may be of such a design that it compensates for influences of backpressure.
- **Controlled safety valve -** Consists of a main valve and a control device. It also includes direct acting safety valves with supplementary loading in which, until the set pressure is reached, an additional force increases the closing force.

The British Standard BS 6759 lists the following types of safety valve:

- **Direct loaded -** A safety valve in which the loading due to the fluid pressure underneath the valve disc is opposed only by direct mechanical loading such as a weight, a lever and weight, or a spring.
- **Conventional safety valve -** A safety valve of the direct loaded type, the set pressure of which will be affected by changes in the superimposed backpressure.
- **Assisted safety valve -** A direct loaded safety valve which, by means of a powered assistance mechanism, is lifted at a pressure below the unassisted set pressure and will, even in the event of failure of the assistance mechanism, comply with all the relevant requirements for safety valves.
- **Pilot operated (indirect loaded) safety valve -** The operation is initiated and controlled by the fluid discharged from a pilot valve, which is itself a direct loaded safety valve.
- **Balanced bellows safety valve -** A valve incorporating a bellows which has an effective area equal to that of the valve seat, to eliminate the effect of backpressure on the set pressure of the valve, and which effectively prevents the discharging fluid entering the bonnet space.
- **Balanced bellows safety valve with auxiliary piston -** A balanced bellows valve incorporating an auxiliary piston, having an effective area equal to the valve seat, which becomes effective in the event of bellows failure.
- **Balanced piston safety valve -** A valve incorporating a piston which has an area equal to that of the valve seat, to eliminate the effect of backpressure on the set pressure of the valve.
- **Bellows seal safety valve -** A valve incorporating a bellows, which prevents discharging fluid from entering the bonnet space.

In addition, the BS 759 standard pertaining to safety fittings for application to boilers, defines full lift, high lift and lift safety valves:

- **Lift safety valve (ordinary class) -** The valve member lifts automatically a distance of at least $1/24^{th}$ of the bore of the seating member, with an overpressure not exceeding 10% of the set pressure.
- **High lift safety valve -** Valve member lifts automatically a distance of at least $1/12^{th}$ of the bore of the seating member, with an overpressure not exceeding 10% of the set pressure.
- **Full lift safety valve -** Valve member lifts automatically to give a discharge area between 100% and 80% of the minimum area, at an overpressure not exceeding 5% of the set pressure.

The following table summarises the performance of different types of safety valve set out by the various standards.

Table 9.2.1 Safety valve performance summary

Standard		Fluid	Overpressure	Blowdown
A.D. Merkblatt A2		Steam	Standard 10% full lift 5%	10%
		Air or gas	Standard 10% full lift 5%	10%
		Liquid	10%	20%
ASME	I	Steam	3%	2-6%
	VIII	Steam	10%	7%
		Air or gas	10%	7%
		Liquid	10% **(see Note 3 below)**	
BS 6759	part 1	Steam	Standard 10% full lift 5%	10%
	part 2	Air or gas	10%	10%
	part 3	Liquid	10 – 25%	2.5 - 20%

Notes:

1. ASME blowdown values shown are for valves with adjustable blowdown.

2. BS 6759 blowdown values shown are for valves with non-adjustable blowdown.

3. 25% is often used for non-certified sizing calculations and 20% can be used for fire protection of storage vessels.

Conventional safety valves

The common characteristic shared between the definitions of conventional safety valves in the different standards, is that their operational characteristics are affected by any backpressure in the discharge system. It is important to note that the total backpressure is generated from two components; superimposed backpressure and the built-up backpressure:

- **Superimposed backpressure -** The static pressure that exists on the outlet side of a closed valve.
- **Built-up backpressure -** The additional pressure generated on the outlet side when the valve is discharging.

Subsequently, in a conventional safety valve, only the superimposed backpressure will affect the opening characteristic and set value, but the combined backpressure will alter the blowdown characteristic and re-seat value.

The ASME/ANSI standard makes the further classification that conventional valves have a spring housing that is vented to the discharge side of the valve. If the spring housing is vented to the atmosphere, any superimposed backpressure will still affect the operational characteristics. This can be seen from Figure 9.2.1, which shows schematic diagrams of valves whose spring housings are vented to the discharge side of the valve and to the atmosphere.

