1

Basic Safety Valves Principles

1.1 Introduction and History

In the oil and gas industry, various service fluids are used, including hydrocarbons that are flammable, toxic, and corrosive. The pressure of fluids in pressurized systems such as pressure vessels and piping can be increased by various factors, including human error, equipment failure, or component failure, such as damage to control valves. In pressurized systems, safety valves are required to handle and release the overpressure fluid. Safety valves reduce excess pressure by releasing fluid from within the plant when a predetermined maximum pressure is reached.

In the earliest days of mankind, when water was boiled to create steam, the necessity of a safety device became apparent. The safety valve was thought to have been invented by the Frenchman Papin, who applied it in 1682 for a steam digester. In 1679, a French physicist Denis Papin invented a high-pressure cooker known as the steam digester or bone digester (also known as Papin's digester). It is a device for extracting fats from bones in a high-pressure steam environment. A lever and a movable weight were used to keep the safety valve closed; by sliding the weight along the lever as illustrated in Figure 1.1, Papin was able to maintain the valve's position and regulate the steam pressure. It has now been discovered that Papin was only the inventor of the improvements just mentioned and that the German Glauber had already been utilizing safety valves some fifty years earlier. The valve opened once the pressure from the steam pressure acting on the valve exceeded the pressure from the weight acting on the lever arm. For designs that require a greater relief pressure setting, an extended lever arm and/or heavier weights are required. Although this simple system worked, additional space was required. There was also the disadvantage of unintended opening of the valve when the device was subjected to the bouncing

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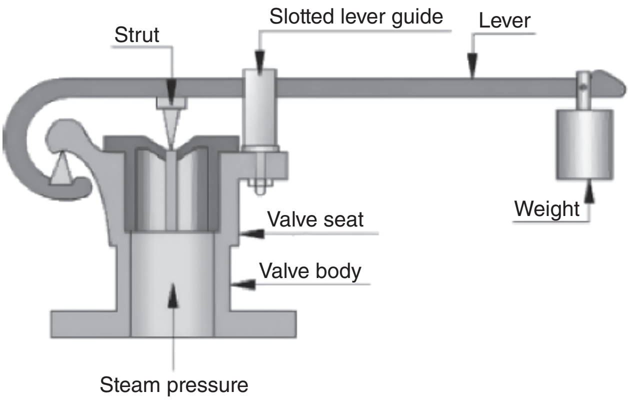

Figure 1.1 The old-style safety valve was operated by sliding a weight along the lever (Courtesy: Shutterstock).

movements of the weight. In the early 19th century, boiler explosions on ships and locomotives often resulted from defective safety devices, which led to the development of the first safety relief valves for industrial use. Between 1905 and 1911, there were 1700 boiler explosions in the United States, resulting in 1300 deaths.

1.2 Maximum Allowable Working Pressure (MAWP)

There is a requirement to install safety valves on piping and equipment (e.g. pressure vessels) where it is expected that their working pressure will exceed the MAWP. An MAWP is a designation established by the American Society of Mechanical Engineers (ASME) for pressure-relief components in vessels. At specific operating temperatures, it determines the maximum amount of pressure that can be applied to the weakest part of the vessel. In addition to the establishment of safety protocols, industrial facilities use the MAWP to prevent explosions by ensuring the system does not exceed a safe operating pressure. The maximum operating pressure (MAWP) of a vessel refers to the maximum level of pressure the vessel may be exposed to, whereas the design pressure refers to the maximum level of pressure it should be exposed to during normal operation. It is generally accepted that the design pressure of a pressurized system is lower than or equal to the maximum acceptable working pressure of the system's vessel. The MAWP is calculated based on the physical limitations of the weakest part of the vessel, whereas the design pressure of a system is determined by the type of pressure system used. The MAWP also differs from the design pressure since the former characteristic changes over the course of the vessel's lifetime. A vessel's MAWP is gradually lowered as a result of wear, use, and corrosion of carbon steel elements.

It was explained that MAWP focuses on the weakest part of the pressure vessel. Using this example, we can identify the weakest part of a vertical pressure vessel. It is assumed that the weakest part of this vessel is located on its body, rather than on the top or bottom dishes. The thickness of the vertical pressure vessel is not constant. Typically, the lower parts of a pressure vessel are thicker than the upper parts. This is due to the fact that the lower parts of the pressure vessel are in direct contact with a larger column of fluid. In spite of this, the upper part of the vessel may have the lowest thickness due to the absence of head pressure. Accordingly, the top of the vessel is the weakest part with the lowest thickness that must be considered when determining MAWP.

The maximum allowable accumulated pressure (MAAP) is specified for vessels protected by pressure relief devices. It is the maximum allowable pressure during discharge from the relieving device. When all relief devices are fully closed, accumulation pressure refers to the maximum pressure that can build within a vessel. In most cases, this pressure is expressed as a percentage of the MAWP. The governing case for opening the relief valve protecting the vessel determines this percentage. A vessel protected against fire has an MAAP of 121% of the MAWP. In other words, the pressure inside the vessel is allowed to rise to 121% of its MAWP before the relief valve opens in order to release the pressure.

1.3 The Importance of Safety Valves and Safety Devices

A safety valve is primarily designed to protect life, property, and the environment. The purpose of a safety valve is to open and relieve excess pressure from vessels or equipment and to prevent further fluid release once normal conditions have been restored. Safety valves are a part of safety systems, which include safety devices such as safety valves, as well as associated piping systems and process equipment used to handle fluids released under excessive pressure. It is important to understand that safety valves are safety devices and are often the last line of defense. The safety valve must be capable of operating at all times and under all conditions so it should be completely reliable. A safety valve should not be misunderstood as a process valve or pressure regulator. Overpressure protection should be its sole purpose.

It is unavoidable to use pressure relief devices in a number of industrial processes. There are safety valves installed on boilers and reactors, pipes and pipelines, pumps and compressors as well as cooling and heating circuits. In safety systems, safety valves are not the only component. Generally, rupture disks as non-reclosing or one-time used safety devices consisting a thin metallic diaphragm are used to protect pressure vessels, equipment, and systems from over pressurization. They are also called pressure safety disks, burst disks, or bursting disks. When the inlet pressure reaches the rupture disk set pressure, the disk bursts. Due to the fact that it is a one-time-use device, it will need to be replaced after it bursts. Rupture disks are either installed directly between flanges or inserted into a corresponding rupture disk holder, which is then mounted between flanges (see Figure 1.2). Typically, rupture disks are designed to relieve pressure at 1.5 times the vessel's MAWP. In addition to being simple and requiring no moving parts, rupture disks are also inexpensive and leak-tight. In spite of this, it is not possible to test them, as they degrade with age and corrosion, and in order to reinstall them, the process area must be shut down. There is the possibility of using a rupture disk in place of a safety valve or of using a rupture disk in conjunction (parallel or series) with a safety valve. If the fluid relief must occur rapidly or if the fluid could disturb the proper functioning of the valve, a rupture disk can be preferred over a safety valve as the primary relief method. For instance, some fluids can freeze during pressure drops and block the safety valve or connected inlet and outlet lines. In comparison with the safety valve, the rupture disk has a higher response pressure. In combination with the safety valve, a rupture disk could be installed upstream of the valve in order to prevent valve plugging, corrosion, leakage,

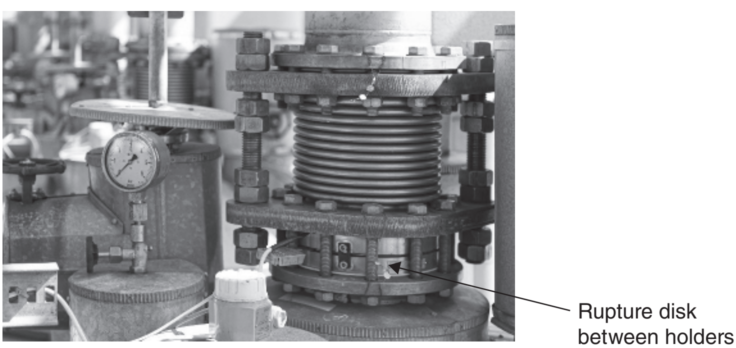

Figure 1.2 Rupture disk between holders and flanges (Credit: Faiz/Adobe Stock).

and wear caused by pressure fluctuations and frequent opening and closing of the valve. Therefore, the lifecycle of safety valves can be extended, and the need for maintenance on the safety valves can be reduced. Whenever the pressure rises significantly and rapidly, the rupture disk serves as a reliable backup system for relieving the pressure if the safety valve cannot respond quickly or fails to open. It should be noted that the reasons mentioned above that rupture disks can be installed in place of safety valves are also true when rupture disks are installed in parallel with safety valves.

