7.16 Relief Valves—Sizing, Specification, and Installation

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Types of Designs:
- Spring-loaded
- Weight-loaded
- Balanced by bellows seals
- Pilot-operated

Design Pressure Ranges:
- Screwed designs from 5 PSIG [34 kPag] to 10,000 PSIG (69 MPa), higher as special
- Flanged steel designs, ANSI CL 150#, 300#, 600#, 900#, 1500# and 2500# ASA
- Flanged cast iron units in 125# and 250#

Ranges of Pilot-Operated Designs
- Vacuum: –1.7 in. H₂O to –14 PSIG (–43.2 mm H₂O to –96.5 kPag)
- Low pressure: 3 in. H₂O to 150 PSIG (76.2 mm H₂O to 1034 kPag)
- Medium to high pressure: 50 to 6,200 PSIG (0.345 to 42.75 MPag)

Design Temperature:
- –450 to 1000°F (–268 to 538°C) with suitable material selections for pressure parts, trim, and springs; breaks occur in the temperature ratings at 450°F (232°C) and 800°F (427°C)

Inlet Connection Sizes:
- 0.5 to 6 in. (12.5 to 150 mm); some suppliers up to 12 in. (300 mm) for special services
- Pilot-operated PRVs available from 1 to 10 in. (25 to 250 mm) with double outlets starting at 2 in. (50 mm)

Orifice Areas:
- API designated orifices: D, E, F, G, H, J, K, L, M, N, P, Q, R, and T (for orifice areas, see Figure 7.16g)
- Non-API orifices and full-bore orifices are available in areas up to 84 in.²

Materials of Construction:
- Pressure parts: cast iron, bronze, cast steel, 300 and 400 series stainless, nickel steel, Monel, Hastelloy, high-temperature carbon steel alloys, materials in compliance with NACE MR0175; trim: basically any machinable alloy, can be cryogenic, NACE, or high-temperature trim

Seat and Seal Materials:
- Metal to metal or soft seats
- Soft seat material options include Aflas, Buna-N, ethylene propylene, Kalrez, Peek, Teflon®, Urathene, Viton®, etc.

Accessories:
- Backflow preventer, dual pilots, field test connection with indicator, filter, pilot lift lever, pressure spike snubber, remote blowdown, remote pressure sensor, remote valve lift indicator, valve monitor, valve position indicator

Cost:
- See Figure 7.16o

Inaccuracy:
- ±2 PSI for pressures up to and including 70 psig (483 kPag)
- ±3% for pressures above 70 to 300 PSIG (483 to 2068 kPag)

* B. P. Gupta and W. Y. Wong should also be credited for some work on this section.
INTRODUCTION

In Section 7.15, the various overpressure protection codes and standards were discussed along with the terminology and nomenclature that is used in connection with pressure relief valve (PRV) design. Some of these terms are also defined and visually illustrated in Figure 7.16a. The main purpose of Section 7.15 was to explain the methods by which the required relief capacities are determined. The purpose of this section is to assume that the required capacity is known and, based on that, to determine the size, design features, and installation details of the required PRV.

One might note that, during recent decades, the language used in connection with overpressure protection valves went through some changes. In the past, all overpressure protection valves were referred to as pressure safety valves (PSVs). Then, with the passage of time, first the liquid relieving valves and then all nonfire protection valves came to be called pressure relief valves (PRVs). By now, in most plants, these distinctions have disappeared, and all overpressure protection valves are referred to as PRVs. This practice is also used in this handbook.

The Nature of PRVs

Pressure relief valves are the last line of defense in the protection of personnel and equipment from the consequences of the accumulation of energy or mass that is greater than allowed by design limits. One of the prime responsibilities of process plant management is to operate in a safe manner, and one of the most important safety considerations is to protect all equipment against overpressure.

Normally, plant operating instructions and controls keep the operating pressures within design limits. In the event of control malfunction, emergency shutdown systems should serve to bring the system down in a safe and orderly manner. However, if the emergency shutdown systems malfunction, the plant design must incorporate pressure relief devices to dispose of the accumulated energy and thereby avoid damage.