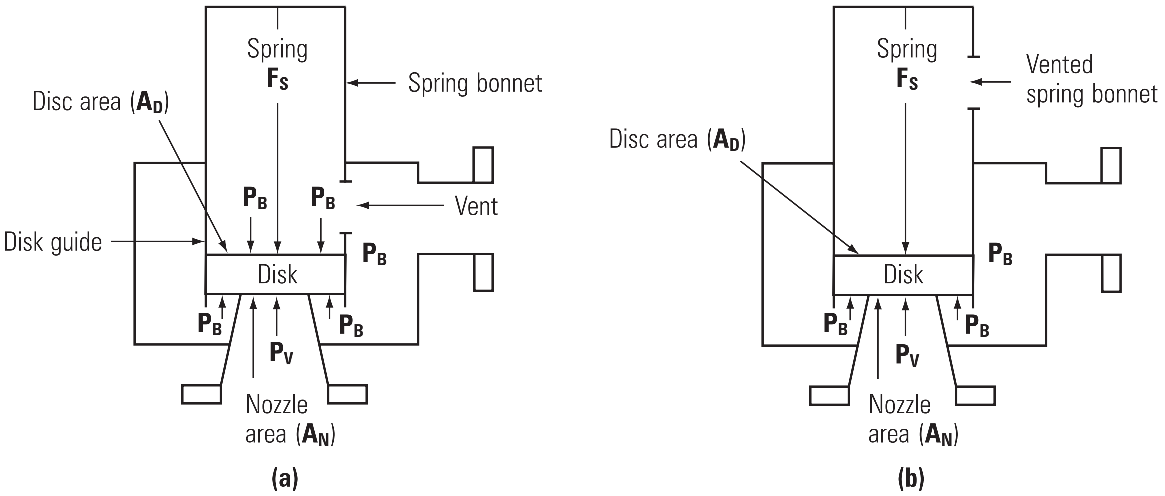


Fig. 9.2.1 Schematic diagram of safety valves with bonnets vented to (a) the valve discharge and (b) the atmosphere

By considering the forces acting on the disc (with area A_D), it can be seen that the required opening force (equivalent to the product of inlet pressure (P_V) and the nozzle area (A_N)) is the sum of the spring force (F_S) and the force due to the backpressure (P_B) acting on the top and bottom of the disc. In the case of a spring housing vented to the discharge side of the valve (an ASME conventional safety relief valve, see Figure 9.2.1 (a)), the required opening force is:

$P_VA_N = F_S + P_BA_D - P_B(A_D - A_N)$ which simplies to Equation 9.2.1

$$P_VA_N = F_S + P_BA_N \qquad \textbf{Equation 9.2.1}$$

Where:
P_V = Fluid inlet pressure
A_N = Nozzle area
F_S = Spring force
P_B = Backpressure
A_D = Disc area

Therefore, any superimposed backpressure will tend to increase the closing force and the inlet pressure required to lift the disc is greater.

In the case of a valve whose spring housing is vented to the atmosphere (Figure 9.2.1b), the required opening force is:

$$P_VA_N = F_S - P_B(A_D - A_N) \qquad \textbf{Equation 9.2.2}$$

Where:
P_V = Fluid inlet pressure
A_N = Nozzle area
F_S = Spring force
P_B = Backpressure
A_D = Disc area

Thus, the superimposed backpressure acts with the vessel pressure to overcome the spring force, and the opening pressure will be less than expected.

In both cases, if a significant superimposed backpressure exists, its effects on the set pressure need to be considered when designing a safety valve system.

Once the valve starts to open, the effects of built-up backpressure also have to be taken into account. For a conventional safety valve with the spring housing vented to the discharge side of the valve, see Figure 9.2.1 (a), the effect of built-up backpressure can be determined by considering Equation 9.2.1 and by noting that once the valve starts to open, the inlet pressure is the sum of the set pressure, P_S, and the overpressure, P_O.