1.4 Overpressure Scenarios and Examples in the Plant

There is a detailed discussion of the potential for overpressure in American Petroleum Institute (API) 521 and International Organization for Standardization (ISO) 23251. It is important to note that the pressure vessels, heat exchangers, operating equipment, and piping are designed to contain the system pressure. In designing the system, the following factors are taken into account: (a) the normal operating pressure at operating temperatures, (b) the effects of any combination of process upsets that may occur, (c) the differential between the operating and set pressures of the pressure-relieving device, and (d) the effect of earthquakes and winds as supplemental loadings.

1.4.1 Closed Outlet of a Vessel

In the event that a manual block valve on the outlet of a pressure vessel is accidentally closed while the equipment is operational, the vessel may be exposed to a pressure greater than the MAWP. In the event of an outlet-block valve being closed, there may be an overpressure, which requires the use of a pressure-relief device most likely. Every valve has the potential to be operated by mistake. Case Study 1.1 illustrates a pressure vessel with a closed outlet due to a closed control valve in the outlet line. It is important to note that closed outlets are not solely the result of the outlet valve being operated by mistake. Various factors can contribute to blocked outlets, including failure of the control valve, mistaken operation of the valve, and failure of the instrument air or power supply. There are, however, other ways of closing outlets in a system in addition to block and control valves. Blocked outlets can be caused by frozen lines, plugged filters on the outlet line, and stuck or misinstalled check valves.

1.4.2 Unintentional Valve Opening

The possibility of an accidental opening of any valve from a source of higher pressure (e.g. the valve located on the inlet line to equipment handling high-pressure steam or process fluids) should be considered. Pressure-relieving capacity may be required for this condition. A process flow diagram in Case Study 1.2 illustrates how an open control valve can result in an overpressure situation in a pressure vessel.

1.4.3 Check Valve Leakage or Failure

In a check valve, fluid flows in one direction and is automatically prevented from flowing backward when the fluid reverses direction. It is common to use a check valve arrangement when sending fluid from a lower-pressure system to a higher-pressure system in order to prevent reverse flow. The use of a single check valve is not always an effective method of preventing overpressure due to reverse flow from a high-pressure source. Therefore, in some cases, the present author proposes to install two check valves in series to increase the safety and reliability of the pressure equipment and piping system in the event of check valve failure. If there is only one check valve installed and it fails to function, high-pressure fluid will flow to the piping, pump, and pressure vessel that are installed upstream of the check valve. This can lead to serious overpressure scenarios in the facilities located upstream of the check valve. A single check valve may be adequate if the backflow high-pressure fluid applies pressure to the upstream pressure vessel which is less than the vessel's test pressure. In most cases, however, the focus should be on preventing reverse flow. Additionally, reverse flow through equipment such as pumps and compressors can result in the destruction of mechanical equipment in addition to overpressure in the upstream system. An additional means of backflow prevention (double check valves in series) should be provided if this hazard is of concern. See Case Study 1.5 for more information.

1.4.4 Utility Failure

It is possible for overpressure in related equipment to result from the failure of utilities such as electricity, instrument air, steam, fuel, and cooling water. It is important to consider the possibility of utility failure when analyzing the possibility of overpressure in equipment. For example, the failure of electricity (for the fans of air coolers or circulation pumps for cooling water) or cooling water may lead to the failure of heat exchangers to perform as expected. Consequently, the temperature of the process can rise, resulting in overpressure in the equipment that is protected. In process vessels, overpressure can result from the failure of electrical or mechanical equipment that provides cooling or condensation. In the event of a loss of instrument air, all air-operated valves are driven into their specified fail position resulting in an overpressure scenario in the vessel. The steam can be used to drive turbines, which, in turn, drive pumps, compressors, blowers, and fans. The partially available utility can be considered to evaluate possible overpressure in protected equipment in case one source of utility fails, but another independent source is still available simultaneously to carry the complete or part of the extra load caused by partial utility failure. Therefore, independent utility alternatives can lower the risk of possible overpressure, and they should be considered during the design process.

1.4.5 Heat Exchanger Tube Failure

The tubes in shell-and-tube heat exchangers are susceptible to failure due to various factors, including thermal shock, vibration, and corrosion. Whatever the cause, the high-pressure stream may overpressure equipment on the low-pressure side of the exchanger. A determination should be made as to whether the low-pressure system is capable of absorbing this release. It is necessary to determine the possible pressure rise in order to determine whether additional pressure relief is required if the flow from the ruptured tube discharges into the lower-pressure stream or shell side. Case Study 1.4 provides further information regarding heat exchanger tube failure.

1.4.6 Transient Pressure Surges

Water Hammer

A liquid-filled system should be carefully evaluated for the possibility of hydraulic shock waves, known as water hammer. As a result of very rapid closure of valves, such as check valves, water hammer can occur in liquid services. A water hammer is a type of overpressure that cannot be controlled by typical pressure-relief valves, as their response times are often too slow. In milliseconds, changing peak pressures can raise the normal operating pressure by a significant amount. In the absence of proper safeguards, these pressure waves may damage pressure vessels and piping. In long pipelines, water hammer is often prevented by limiting the speed at which valves can be closed. A pulsation dampener could be considered in cases where water hammer occurs.

Steam Hammer

There is a possibility that a peak-pressure surge, called steam hammer, may occur in piping that contains compressible fluids. Rapid valve closure is generally the cause of the most common occurrence. As this oscillating pressure surge occurs in milliseconds, the normal operating pressure may rise by many times, causing vibration and violent movement of piping and possibly resulting in equipment rupture. Due to their slow response time, pressure-relief valves cannot be effectively used as protective devices. Steam hammer can be prevented by avoiding the use of quick-closing valves.

Fire

Equipment exposed to plant fire has a risk of overpressure in case of fire, resulting from fluid expansion or vaporization as per Case Study 1.3.

1.4.7 Process Change/Chemical Reaction

A significant change in operating process parameters such as the temperature increase may make equipment susceptible to damage. When reacting systems shift equilibrium, excess gas or excess heat can result, causing overpressure. For the design of relief valves, these possibilities must be carefully examined.

1.4.8 Summary and Case Studies

The purpose of this paragraph is to summarize some of the main causes of overpressure scenarios in pressurized systems. High pressure can damage piping and equipment for various reasons, including failure of the cooling system, which causes liquid or gas to be heated and pressurized. Excessive fluids are flowing through the piping and equipment as a result of control system failure, disconnection of electricity or compressed air, fire in the plant, failure of the heat exchanger tube, chemical reaction, blocked discharge, or ambient temperature increase. There is a possibility that each of the events listed above may occur individually and separately from one another. It is also possible for them to occur simultaneously.