The relative simplicity and the self-contained and self-actuating nature of the PRV valve make it the most reliable device short of the rupture disc (which does not, however, reclose). It is important to remember that a pressure relief valve is installed only to limit the pressure; it will not regulate, reduce, or depressurize the system unless special provisions are incorporated.

The Purpose of PRVs

Pressure relief valves are commonly installed for one or more of the following reasons:

1. To guarantee the safety of operating personnel
2. To prevent the destruction of capital investment as a result of overpressure
3. To conserve process material from loss during and after an overpressure-related accident
4. To minimize unit downtime caused by overpressure
5. To comply with local, state, national, and other court-enforceable regulations
6. To avoid civil suits resulting from property or personal damage external to the plant caused by overpressure

By designing and installing reliable overpressure protection systems, the plant will not only obtain favorable insurance treatment, it will minimize pollution (primarily air pollution) by preventing the discharge of overpressure vapors.

System Integrity and Noise

Because one of the reasons for installing a pressure relief valve is compliance with local codes and regulations, the designer must take into consideration the system integrity, in particular the noise produced by the valve when it opens. The
valve may relieve the required amount of process fluid, but the vibrations caused by the sound power noise of the valve may be beyond the maximum allowable for which the discharge piping was designed.

Failures in relief valve discharge piping have been reported that can be linked to high sound power levels (SPLs) inside the piping downstream of the relief valve and at the point where the discharge piping joins the relief system header. There have been cases reported in which excessive velocities in the piping immediately downstream of the relief valve have resulted in a “standing sonic wave” at the juncture of the valve discharge piping and the header piping, i.e., where the first increase in pipe size occurs.

Special care must be taken to review the actual maximum flows that can exist in the discharge piping. Velocities must be calculated and noise calculations made to guard against fatigue failures caused by excessive vibration induced by a high SPL. When making these calculations, it is necessary to use the actual installed capacity of the valve. This is because, in most cases, the selected valve has greater capacity than the calculated required capacity. Under certain relieving conditions, at least for some time period, the actual flow corresponds to the size of the actual valve orifice rather than to the calculated required capacity. This consideration is especially important for valves greater than 3 in. (75 mm) and, unfortunately, there is no known technique for assessing this problem.
Reliability, Testing, and Redundancy

The designer may also have to consider the requirements imposed by the insurance underwriting groups. Because the purpose of overpressure protection is to prevent the destruction of capital investment and to provide personnel safety, such considerations as toxicity, polymerization, corrosion, and damage to other equipment in the plant must also be considered when deciding on the discharge destinations of PRVs.

Because unit downtime and loss of material are both to be minimized, it is also important that the PRVs provide tight shutoff against maximum operating pressure while it is below the set point for actuation. Personnel safety and the minimization of property damage lead to requirements for high reliability, both in terms of accuracy and repeatability.

A pressure-relieving valve in a chemical plant is rather unique in that it, hopefully, will never need to operate. Furthermore, it is also rare that any such system would ever be operated for test purposes, although certain of its components might be tested periodically. The capability for system testing is usually not provided because of the cost of the added valves and bypasses that would be needed. Even when such capability is provided, the system test is performed only at rather long intervals.

A pressure relief valve is not tested weekly for its condition as one might test an emergency generator or a fire pump. We expect the PRV valve to work when called upon in spite of the extended periods of stagnation while exposed to process fluids, operating temperatures, and operating pressures, plus to the full range of ambient conditions. This requirement that the valve work when called upon, coupled with the requirement to protect the safety of personnel and equipment, drives the designers to consider redundancy. Such designs are exemplified by duplicate or multiple relief valves, rupture discs plus safety valves, flare valves backed up by pressure relief valves, etc.