$(P_S + P_O)A_N = F_S + P_BA_N$ which simplies to Equation 9.2.3

$$P_SA_N = F_S + A_N(P_B - P_O) \qquad \textbf{Equation 9.2.3}$$

Where:
P_S = Set pressure of safety valves
A_N = Nozzle area
F_S = Spring force
P_B = Backpressure
P_O = Overpressure

Therefore, if the backpressure is greater than the overpressure, the valve will tend to close, reducing the flow. This can lead to instability within the system and can result in flutter or chatter of the valve.

In general, if conventional safety valves are used in applications, where there is an excessive built-up backpressure, they will not perform as expected. According to the API 520 Recommended Practice Guidelines:

- A conventional pressure relief valve should typically not be used when the built-up backpressure is greater than 10% of the set pressure at 10% overpressure. A higher maximum allowable built-up backpressure may be used for overpressure greater than 10%.

The British Standard BS 6759, however, states that the built-up backpressure should be limited to 12% of the set pressure when the valve is discharging at the certified capacity.

For the majority of steam applications, the backpressure can be maintained within these limits by carefully sizing any discharge pipes. This will be discussed in Module 9.4. If, however, it is not feasible to reduce the backpressure, then it may be necessary to use a balanced safety valve.

Balanced safety valves

Balanced safety valves are those that incorporate a means of eliminating the effects of backpressure. There are two basic designs that can be used to achieve this:

- **Piston type balanced safety valve.**
  Although there are several variations of the piston valve, they generally consist of a piston type disc whose movement is constrained by a vented guide. The area of the top face of the piston, A_P, and the nozzle seat area, A_N, are designed to be equal. This means that the effective area of both the top and bottom surfaces of the disc exposed to the backpressure are equal, and therefore any additional forces are balanced. In addition, the spring bonnet is vented such that the top face of the piston is subjected to atmospheric pressure, as shown in Figure 9.2.2.

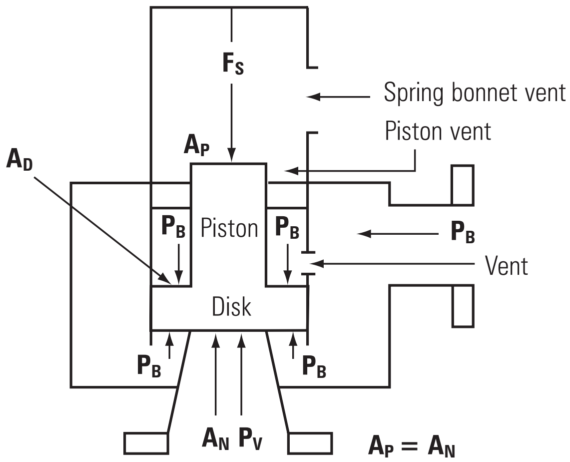


Fig. 9.2.2 Schematic diagram of a piston type balanced safety valve

By considering the forces acting on the piston, it is evident that this type of valve is no longer affected by any backpressure:

$$P_V A_N = F_S + P_B (A_D - A_P) - P_B (A_D - A_N)$$

Where:
P_V = Fluid inlet pressure
A_N = Nozzle area
F_S = Spring force
P_B = Backpressure
A_D = Disc area
A_P = Piston area

Since A_P equals A_N, the last two terms of the equation are equal in magnitude and cancel out of the equation. Therefore, this simplifies to Equation 9.2.4.

$$P_V A_N = F_S$$ **Equation 9.2.4**

Where:
P_V = Fluid inlet pressure
A_N = Nozzle area
F_S = Spring force

- **Bellows type balanced safety valve.**
  A bellows with an effective area (A_B) equivalent to the nozzle seat area (A_N) is attached to the upper surface of the disc and to the spindle guide.

  The bellows arrangement prevents backpressure acting on the upper side of the disc within the area of the bellows. The disc area extending beyond the bellows and the opposing disc area are equal, and so the forces acting on the disc are balanced, and the backpressure has little effect on the valve opening pressure.