Case Study 1.1

According to Figure 1.3, there is a control valve located on the outlet line of a pressure vessel, which is used to adjust the level of fluid within the vessel. Pneumatic air is used to operate (open and close) the control valve. Assume that the pneumatic air supply system has failed, resulting in the control valve remaining closed. Consequently, the fluid cannot be discharged from the outlet line of the pressure vessel, and its accumulation inside the vessel increases the vessel's pressure above MAWP. To release the excess pressure, the pressure relief valve (PRV) on the top of the vessel must be opened. Moreover, another overpressure scenario or pressure build-up in the vessel which leads to the operation of PRV is blockage of the vessel discharge, which is also the case here as the control valve remains in the closed position and blocks vessel discharge.

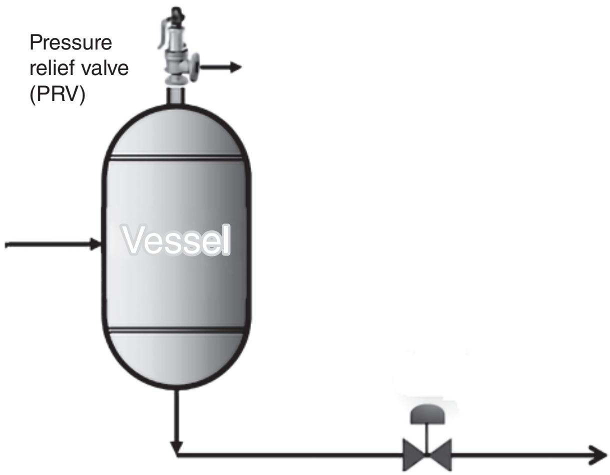

Figure 1.3 The failure of the pneumatic supply system to the control valve results in a scenario of overpressure within the vessel and the operation of the PRV.

Case Study 1.2

Two vertical pressure vessels are shown in Figure 1.4. A liquid is exiting the first vessel on the left and entering the second vessel after passing through the control valve. Assume that the second pressure vessel is full of liquid and is under pressure. When this occurs, the control valve must be closed in order to prevent liquid from flowing to the second vessel on the right. The pressure in the second pressure vessel will rise above

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Case Study 1.2 (Continued)

the MAWP if the control valve is left open, so the pressure safety valve (PSV) must release the overpressure liquid.

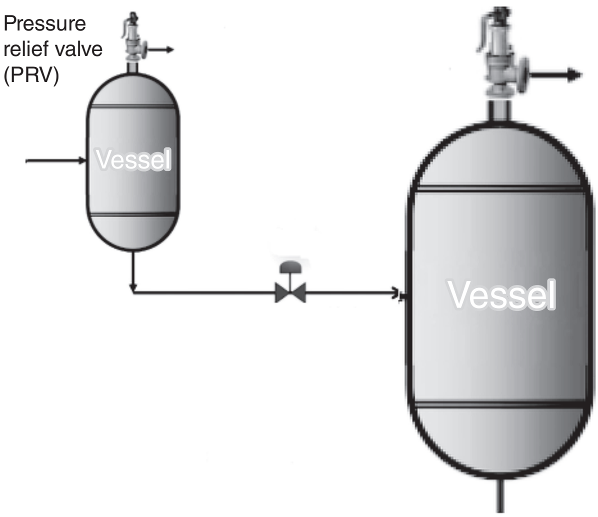

Figure 1.4 There is an overpressure situation in the second vessel on the right as a result of the upstream control valve remaining open.

Case Study 1.3

Figure 1.5 illustrates a fire case near a pressure vessel that resulted in an overpressure scenario and catastrophic rupture of the vessel. A PRV will discharge the excess pressure in such a situation.

Case Study 1.4

As shown in Figure 1.6, a tube rupture may occur as a result of corrosion, fatigue, or brittle fraction in a heat exchanger. In the event of a rupture of the tube, the fluid inside the tube enters the shell side, which increases the shell side pressure, requiring the use of a PSV to release the excess pressure.

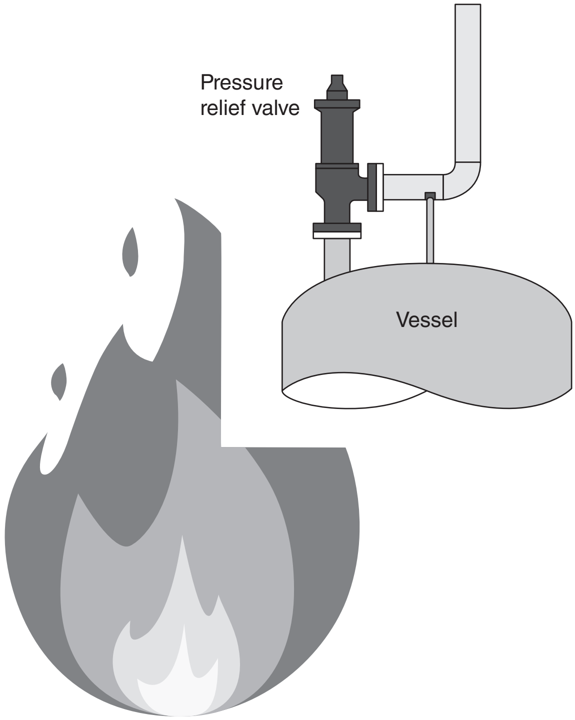

Figure 1.5 An incident involving a fire near a pressure vessel and the operation of the PRV.

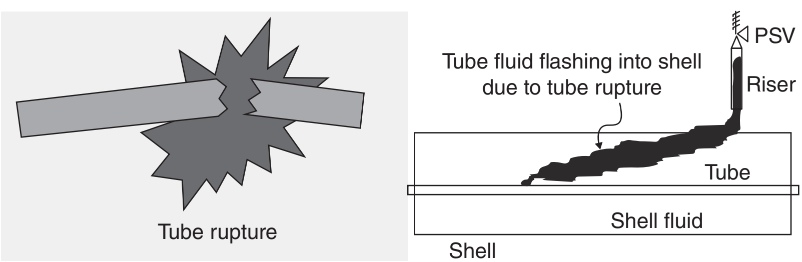

Figure 1.6 A ruptured tube in a heat exchanger causes shell-side overpressure and causes the PSV to operate.

Case Study 1.5
As shown in Figure 1.7, an increase in ambient temperature can result in an increase in temperature within the vessel. The vessel contains gas whose pressure increases with increasing temperature. Due to the

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Case Study 1.5 (Continued)

pressure increase exceeding MAWP, the PRV at the top of the vessel releases the excess pressure.

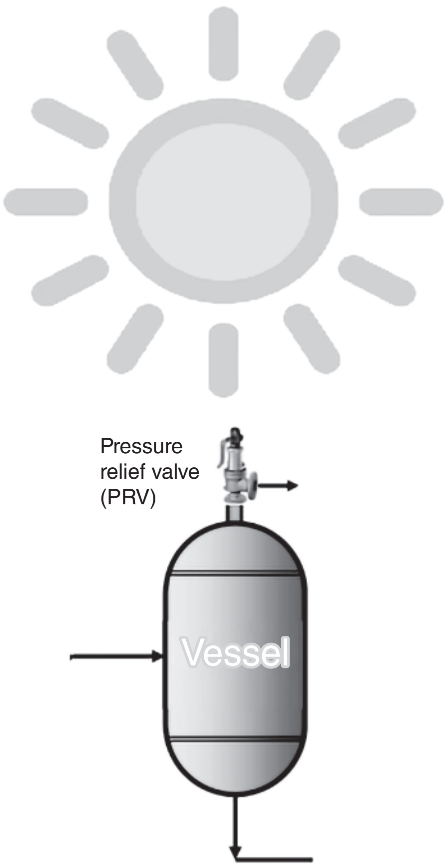

Figure 1.7 Increase in pressure in the vessel as a result of an increase in ambient temperature.