Safety Checklist

Section 7.15 listed and discussed the code requirements and practices recommended by standards that have been generated by regulating. In addition, the following considerations and options should be kept in mind:

1. The use of extra safety factors in sizing or rating over and above those established in codes, regulations, and recommended practices
2. The provision of other protective facilities that may result in credits under the codes or regulations
3. The provision of credit for redundancy or other protective facilities, even though such credit may not be clearly established in codes or regulations
4. Preferences, particularly in installation practices, based on operating or maintenance practices
5. The establishment of minimum design pressures for various types of equipment in various services (This would affect the pressure-relieving systems in that operating pressure may not always bear the same relationship to design pressure and smaller relieving valves set at the minimum design pressure may be suitable.)
6. The relationship between operating pressure and relief valve set pressure as affected by the upsets to operating conditions that are acceptable before pressure relief occurs
7. The standardization of relieving device sizes and types and the standardization of relieving device mounting nozzle sizes and locations for various types of equipment in different services
8. The inspection and test procedures established by the company for its pressure-relieving systems or the components of those systems
9. The accounting needs and practices of the company as they might affect flow detection and metering in the pressure-relieving system or at the valve
10. Noise produced and maximum level of noise allowed in the discharge piping and header, depending on its diameter

THE SIZING OF PRVS

Before sizing the pressure relief valve, one must determine if the process material released will be vapor or gas, liquid, or a mixture of liquid and vapor (two-phase). Each of these cases is separately discussed below.

The design engineer should also remember that PRV sizing programs are available on CDs from the manufacturers. While these programs do save time, it is advisable to fully understand the sizing steps and considerations. For these reasons, both graphical methods of approximate PRV sizing and accurate calculations will be described in the following pages.

Backpressure

Backpressure can adversely affect the set pressure, relieving capacity, stability, and life span of all types of pressure relief valves. Figure 7.16b represents the correction curve for the effects of constant backpressure in reducing the flow across the nozzle of conventional, nonbalanced valves when the spring setting has been compensated for the constant backpressure.

The effect of backpressure on bellows sealed valves, whether it is fixed or variable, is a function of the specific valve size and design. There is general acceptance of the fact that a backpressure up to 30% of inlet pressure will not need correction. Above that value, the backpressure effect should be evaluated by considering whether it is superimposed backpressure or built-up backpressure.

Superimposed Backpressure  The superimposed backpressure is the pressure that is present at the PRV outlet in the relief header when the valve opens. This pressure is a “gauge” pressure and is expressed in units such as PSIG, kg/cm² (g) or kPag. Generally, the superimposed backpressure is assumed to be constant, which is an incorrect assumption if more than one PRV is discharging into the same relief header.
In reality, this pressure is variable and is changing as a function of the number of PRVs relieving into the header at any one time.

As was discussed in Section 7.15, a fire zone has an area of 2500 to 5000 ft², and a local fire might cause discharges from only one PRV in that area. Similarly, if the cause of the overpressure condition is a blocked outlet, it too might affect only one or two PRVs. On the other hand, if the supply of electric power, cooling water, instrument air, or steam fails, the failure of such utilities can cause many PRVs to be relieving at the same time, and this, in turn, can cause the superimposed backpressure in the relief header to rise substantially.

**Built-Up Backpressure**  The built-up backpressure is the pressure drop between the PRV outlet and the end of the discharge piping. Therefore, it is the sum of the pressure losses in the pipe fittings, valves, and the pipe itself. Its units can be given in PSI, kg/cm², and kPa. When choke flow occurs, the built-up pressure can be very high.

The built-up backpressure is a function of the discharge flow rate, the sizes of the outlet fittings and pipe, the number of valves and other restrictions, and also by the compressibility of the discharging vapors and by temperature. The built-up backpressure will therefore be lower if the PRV is connected to a short tail pipe that vents to atmosphere.

**Backpressure Effects**  The backpressure can affect the set pressure of the pressure relief valve. This is illustrated in Figure 7.16c, which considers several valve designs and means for remedying this effect. It is shown in this figure that venting or not venting the bonnet can change the direction of the backpressure effect.

If the backpressure builds up as the valve opens, the valve may chatter and reclose. If the backpressure is constant and is

**FIG. 7.16b**
Constant backpressure sizing factor, applicable when sizing conventional pressure relief valves for gas and vapor services.

![Graph showing backpressure sizing factor](image-url)

**FIG. 7.16c**
Effect of backpressure on set pressure. ($A_n =$ nozzle area; $A_D =$ disc area; $A_B =$ piston area; $A_B =$ bellows area.)
already present when the valve starts to open, it should be possible (if all code and insurance requirements are fully satisfied) to compensate for it by raising or lowering the spring setting.