  The bellows vent allows air to flow freely in and out of the bellows as they expand or contract. Bellows failure is an important concern when using a bellows balanced safety valve, as this may affect the set pressure and capacity of the valve. It is important, therefore, that there is some mechanism for detecting any uncharacteristic fluid flow through the bellows vents. In addition, some bellows balanced safety valves include an auxiliary piston that is used to overcome the effects of backpressure in the case of bellows failure. This type of safety valve is usually only used on critical applications in the oil and petrochemical industries.

  In addition to reducing the effects of backpressure, the bellows also serve to isolate the spindle guide and the spring from the process fluid, this is important when the fluid is corrosive.

  Since balanced pressure relief valves are typically more expensive than their unbalanced counterparts, they are commonly only used where high pressure manifolds are unavoidable, or in critical applications where a very precise set pressure or blowdown is required.

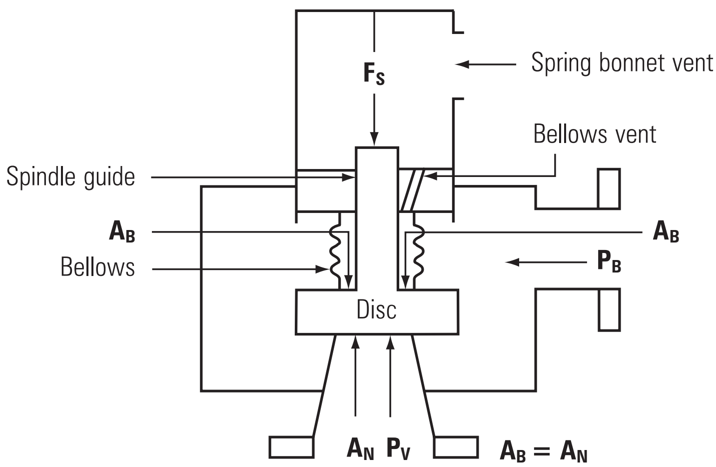


Fig. 9.2.3 Schematic diagram of the bellows balanced safety valve

Pilot operated safety valve

This type of safety valve uses the flowing medium itself, through a pilot valve, to apply the closing force on the safety valve disc. The pilot valve is itself a small safety valve.

There are two basic types of pilot operated safety valve, namely, the diaphragm and piston type.

The diaphragm type is typically only available for low pressure applications and it produces a proportional type action, characteristic of relief valves used in liquid systems. They are therefore of little use in steam systems, consequently, they will not be considered in this text.

The piston type valve consists of a main valve, which uses a piston shaped closing device (or obturator), and an external pilot valve. Figure 9.2.4 shows a diagram of a typical piston type, pilot operated safety valve.