Case Study 1.6

According to Figure 1.8, a pressure vessel with tag number V-01 is used to separate liquids from gases. Liquid from the bottom of the vessel is pumped forward. The system is equipped with two pumps. The top pump is the main pump and the bottom pump is a bypass used in the event that the upper pump requires maintenance. Immediately after the pump there is a check valve with a red circle around it that prevents backflow from downstream to upstream. If the check valve fails, fluid enters the pump from the discharge side to the suction side. As a result of this reverse flow, the pump may be damaged and its performance may be compromised. The high-pressure fluid can enter the V-01 pressure vessel and increase the vessel's pressure above MAWP. As a consequence, a PSV needs to be installed on V-01 in order to release the overpressure in this case as well as in other potential overpressure scenarios.

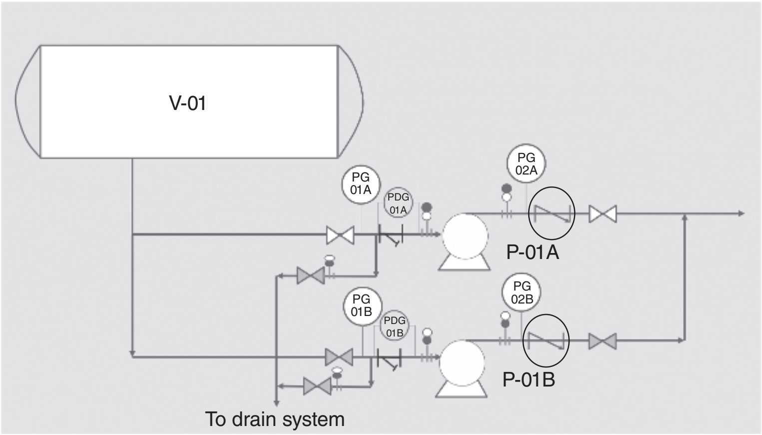

Figure 1.8 Check valve arrangements installed after pumps.

1.5 Variations in Safety/Relief Valves

In general, "safety valves" and "safety relief valves" refer to various pressure relief devices designed to prevent excessive accumulation of internal fluid pressure. A wide range of safety relief valves are available for various applications and performance requirements. The use of safety valves is governed by various national standards, which require different designs to meet those standards. Furthermore, the terms "safety" and "relief" are frequently used interchangeably, but this is not appropriate. Safety valves are used to control the flow of compressible fluids, such as steam and other gases. As a result of this compressibility, overpressure must be relieved quickly. The gas or steam may be discharged into the atmosphere or directed back into the piping system. Fluids that are not compressible, such as water and oil, require relief valves. The immediate discharge of full flow is not required since a very small flow significantly reduces the risk of overpressure.

The terms associated with safety and safety relief valves are defined in most national standards. The terminology used in the United States and Europe differs significantly. There are several important differences between Europe and the United States, including the fact that a valve referred to as a “safety valve” in Europe is referred to as a “safety relief valve” or a “pressure relief valve” in the United States. The ASME PTC25 standard addressing pressure relief devices defines the following generic terms:

Pressure relief valve (PRV): As a pressure relief device, it opens to relieve excess pressure and then closes and prevents the flow of fluid after normal conditions are restored. Its opening is generally characterized by a rapid opening action or by an opening that is proportional to the increase in pressure above the opening pressure. The device may be used for either compressible or incompressible fluids, depending on the design, adjustment, or application. As a general term, this term includes safety valves, relief valves, and safety relief valves as well. There are several types of PRVs listed in ASME PT25, which are explained as follows:

Low-lift PRV: PRVs in which the actual discharge area is the curtain area determined by the position of the disk (see Figure 1.9). During its relief cycle, it often remains relatively unstable since it will not necessarily lift fully open to its capacity and will act more or less proportionately to the pressure increase. Noncompressible fluids are typically handled by low-lift PRVs.

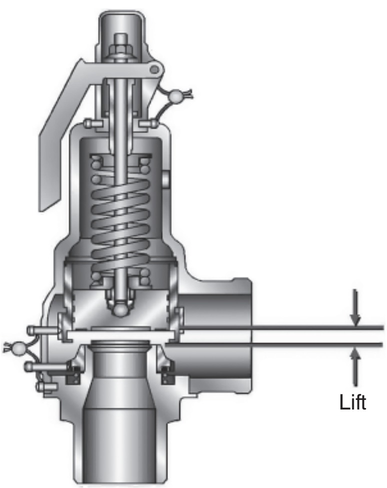

Figure 1.9 Low-lift PRV.

Figure 1.10 Full-lift PRV.

Full-lift PRV: This type of PRV has a bore area that serves as the discharge area. In a full-lift PRV, the disk lifts sufficiently so that the curtain area determined by the position of the disk no longer affects the discharge area. The bore area determines the discharge area, and therefore the valve's capacity. Compressible fluids such as steam can be handled by full-lift PRVs. Figure 1.10 illustrates a full-lift PRV in which the disk is fully lifted and the liquid in the discharge line is enclosed in the bore of the discharge pipe, covering the entire internal area of the pipe.

Reduced bore PRV: This type of PRV is characterized by a flow path below the seat that is smaller than the flow path at the inlet to the valve, which creates a venturi effect (see Figure 1.11).

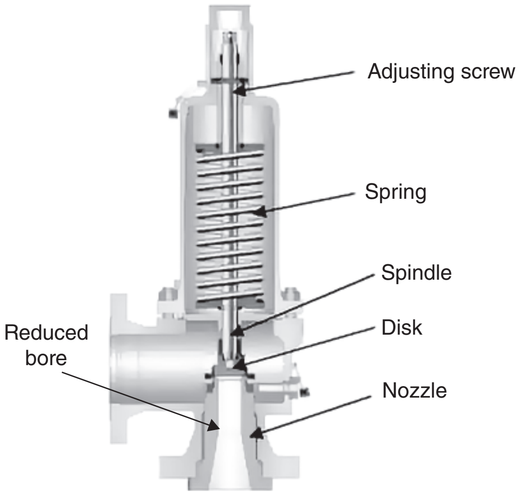

Figure 1.11 Reduced bore PRV.

Full bore PRV: The bore area of a PRV is equal to the flow area at the inlet, and there are no obstructions in the bore area between the inlet and flow areas.

Direct spring-loaded PRV: A PRV in which the disk is held closed by a spring.

Pilot-operated PRV: Normally, conventional PRVs are held closed by a spring or similar mechanism that presses a disk or piston against the seat, which is forced open when the pressure exceeds the mechanical value of the spring. Pilot-operated pressure relief valves (POPRVs) are PRVs in which the principal relieving device is controlled by an auxiliary PRV that is self-actuated.

Using a POPRV, a small amount of fluid is piped to the rear of the sealing disk in order to keep the valve shut. POPRVs consist of a pilot valve (or control pilot), a main valve, a pilot tube also called a sensing line, a dome, a disk or piston, and a seat. While there are many designs available, the control pilot is essentially a conventional PRV with the special function of controlling the pressure on the main valve dome. Domes are the volumes located above pistons. Typically, a small pilot tube is used to supply pressure to the dome from the upstream side (the protected system). POPRV exhaust is directed into a pipe or open air on the downstream side. As a floating and unbalanced component, the piston moves to open and closed positions in response to fluid pressure.