In conventional pressure relief valves, constant backpressures up to the critical pressure ratio can be compensated by spring setting without affecting the capacity. Above that setting, compensation can be used, but (as will be discussed later) an appropriate capacity reduction factor must be employed in sizing for both vapors and liquids.

Figure 7.16d shows that the dimensions and design of the particular valve will establish the change needed in the spring setting and that this change is a function of the backpressure. Therefore, it is not suggested that one compensate for backpressure with the spring setting without consulting the manufacturer of the particular valve. In fact, it is suggested that spring setting adjustment be limited to the non-critical applications and that pilot or bellows seal designs be used to guarantee that the PRV will open on set pressure on all critical applications.

**Sizing for Vapor and Gas Relief**

The basis for almost all pressure relief valve sizing for process industry service is found in the ASME Unfired Pressure Vessel Code Section VIII, Division 1, described in Section 7.15.

The basic sizing equation results from capacity conversions for relief valves described in Appendix 11 of that code. This states that the test media capacity is converted to any other vapor or gas by Equation 7.16(1),

\[ W = K_b CKAP \sqrt{\frac{M}{TZ}} \]  \hspace{1cm} 7.16(1)

where

- \( W \) = the relieving flow of gas or vapor, lbm/hr
- \( K_b \) = a correction factor for constant backpressure, which can be obtained from Figure 7.16b
- \( C \) = a constant for gas or vapor, which is a function of the ratio of specific heats “k”; it can be obtained from Figure 7.15b or from Equation 7.16(2), below,

\[ C = 520 \left( \frac{2}{k+1} \right)^{1/(k-1)} \]  \hspace{1cm} 7.16(2)

- \( k \) = the specific heat ratio of the particular gas or vapor, which can be obtained from Figure 7.15a
- \( K \) = the coefficient of discharge, which is determined from tests
- \( A \) = the required nozzle area of the valve, in square inches
- \( P = 1.1 \times (\text{set pressure}) + \text{atmospheric pressure in PSIA} \)
- \( M \) = the molecular weight of the gas or vapor
- \( T \) = the absolute relieving temperature, °Rankine (°F + 460)
- \( Z \) = vapor compressibility at inlet conditions

The basic equation can be manipulated almost any number of ways, and each manufacturer and designer has its own favorite sizing procedure.

**Graphical Method** A commonly accepted and easily used graphical approach is shown in Figures 7.16e and 7.16f. Here, the orifice designations of the nozzle areas are those listed in Table 7.16g, which represent the most common API area designations. However, if manufacturer’s formulas are used, care must be exercised to use the orifice area with the corresponding recommended formulas. Table 7.16g shows the tabulated nozzle orifice areas and corresponding orifice designations for the API and ASME formulas provided. Using the ASME formula and selecting an orifice based the API area may result in improper valve sizing.

**Sizing by Calculation** Those who prefer calculations to using the graphical method first have to determine if the flow is critical or subcritical. Critical flow occurs when the gas, as a result of the lower pressure, expands downstream of the PRV’s orifice and reaches sonic velocity, which it cannot exceed. The flow rate that corresponds to flow at sonic velocity is called **critical flow**. One can calculate the downstream pressure that, if reached, will result in critical flow (\( P_{cr} \)) by Equation 7.16(3).

\[ P_{cr} = P_s \left[ \frac{2}{(k+1)} \right]^{k/(k-1)} \]  \hspace{1cm} 7.16(3)
7.16 Relief Valves—Sizing, Specification, and Installation


**Critical Flow Sizing**  Table 7.15a lists the critical flow pressure ratio values at standard conditions for a number of gases. When the downstream pressure $P_2$ is less than or equal to the critical flow pressure $P_{cf}$, the relieving flow will be in the critical region. Under these conditions, Equations 7.16(4) and 7.16(5) can be used to determine the required PRV discharge area ($A$).