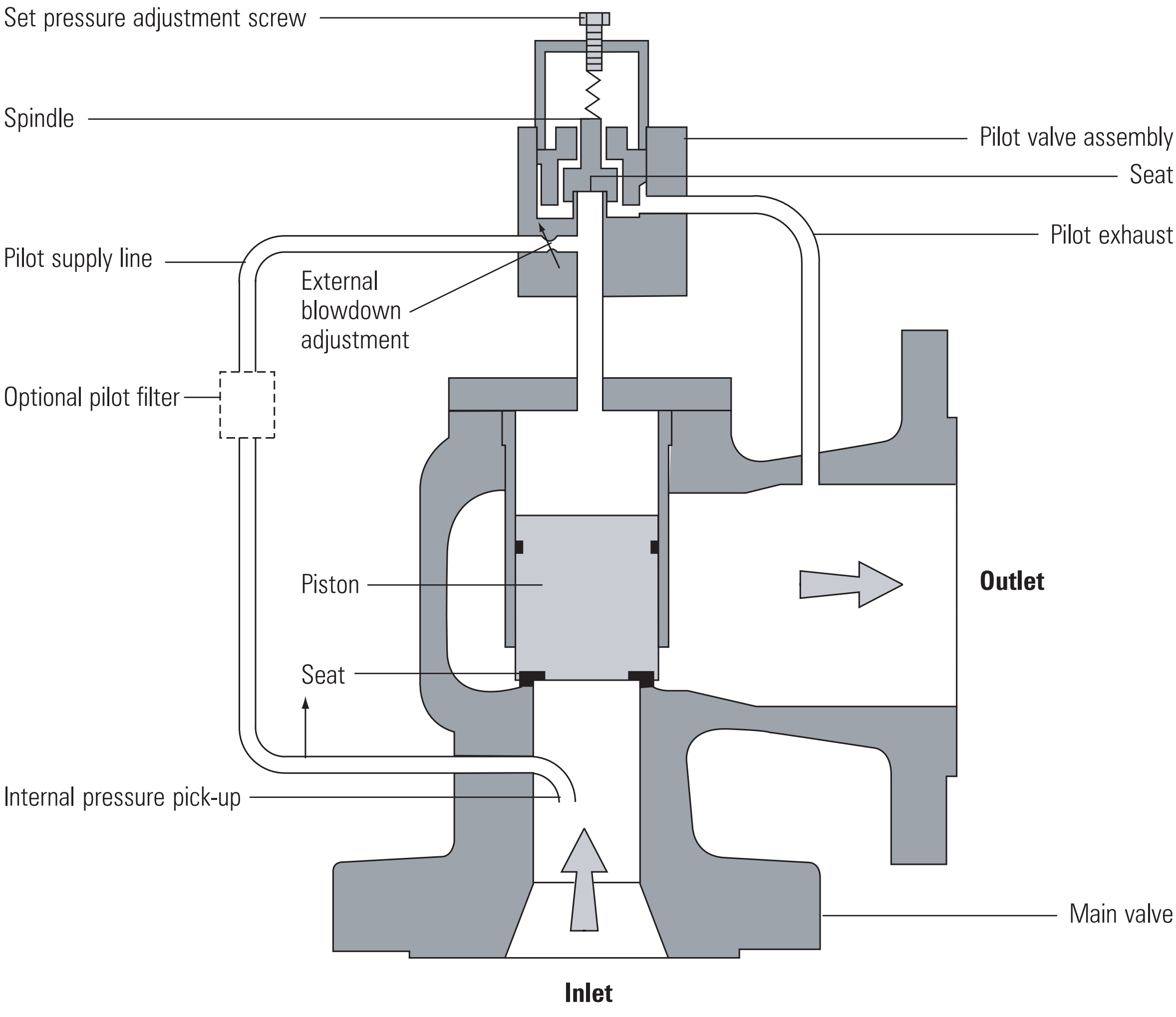


Fig. 9.2.4 A piston type, pilot operated safety valve

The piston and seating arrangement incorporated in the main valve is designed so that the bottom area of the piston, exposed to the inlet fluid, is less than the area of the top of the piston. As both ends of the piston are exposed to the fluid at the same pressure, this means that under normal system operating conditions, the closing force, resulting from the larger top area, is greater than the inlet force. The resultant downward force therefore holds the piston firmly on its seat.

If the inlet pressure were to rise, the net closing force on the piston also increases, ensuring that a tight shut-off is continually maintained. However, when the inlet pressure reaches the set pressure, the pilot valve will pop open to release the fluid pressure above the piston. With much less fluid pressure acting on the upper surface of the piston, the inlet pressure generates a net upwards force and the piston will leave its seat. This causes the main valve to pop open, allowing the process fluid to be discharged.

When the inlet pressure has been sufficiently reduced, the pilot valve will reclose, preventing the further release of fluid from the top of the piston, thereby re-establishing the net downward force, and causing the piston to reseat.

Pilot operated safety valves offer good overpressure and blowdown performance (a blowdown of 2% is attainable). For this reason, they are used where a narrow margin is required between the set pressure and the system operating pressure. Pilot operated valves are also available in much larger sizes, making them the preferred type of safety valve for larger capacities.

One of the main concerns with pilot operated safety valves is that the small bore, pilot connecting pipes are susceptible to blockage by foreign matter, or due to the collection of condensate in these pipes. This can lead to the failure of the valve, either in the open or closed position, depending on where the blockage occurs.