The pilot-operated valve is a self-contained system that does not require external power or pressure. Using system media and pressure, the pilot valve controls the main valve operation by either opening or closing it automatically. Due to the way that the pressure is routed around to the dome above the piston, when the upstream pressure tries to push the piston open, it is opposed by the fluid pressure above the piston. When the system is operating normally, the system pressure is collected at the main valve inlet and routed to the dome through a line located under the pilot valve. Based on the illustration in Figure 1.12, since the area of the piston on which fluid forces are acting in the dome is greater than the area on the upstream side, the dome side has a greater force than the upstream side. As a result, a net sealing force is produced during normal operation. Upon reaching the set pressure, the pilot valve actuates and releases the fluid into another line or path rather than sending it to the dome. Consequently, the pressure under the piston exceeds the pressure in the dome, causing the main valve to open.

There are a number of advantages associated with POPRVs, including their high capacity, precision control, and wide range of applications. As pilot-operated valves have the ability to handle high flow rates and pressure

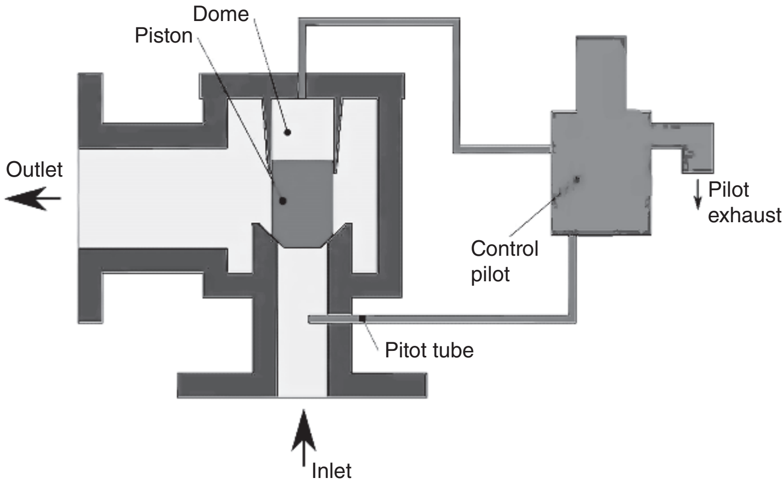

Figure 1.12 Pilot-operated pressure relief valve.

drops, they are ideal for large-scale industrial applications. These valves provide exceptional control over fluid flow, providing a high degree of accuracy and responsiveness. They are suitable for a wide range of industries and applications, making them an excellent choice. Complexity and higher maintenance requirements and frequency are two disadvantages of POPRV. As a result of the additional components and interconnections required for pilot-operated valves, their complexity and cost can be increased. Due to the potential for wear and tear on the pilot valve and sensing line, pilot-operated valves may require more frequent maintenance.

Conventional direct spring-loaded PRV: A direct spring-loaded PRV whose operation including opening and closing pressure as well as relieving capacity is directly influenced by changes in the back pressure exerted at the outlet and that is held closed by a spring force. Therefore, conventional direct spring-loaded PRVs are best suited for applications with no back pressure. A conventional direct spring-loaded PRV is shown in Figure 1.13, where the discharge of the safety valve is connected to the spring housing or spring area. The back pressure applied through the discharge line affects the operating characteristics of the valve, such as the opening and closing pressure and the relieving capacity.

A back pressure may be caused by the valve outlet being connected to a normally pressurized system or by other PRVs venting into a common header. Back pressure that may occur in the downstream system while the valve is closed is known as superimposed back pressure. There is an impact

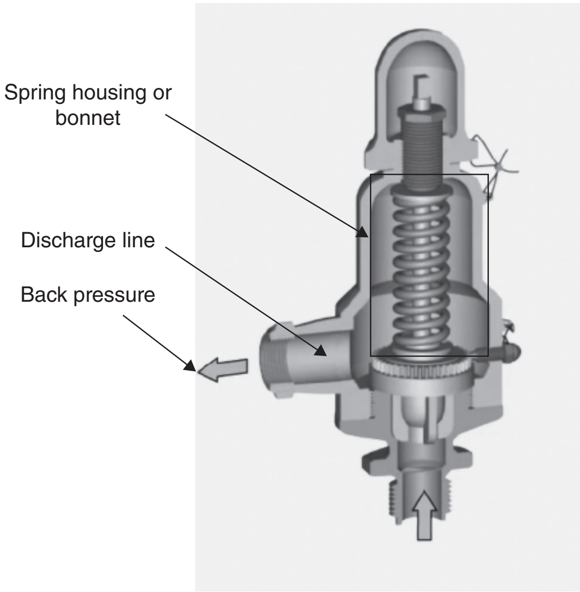

Figure 1.13 Conventional direct spring-loaded PRV.

of superimposed back pressure on the opening of conventional relief valves. In the closed position, this back pressure will provide an additional spring force to the valve disk. Consequently, it may be possible to compensate for a constant back pressure by reducing the spring force. Back pressure can have a significant impact on a valve's performance by increasing its set pressure and reducing its capacity. As an example, a valve set at 100 pounds per square inch gauge (psig) that is subjected to 10 psig of back pressure will not reach its set point until the system pressure is 110 psig. If there is too much back pressure, the valve may chatter (open and close rapidly), which may cause damage to it. It should be noted that back pressure has no effect on POPRV operation.

Balanced direct spring-loaded PRV: It is a direct spring-loaded PRV that incorporates measures such as bellows to minimize the effects of back pressure on the operation of the valve. When a conventional direct spring-loaded relief PRV is used in a back-pressure service, it will not perform for two reasons. First, the normal back pressure will contribute to the set point of the relief valve. For example, a constant back pressure of 10 psi will cause the relief valve to lift at a pressure of 10 psi above its normal setting. Second, the back pressure will act to force the relief valve closed, which usually results in a chattering situation whereby the valve opens, flow begins, back pressure builds, the valve slams shut, and is promptly reopened.

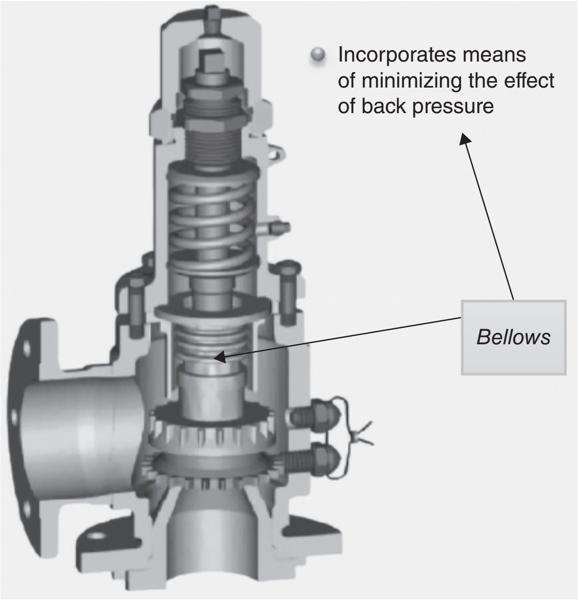

Figure 1.14 Balanced direct spring-loaded PRV with a bellows.

Balanced direct spring-loaded PRV is a spring-loaded valve that contains a bellows arrangement or other means to prevent back pressure from affecting the set point. By incorporating bellows as seen in Figure 1.14, the effect of back pressure on the valve's operational characteristics is minimized. In a balanced bellows PRV, the metal bellows isolate the area above the disk from the superimposed back pressure. Back pressure from the discharge side of the relief valve is prevented from affecting this area. It is believed that when the back pressure is applied to the bellows, equal upward and downward forces are created on the bellows, which nullify each other's effects, so that the effect of the back pressure on the bellows and the valve internal (disk) remains zero. Moreover, bellows have the advantage of isolating the spring from the discharged fluid, which prevents corrosion of the spring. There may be instances where the discharged fluid is sticky, which may cause it to attach to the spring and compromise its performance. In such cases, bellows can also be useful.