\[
A = \left[ \frac{W}{CK_dP_1K_bK_c} \right] \sqrt{\frac{TZ}{M}} \quad \text{(in US units)} \quad 7.16(4)
\]
\[
A = 13,136 \left[ \frac{W}{CK_dP_1K_bK_c} \right] \sqrt{\frac{TZ}{M}} \quad \text{(in SI units)} \quad 7.16(5)
\]

where

- $A$ = the required effective discharge area of the PRV in in.² (mm²)
- $W$ = the required flow rate to be relieved in lb/hr (kg/hr)
- $P_{cf}$ = the downstream pressure, which results in critical flow in PSIA
- $P_1$ = the upstream relieving pressure in PSIA
- $K = \text{the ratio of specific heats for any ideal gas}
- $C$ = a coefficient that is a function of the specific heat ratio of the gas or vapor at inlet relieving conditions from Figure 7.15b. If $C$ cannot be so determined, it is suggested that one use $C = 315$
- $K_d$ = the effective coefficient of discharge; for preliminary sizing, a value of 0.975 can be used
- $K_b$ = the capacity correction factor for backpressure, which can be obtained from manufacturer’s literature or estimated from the API RP 520 based Figure 7.16h for the preliminary sizing of balances bellows PRVs
- $K_c$ = a factor reflecting the affect of a rupture disc being installed upstream of the PRV (Its value is 1.0 if there is no rupture disc. When a rupture is installed and there is no published value available for the combination, use the value of 0.9.)
- $T$ = the inlet temperature of the gas or vapor being relieved in °R (°C)
- $Z$ = the compressibility factor, reflecting the deviation of the process vapors from an ideal gas under relieving conditions at the PRV inlet
- $M$ = the molecular weight of the process gas or vapor being relieved

**FIG. 7.16e**

Graphical method of sizing pressure relief valves for vapor or gas services.
**FIG. 7.16f**
Graphical method of sizing pressure relief valves for gas services.

**TABLE 7.16g**
PRV Nozzle Orifice Areas in Square Inches (in.\(^2\) = 645 mm\(^2\))

<table>
<thead>
<tr>
<th>Orifice Designation</th>
<th>API Area</th>
<th>Actual (ASME) Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>.110</td>
<td>.1279</td>
</tr>
<tr>
<td>E</td>
<td>.196</td>
<td>.2279</td>
</tr>
<tr>
<td>F</td>
<td>.307</td>
<td>.3568</td>
</tr>
<tr>
<td>G</td>
<td>.503</td>
<td>.5849</td>
</tr>
<tr>
<td>H</td>
<td>.785</td>
<td>.9127</td>
</tr>
<tr>
<td>J</td>
<td>1.287</td>
<td>1.496</td>
</tr>
<tr>
<td>K</td>
<td>1.838</td>
<td>2.138</td>
</tr>
<tr>
<td>L</td>
<td>2.853</td>
<td>3.317</td>
</tr>
<tr>
<td>M</td>
<td>3.60</td>
<td>4.186</td>
</tr>
<tr>
<td>N</td>
<td>4.34</td>
<td>5.047</td>
</tr>
<tr>
<td>P</td>
<td>6.38</td>
<td>7.417</td>
</tr>
<tr>
<td>Q</td>
<td>11.05</td>
<td>12.85</td>
</tr>
<tr>
<td>R</td>
<td>16.0</td>
<td>18.60</td>
</tr>
<tr>
<td>T</td>
<td>26.0</td>
<td>28.62</td>
</tr>
</tbody>
</table>

**FIG. 7.16h**
Variable or constant backpressure sizing factor, \(K_b\), for balanced bel lows pressure relief valves on vapor or gas service. The curves represent a compromise of the values recommended by a number of relief valve manufacturers and may be used when the make of a valve or the actual critical flow pressure point for the vapor or gas is unknown. When the make is known, the manufacturer should be consulted for the correction factor. These curves are for set pressures of 50 PSIG (345 kPa) and above. For set pressures lower than 50 PSIG (345 kPa), the manufacturer should be consulted for the values of \(K_b\).
7.16 Relief Valves—Sizing, Specification, and Installation

P₁ = (for conventional PRVs) the set pressure × (1 + accumulation allowed by code having jurisdiction) + atmospheric pressure in PSIA (kPaa); (for pilot-operated PRV valves) = the set pressure plus accumulation minus ∆P_inlet in PSIA (kPaa)

∆P_inlet = the inlet pipe loss upstream to the PRV in PSI (kPa)

Subcritical Flow Sizing
If the PRV is provided with bellows seals, the sizing for subcritical flow can be based on Equation 7.16(4) or 7.16(5), but the backpressure correction factor K_b should consider the subcritical flow and the tendency of the disc of the PRV to drop to below full lift. For these reasons, the K_b factor should be obtained from the manufacturer.