The British Standard BS 6759 states that all pilot operated safety valves should have at least two independent pilot devices, which are connected individually and arranged such that failure of either of the pilot will still enable the safety valve to continue to operate effectively.

Full lift, high lift and low lift safety valves

The terms full lift, high lift and low lift refer to the amount of travel the disc undergoes as it moves from its closed position to the position required to produce the certified discharge capacity, and how this affects the discharge capacity of the valve.

A full lift safety valve is one in which the disc lifts sufficiently, so that the curtain area no longer influences the discharge area. The discharge area, and therefore the capacity of the valve are subsequently determined by the bore area. This occurs when the disc lifts a distance of at least a quarter of the bore diameter. A full lift conventional safety valve is often the best choice for general steam applications.

The disc of a high lift safety valve lifts a distance of at least $1/12^{th}$ of the bore diameter. This means that the curtain area, and ultimately the position of the disc, determines the discharge area. The discharge capacities of high lift valves tend to be significantly lower than those of full lift valves, and for a given discharge capacity, it is usually possible to select a full lift valve that has a nominal size several times smaller than a corresponding high lift valve, which usually incurs cost advantages. Furthermore, high lift valves tend to be used on compressible fluids where their action is more proportional.

In low lift valves, the disc only lifts a distance of $1/24^{th}$ of the bore diameter. The discharge area is determined entirely by the position of the disc, and since the disc only lifts a small amount, the capacities tend to be much lower than those of full or high lift valves.

Materials of construction

Except when safety valves are discharging, the only parts that are wetted by the process fluid are the inlet tract (nozzle) and the disc. Since safety valves operate infrequently under normal conditions, all other components can be manufactured from standard materials for most applications. There are however several exceptions, in which case, special materials have to be used, these include:

- Cryogenic applications.
- Corrosive fluids.
- Where contamination of discharged fluid is not permitted.
- When the valve discharges into a manifold that contains corrosive media discharged by another valve.

The principal pressure-containing components of safety valves are normally constructed from one of the following materials:

- **Bronze -** Commonly used for small screwed valves for general duty on steam, air and hot water applications (up to 15 bar).
- **Cast iron -** Used extensively for ASME type valves. Its use is typically limited to 17 bar g.
- **SG iron -** Commonly used in European valves and to replace cast iron in higher pressure valves (up to 25 bar g).
- **Cast steel -** Commonly used on higher pressure valves (up to 40 bar g). Process type valves are usually made from a cast steel body with an austenitic full nozzle type construction.
- **Austenitic stainless steel -** Used in food, pharmaceutical or clean steam applications.

For extremely high pressure applications, pressure containing components may be forged or machined from solid.

For all safety valves, it is important that moving parts, particularly the spindle and guides are made from materials that will not easily degrade or corrode. As seats and discs are constantly in contact with the process fluid, they must be able to resist the effects of erosion and corrosion. For process applications, austenitic stainless steel is commonly used for seats and discs; sometimes they are 'stellite faced' for increased durability. For extremely corrosive fluids, nozzles, discs and seats are made from special alloys such as 'monel' or 'hastelloy'.

The spring is a critical element of the safety valve and must provide reliable performance within the required parameters. BS 6759 lists recommended materials, but most other standards just insist on sensible materials based on sound engineering practice. Standard safety valves will typically use carbon steel for moderate temperatures. Tungsten steel is used for higher temperature, non-corrosive applications, and stainless steel is used for corrosive or clean steam duty. For sour gas and high temperature applications, often special materials such as monel, hastelloy and 'inconel' are used.

Safety valve options and accessories

Due to the wide range of applications in which safety valves are used, there are a number of different options available:

Seating material

A key option is the type of seating material used. Metal-to-metal seats, commonly made from stainless steel, are normally used for high temperature applications such as steam. Alternatively, resilient discs can be fixed to either or both of the seating surfaces where tighter shut-off is required, typically for gas or liquid applications. These inserts can be made from a number of different materials, but Viton, nitrile or EPDM are the most common. Soft seal inserts are not recommended for steam use.