It is recommended to open a vent hole on the bonnet in order to monitor the leak from the bellows and to reduce the impact of back pressure on set pressure in the event of a leak. This hole on the bonnet has the disadvantage that, in case of failure of the bellows, fluid that may be toxic, corrosive, or flammable will be released into the atmosphere. In balanced bellows type relief valves, some installation operators have experienced a number of failures of the bellows. If the bellows fail, process fluids are released into the atmosphere through the PRV bonnet vent. In the event of an overpressure situation, the disk of the relief valve will lift to allow process fluid to drain into the outlet of the valve. Any holes in the damaged bellows may allow the fluid to reach the bonnet vent. When back pressure builds up in a common vent system, process fluids can backflow to the outlet of a PRV with damaged bellows. Consequently, process fluids may be released into the bonnet vent of the damaged relief valve. Due to the fact that many process fluids are flammable and/or toxic, this is a potentially hazardous situation. Therefore, some installation operators have modified the bonnet vents of balanced bellows PRVs in order to avoid this risk. However, such modifications may adversely affect the valve's performance in both normal operation and in the event of a bellows failure. Plugging the bonnet vent is the most common modification. The valve's performance will be impaired as a result of going against the recommendations of API RP 520 Code of Practice. By installing a plug, a failed bellows will not be detected. A balanced bellows safety valve's bonnet must always be vented to ensure proper operation and to provide a telltale in the event of a bellows failure. These open vents should not be plugged. The telltale or telltale indicator may include a male-threaded connector that can be inserted into the bonnet hole, along with a pressure gauge, as well as a female connector that can be inserted into male-threaded piping. When flammable, toxic, or corrosive fluids are present in the bonnet vent, they should be pumped to a safe location.

In addition to the bellows design, the balanced piston is another design that prevents back pressure from affecting the operation of the PRV. Using this design, the top and bottom surfaces of the disk exposed to back pressure have equal effective areas, which means that any additional forces due to back pressure are balanced.

Internal spring PRV: A direct spring-loaded PRV whose spring and all or part of the operating mechanism are exposed to system pressure when closed.

Temperature PRV: A PRV that may be actuated by the pressure or temperature at the valve inlet. The valves of this type can be installed on water tanks to release water if their pressure or/and temperature exceeds the preset limits. By using the Temperature-Pressure (TP) relief valve, the temperature and pressure of the hot water contained in a domestic storage heater can be controlled and limited, preventing steam from forming at temperatures over 100°C.

Power-actuated PRV: A PRV that is actuated (opened and closed) by an external power device. It is possible to use water, steam, or electricity as the external power source.

Safety valve: A PRV characterized by rapid opening (pop action) or closing and normally used to relieve compressible fluids such as air and steam.

Relief valve: A PRV characterized by gradual opening or closing generally proportional to the increase or decrease in pressure. It is normally used for incompressible fluids such as oil and water.

Safety relief valve: A PRV characterized by rapid opening or closing or gradual opening or closing generally proportional to the increase or decrease in pressure. It can be used for compressible or incompressible fluids.

1.6 Safety Valve Parts

A safety valve and its important components are illustrated in Figure 1.15. A left angle pattern valve **body** is the basic component of the design, with the valve inlet connection, or ***nozzle***, mounted on the pressure-containing system. It is the valve body that contains the pressure of the system, and when it is not functioning properly such as valve body leakage, the fluid is discharged into the atmosphere. By means of the inlet connection or nozzle, the system pressure exerts pressure on the disk. For connection to a piped discharge system, the outlet connection can be screwed or flanged. The safety valve may not have an outlet connection in some applications, such as compressed air systems, and the fluid will be vented directly into the atmosphere.

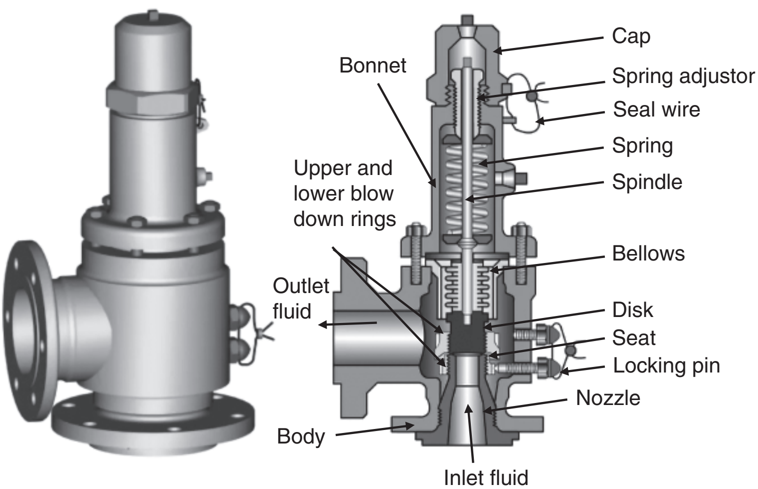

Figure 1.15 Safety valve parts.

In a safety valve, the nozzle often forms a part or all of the inlet flow passage and is responsible for containing pressure like the valve body. Depending on the valve design, the inlet can either be a full nozzle or a seminozzle. Typically, a full nozzle forms the entire inlet flow passage and is threaded into the body of the valve as illustrated in Figure 1.15. The seminozzle is a nozzle that forms only a portion of the inlet flow passage and is typically not removable from the valve body. Full nozzle design is typically suitable for corrosive and high-pressure applications. The semi-nozzle type construction should be used for nontoxic, noncorrosive media under moderate pressure. Essentially, the seminozzle design consists of a seating ring fitted into the body, the top of which serves as the valve seat. In addition to the disk, only the **inlet port**, also known as the approach channel, is always exposed to the process fluid during normal operation. Under normal operating conditions, the **disk** is held against the **seat** or nozzle seat by the **spring**, which is mounted atop the body in a **spring housing arrangement (or bonnet)**. The bonnet is also known as a **spring casing**, which houses and protects the spring from the environment. Depending on the configuration, the bonnet may be pressure containing or none-pressure containing. When the valve has bellows, the bonnet is not in contact with the fluid and therefore is not considered a pressure-containing component. It is important that the contact between the seat and disk be tight in order to prevent leakage through the valve. Standard safety valve designs include a metal-to-metal seal between the disk and seat, which means that both the disk and seat are metallic. The disk in a safety valve must be opened rapidly, which is known as the pop type, in order to produce a rapid opening characteristic. A spring provides the downward and closing force on the disk during operation. A **spring adjustor** also called **adjusting screw** is usually used to adjust the amount of compression on the spring, which determines the pressure at which the disk is lifted. If a higher set point is required, the spring must be compressed by lowering the spring adjustor. It is necessary to relax the spring by raising the spring adjustor if a lower set point is required. A **cap** is the top part of the safety valve, which covers the spring adjustor. The cap may be bolted or threaded to the bonnet. Furthermore, the **spindle** or **stem** guides the disk to be aligned correctly on the seat and guides the disk during its travel.

1.7 Safety Valve Dismantling

The first step to dismantling a safety valve is to remove the seal wire located at the top of the valve. The cap on the top of the valve may be disconnected by unscrewing it or by loosening the bolts if it is attached to the valve by means of a flange so that the cap can be detached. Afterward, the operator will have access to the stem adjustor which will be unscrewed and therefore be able to remove it from the valve by unscrewing it. As soon as the stem adjustor has been removed, the bottom seal wire can be removed and the locking pin should be unscrewed in order to allow the inlet nozzle to be disengaged from the valve after removing the stem adjustor. Having removed the disk and the blowdown rings, it is now possible to remove the stem and finally the spring as well. It is the body of the valve that is the last piece that can be seen after removing all other parts.

1.8 Basic Safety Valve Operation

The disk begins to lift off the seat and the fluid begins to escape when the static inlet pressure exceeds the set pressure. However, after the spring begins to compress, the spring force will increase, which means that a significant amount of pressure is required for any further lifting to occur and for any significant flow to pass through the valve. There is a term called **overpressure** that refers to the additional pressure rise that must occur before the safety valve can be discharged at its rated capacity. Therefore, overpressure is higher than the set pressure. The disk arrangement must be designed to provide rapid opening (in case of using a safety valve) in order to achieve full opening under such a small overpressure. It is usually necessary to place a shroud, skirt, hood, or ring around the disk so that more fluid can contact the underside of the disk when the valve is opened. According to Figure 1.16, when the valve is closed, system pressure acts

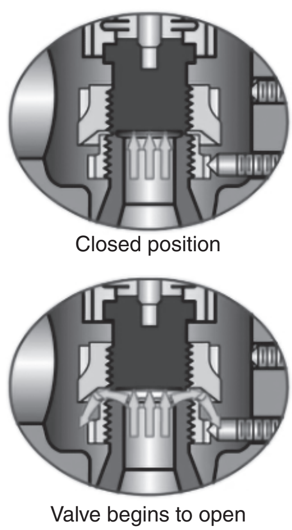

Figure 1.16 An application of force from the inlet fluid to the disk in the closed and open positions for a pressure safety valve with blowdown rings.

only below the disk. As the fluid escapes to the discharge area, however, the pressure applied by the inlet fluid acts on the larger area of the disk due to the use of the upper blowdown ring. Thus, when the disk is open, the pressure applied by the inlet fluid to the under the disk is greater than when it is closed. When the disk moves upward and the valve opens, the inlet fluid pressure enhances the lift of the disk. When the valve must be opened rapidly, such as with a PSV, this arrangement, which includes blowdown rings, is required. Overpressure and blowdown values are influenced by the design or arrangement of blowdown rings. The following paragraph provides an explanation of the term blowdown.

It is necessary to close the valve again once normal operating conditions have been restored, but due to the large area of the disk still exposed to the fluid, the valve will not close until the pressure has dropped below the original set pressure. A **blowdown** is the difference between the set pressure and this **reseating pressure**, which is normally expressed as a percent of the set pressure. Previously, it was explained that the design and arrangement of the blowdown rings influence the values of blowdown and overpressure. The upper blowdown ring is typically factory-set and removes manufacturing tolerances that are responsible for affecting the geometry of the huddling chamber. In addition, the lower blowdown ring is also factory-set to achieve the appropriate code performance requirements, but it may be modified under certain circumstances. In the top position of the lower blowdown ring, the huddling chamber volume is such that the valve pops rapidly, thereby minimizing the overpressure value, but requiring greater blowdown before the valve re-seats. It should be noted that when the lower blowdown ring is adjusted to its lowest position, there is minimal restriction in the huddling chamber. A greater overpressure will therefore be required before the valve is fully opened, but the blowdown value will be reduced.

1.9 Safety Valve Essential Pressure Settings

To recap what has been discussed in the previous paragraphs, there are three important pressure settings for a safety/relief valve: the **set pressure**, the **relieving pressure**, and the **reseat pressure**, which are illustrated in Figure 1.17. Set pressure refers to the pressure at which a safety valve opens clearly for the first time. This pressure is also referred to as the set point pressure, the popping or pop pressure, the cracking pressure, or the beginning of discharge pressure. The set pressure ensures that the valve opens at the desired pressure in order to prevent an overpressure situation. Until the

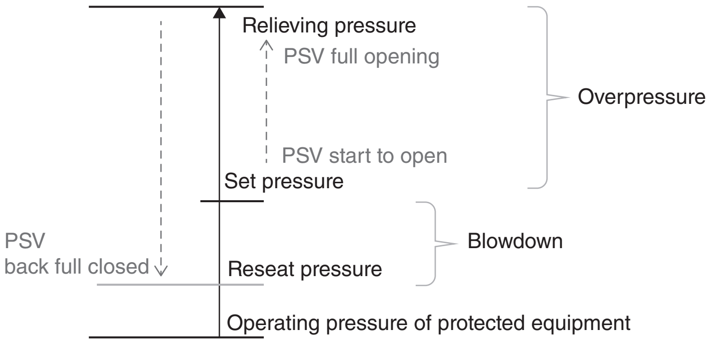

Figure 1.17 The essential pressure settings of a safety/relief valve.

vessel's pressure drops below the set pressure, the PRV remains open. Afterward, the relief valve closes again. In terms of measurement, it is expressed in psig or bar typically. Changing the set pressure of your valve may require replacing the installed spring or adjusting the spring force through the spring adjustor. Relieving pressure (PR) is the pressure at which the safety valve reaches its maximum capacity and full opening. In simple terms, it is the sum of the set pressure (PS) and the overpressure (PO). An important terminology for relief devices is overpressure. This refers to the maximum pressure a pressure relief device can handle or relieve during an overpressure event. There is a maximum amount of pressure that can be applied above the set pressure of a valve before it reaches its maximum capacity. In the context of safety valves, overpressure can be defined as the percentage of the set pressure at which the valve is designed to operate. In safety valves, reseat pressure is the pressure at which the valve closes or reseats. The term "blowdown" refers to the pressure encountered when a PRV is closed, discontinuing the relief flow. This pressure value is lower than the set pressure and is commonly expressed as a percentage of the set pressure.

Questions and Answers

1.1 Which statements are correct regarding maximum allowable working pressure (MAWP)?
Answer: It is incorrect to choose Option A, since the MAWP is gradually lowered as a result of wear and corrosion. Similarly, Option B is incorrect since the design pressure is lower or at a maximum equal to the MAWP. Option C and option D are both valid options.

A Maximum allowable working pressure is a constant value during the life of the pressure vessel.

- **B** The design pressure is always greater than MAWP.
- **C** The MAWP is less than the maximum allowable accumulation pressure (MAAP).
- **D** By ensuring the system does not exceed a safe operating pressure, industrial facilities use the MAWP to establish safety protocols and prevent explosions.

1.2 Which of the following statements is correct regarding the use of safety devices in oil and gas plants?
Answer: Safety valves are more expensive than rupture disks, so option A is incorrect. Option B is also incorrect, as rupture disks do not have flange ends, but are typically installed between two flanges. A rupture disk can be installed directly between two flanges or between two holders that are installed between flanges. The correct answer is option C. Option D is incorrect since rupture disks are typically made of thin metallic diaphragms.

- **A** Compared to rupture disks, safety valves are more cost-effective.
- **B** Flange ends are typically present on rupture disks.
- **C** It may be necessary to install the rupture disk before the safety valve in order to prevent corrosion, leakage, or wear and plugging of the safety valve.
- **D** A rupture disk is typically made of a thin plastic diaphragm.

1.3 What is the primary reason for design and use of pressure safety valves?
Answer: Option B is the correct answer.

- **A** To control the pressure of a pressurized system
- **B** To protect life, property, and environment
- **C** To release overpressure for pressurized equipment and components
- **D** All above options are incorrect

1.4 Identify the correct statement regarding pressure relief valves.
Answer: Option A is incorrect since a safety valve must be operated at all times and under all circumstances. There is also a problem with option B since pressure relief valves are designed to open at a predetermined set pressure, not a back pressure. The correct choice is option C. Option D is incorrect since balanced relief valves minimize the effects of back pressure whereas conventional relief valves do not.