Table 9.2.2 Seating materials used in safety valves

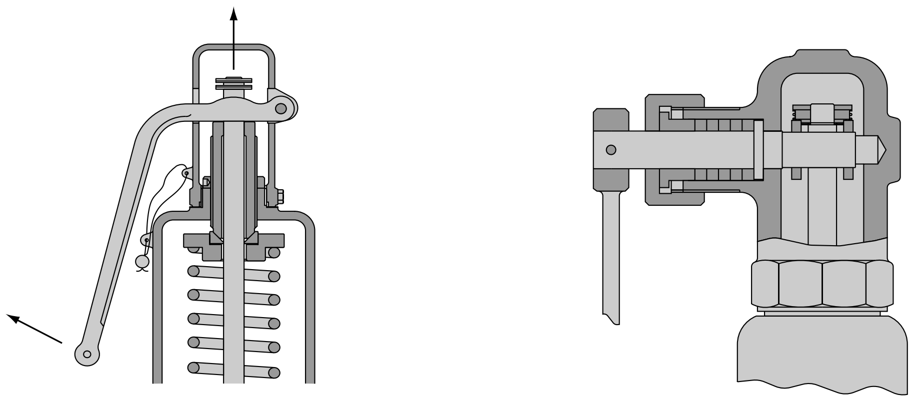
Seal material	Applications
EPDM	Water
Viton	High temperature gas applications
Nitrile	Air and oil applications
Stainless steel	Standard material, best for steam
Stellite	Wear resistant for tough applications

Levers

Standard safety valves are generally fitted with an easing lever, which enables the valve to be lifted manually in order to ensure that it is operational at pressures in excess of 75% of set pressure. This is usually done as part of routine safety checks, or during maintenance to prevent seizing. The fitting of a lever is usually a requirement of national standards and insurance companies for steam and hot water applications. For example, the ASME Boiler and Pressure Vessel Code states that pressure relief valves must be fitted with a lever if they are to be used on air, water over 60°C, and steam.

A standard or open lever is the simplest type of lever available. It is typically used on applications where a small amount of leakage of the fluid to the atmosphere is acceptable, such as on steam and air systems, (see Figure 9.2.5 (a)).

Where it is not acceptable for the media to escape, a packed lever must be used. This uses a packed gland seal to ensure that the fluid is contained within the cap, (see Figure 9.2.5 (b))



(a) Open **(b) Packed**

Fig. 9.2.5 Levers

For service where a lever is not required, a cap can be used to simply protect the adjustment screw. If used in conjunction with a gasket, it can be used to prevent emissions to the atmosphere, (see Figure 9.2.6).

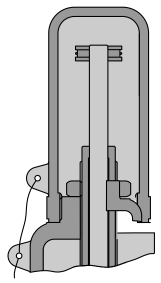


Fig. 9.2.6 A gas tight cap

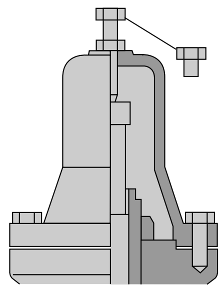


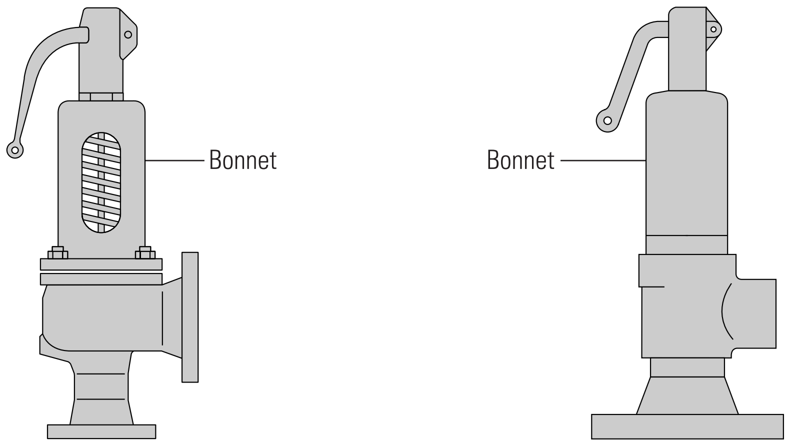
Fig. 9.2.7 A test gag

A test gag (Figure 9.2.7) may be used to prevent the valve from opening at the set pressure during hydraulic testing when commissioning a system. Once tested, the gag screw is removed and replaced with a short blanking plug before the valve is placed in service.

Open and closed bonnets

Unless bellows or diaphragm sealing is used, process fluid will enter the spring housing (or bonnet). The amount of fluid depends on the particular design of safety valve. If emission of this fluid into the atmosphere is acceptable, the spring housing may be vented to the atmosphere – an open bonnet. This is usually advantageous when the safety valve is used on high temperature fluids or for boiler applications as, otherwise, high temperatures can relax the spring, altering the set pressure of the valve. However, using an open bonnet exposes the valve spring and internals to environmental conditions, which can lead to damage and corrosion of the spring.

When the fluid must be completely contained by the safety valve (and the discharge system), it is necessary to use a closed bonnet, which is not vented to the atmosphere. This type of spring enclosure is almost universally used for small screwed valves and, it is becoming increasingly common on many valve ranges since, particularly on steam, discharge of the fluid could be hazardous to personnel.



Open bonnet **Closed bonnet**

Fig. 9.2.8 Spring housings

Bellows and diaphragm sealing

Some safety valves, most commonly those used for water applications, incorporate a flexible diaphragm or bellows to isolate the safety valve spring and upper chamber from the process fluid, (see Figure 9.2.9).

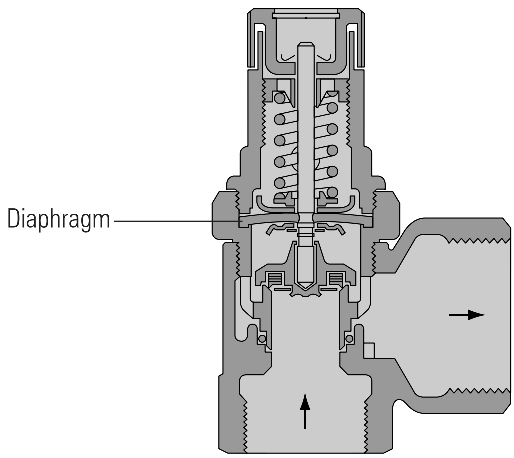


Fig. 9.2.9 A diaphragm sealed safety valve

An elastomer bellows or diaphragm is commonly used in hot water or heating applications, whereas a stainless steel one would be used on process applications employing hazardous fluids.

Questions

1. What is the typical maximum overpressure value for a standard safety valve used on steam applications, according to most national standards?

a| 5% ☐
b| 10% ☐
c| 15% ☐
d| 20% ☐

2. Superimposed backpressure affects which operational characteristic of a safety valve?

a| Blowdown ☐
b| Discharge capacity ☐
c| Set value ☐
d| All of the above ☐

3. Which type of conventional safety valve is most suitable for steam applications on the basis of its relationship between cost and discharge capacity?

a| Full lift ☐
b| High lift ☐
c| Low lift ☐
d| Full bore ☐

4. Which of the following statements about pilot operated safety valves are true?

i. Small margins of overpressure and blowdown are achievable

ii. The closing force increases as the inlet pressure increases, ensuring a tight shut-off

iii. Pilot operated valves can fail in the open or closed position due to the build up of condensate in the pilot connecting pipes

a| i only ☐
b| iii only ☐
c| i and ii ☐
d| i, ii and iii ☐

5. Which material would be most suitable for safety valves used on high pressure steam applications up to 25 bar?

a| Austenitic stainless steel ☐
b| SG iron ☐
c| Cast carbon steel ☐
d| Bronze ☐

6. Which of the following bonnet arrangements would be required on a system where it is important that none of the steam escapes?

a| Open bonnet and packed lever ☐
b| Closed bonnet and open lever ☐
c| Closed bonnet and packed lever ☐
d| Gas tight cap ☐

Answers

1:b, 2:c, 3:a, 4:d, 5:b, 6:c