A The pressure relief valve should only be operated during the start-up or shutdown phases of a facility, since these are the phases that present the greatest level of risk.
B It is necessary for pressure relief valves to open at a predetermined back pressure.
C A pressure relief valve must flow at a rated capacity at a specified overpressure.
D Conventional relief valves are designed to minimize the effect of back pressure.

1.5 In Figure 1.18, what type of relief valve is shown?
Answer: The correct answer is option B. On the top and right corner of the main valve is the pilot valve, which is a type of relief valve. In this example, the upstream fluid in green color is directed to the area above the disk through the pilot valve, and because the area above the disk is larger than the area under the disk, the fluid force above the disk is greater than the fluid flow under the disk, and this maintains the valve in the closed position.

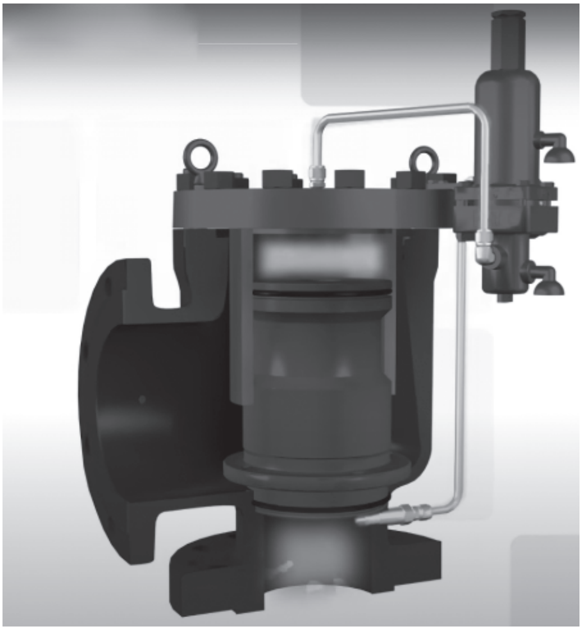

Figure 1.18
A PRV.

A Conventional direct spring-loaded PRV
B Pilot-operated PRV

- **C** Balanced direct spring-loaded PRV
- **D** Internal spring PRV

1.6 In pressurized facilities, which type of overpressure cannot be reduced by using pressure relief valves?
Answer: Option A is the correct answer.

- **A** Water hammer
- **B** Fire
- **C** Heat exchanger tube failure
- **D** Check valve leakage failure

1.7 In regard to the safety valves, identify the correct statement.
Answer: It is incorrect to choose option A, as a safety valve opens rapidly and fully as soon as the pressure setting is reached, which is unlike a relief valve. In addition, option B is incorrect because the difference between the set pressure and the reseat pressure is called blowdown, not overpressure. Due to the fact that relief valves are used for noncompressible fluids (liquids) such as oil, Option C is not appropriate. Option D is the correct answer.

- **A** A safety valve gradually opens as the inlet pressure increases above the set pressure
- **B** The difference between the set point and the reseat pressure or the pressure at which the safety valve closes is called overpressure.
- **C** A relief valve is used for compressible fluids.
- **D** The system pressure must be reduced below the set pressure in order for the safety valve to completely close and the disk to reseat.

1.8 A standard safety valve can be operated by ______.
Answer: In this case, option D is the correct answer since standard safety valves do not have any means of operating them, such as handwheel and gear box or actuators that work with electricity, air, or hydraulic forces. Fluid flowing through pressurized components, such as piping and pressure vessels, operates the safety valve.

- **A** Electricity
- **B** Hydraulic
- **C** Air
- **D** None of the above

1.9 A safety valve must be open in predetermined _____.
Answer: Option C is the correct answer.

- **A** Blowdown pressure
- **B** Back pressure
- **C** Set pressure
- **D** Relieving pressure

1.10 The flow rate of a pressure relief valve must be equal to its rated capacity at a specified __________.
Answer: Option A is the correct answer.

- **A** Overpressure
- **B** Back pressure
- **C** Blowdown pressure
- **D** Reseat pressure

1.11 Identify the correct statement regarding pressure relief valves.
Answer: There is an error in Option A, since rupture disks are non-reclosing relief devices, whereas safety valves are reclosing relief devices. The correct option is B. It is incorrect to select option C since the balanced relief valve contains bellows or a balanced plug to minimize the effect of back pressure and is not a conventional relief valve. Option D is incorrect since the valve opens when the static inlet pressure of a safety valve increases to a point at which the valve lift is measurable.

- **A** The pressure relief valve is an example of a non-reclosing pressure relief device.
- **B** The terms cracking pressure, opening pressure, pop pressure, and start-to-discharge pressure refer to the same phenomenon.
- **C** In a conventional relief valve, means are provided for minimizing the effect of back pressure.
- **D** An overpressure occurs when the static inlet pressure of a safety valve increases to a point at which there is a measurable lift.

1.12 The value of increasing inlet static pressure at which there is a measurable disk lift is called ______.
Answer: Option C is the correct answer.

- **A** Overpressure
- **B** Blowdown pressure
- **C** Opening pressure
- **D** MAWP

1.13 Which of the following terms is synonymous with opening pressure?
Answer: Option D is the correct answer.
- **A** Cracking pressure
- **B** Pop pressure
- **C** Start to discharge pressure
- **D** All three answers are correct

1.14 What is the benefit of bellows?
Answer: Option D is the correct answer.
- **A** Ensure that the safety valve's operating characteristics are not affected by back pressure
- **B** Protect the spring and spring chamber from corrosive and sticky fluids
- **C** Close the valve at the reseating pressure
- **D** Options A and B are correct answers

1.15 Relieving pressure equals ________.
Answer: Option A is the correct answer.
- **A** Set pressure + Overpressure
- **B** Set pressure + Overpressure + Total back pressure
- **C** Overpressure + Blowdown
- **D** Set pressure – Overpressure

1.16 Blowdown equals ________.
Answer: Option C is the correct answer.
- **A** Set pressure – Resealing pressure
- **B** Overpressure – Set pressure
- **C** Set pressure – Reseating pressure
- **D** Overpressure + Set pressure

1.17 Safety valves and relief valves differ primarily in their range of opening at ______.
Answer: Option A is the correct answer.
- **A** Set pressure
- **B** Closing
- **C** Fully rated capacity
- **D** Relieving pressure

1.18 Select the type of pressure-relieving device from the following list based on the following description. In addition to gas or vapor service, they are also used in liquid service.

Answer: In general, safety valves and conventional safety valves are suitable for compressible services such as gas, while relief valves are suitable for noncompressible or liquid services. It is possible to use a safety relief valve for both liquids and gases. Therefore, option A is the correct answer.

A Safety relief valve
B Safety valve
C Relief valve
D Conventional safety valve

1.19 What type of relief valve is suitable for the given application? There are particles in the fluid, and it is corrosive and sticky.

Answer: A pilot-operated relief valve is not suitable for fluids that contain particles, as the particles may get trapped inside the connecting tubes and interfere with the function of the valve. The balanced disk relief valve is more suitable for applications with variable back pressure in order to minimize the impact of back pressure on the valve's operation. There are major disadvantages to conventional safety valves, including the fact that the spring is exposed to corrosive and sticky fluid, which enhances the corrosion of the spring, as well as the fact that sticky fluid and particles can stick to the spring, preventing the spring from functioning properly. Choosing option D is the right decision since bellows protect the spring and spring housing from contact with sticky and corrosive fluids.

A Pilot-operated relief valve
B Balanced disk relief valve
C Conventional relief valve
D Bellows relief valve

1.20 What is the common limitation for pressure relief devices, including safety valves, relief valves, safety relief valves, and balanced safety relief valves?

Answer: Option C is the correct answer

A The effect of back pressure on valve performance
B Not suitable for corrosive services
C Cannot be used for pressure control or bypass valves
D All three options are incorrect

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