When sizing conventional or pilot-operated PRVs for subcritical conditions (P₂ > P_c), Equation 7.16(6) or 7.16(7) should be used.

A₁ = [W/735F₂K_dK_c] \sqrt{(TZ/MP₁(P₁ - P₂))} (in US units)  
7.16(6)

A = 17.9[W/F₂K_dK_c] \sqrt{(TZ/MP₁(P₁ - P₂))} (in SI units)  
7.16(7)

where

F₂ = the subcritical flow coefficient

Backpressure Effect on Capacity
Backpressure affects the capacity and thus the sizing of relieving devices. In a sense, the PRV is similar to an open control valve, because its upstream pressure is the process pressure, and its downstream pressure is that which exists in the relieving header. However, instead of being a controlling element, it is controlled by the pressure conditions at its inlet and outlet.

Most safety valves will handle flow very similar to a theoretical nozzle as long as they are fully open (at full lift) so that the controlling flow area is established by the nozzle. The capacity of a theoretical nozzle is not affected by the downstream pressure as long as it does not rise to the point where the ΔP drops below the critical pressure drop needed to maintain sonic flow. At higher backpressures, the flow becomes subsonic.

The effect of backpressure on the capacity of a conventional safety valve with an unvented bonnet is shown in Figure 7.16i. Note that the two sources of backpressure (superimposed and built-up) produce different effects. Because of this capacity reduction due to lift action, conventional valves should never be used where backpressure variation can exceed 10% of the set pressure.

Sizing for Steam Relief
The need for steam relief sizing is more often encountered in the design of power plants than chemical plants. The sizing method itself is straightforward once the required load and the relieving conditions are established. ASME Code Section I is used in sizing steam PRVs for fired boilers whereas, for nonfired vessels, ASME Code Section VIII is applicable. The basic steam sizing equation is a modification of Napiers.

A₁ = W_s/(51.5P₁K_dK_cK_cK_HSN) (in US units)  
7.16(8)

A₁ = (190.4W_s)/(P₁K_dK_cK_cK_HSN) (in SI units)  
7.16(9)

where

A, P₁, K_d, K_c, K_HS, K_N = as defined in connection with Equation 7.16(4)

W_s = the required relieving steam capacity, lbm/hr (kg/hr)

K_N = the Napier correction factor, which is 1.0 if P₁ < 1500 PSIA (10,339 kPaa) [For pressures between 1500 PSIA (10,339 kPaa) and 3,200 PSIA (22,057 kPaa), use Equations 7.16(10) and 7.16(11) to calculate the value of K_N.]

K_N = (0.1906P₁ – 1000)/(0.2292P₁ – 1061) (in US units)  
7.16(10)

K_N = (0.02764P₁ – 1000)/(0.03324P₁ – 1061) (in SI units)  
7.16(11)

K_HSN = the superheat correction factor, which is 1.0 for saturated steam (For steam tables, refer to Appendix 5 or see manufacturers’ tables.)
Safety and Miscellaneous Sensors

Sizing for Liquid Relief

The 1986 edition of ASME UG-131 requires that, for pressure relief valves on incompressible fluid service, a capacity certification test using water at a temperature between 40 and 125°F be conducted. For any other fluid, the manufacturer’s tables generally can be used as long as the equivalent water volumetric rate in gpm is used to enter these tables.

Division I of the ASME Code Section VIII, since 1980, has required that liquid service PRVs be provided with capacity certification. This certification requires that the rated coefficient of discharge be based on 10% overpressure. Existing PRVs that were manufactured before 1980, were not provided with certification, but were sized with 25% overpressure allowance need not be replaced, but new PRVs must be designed for 10% overpressure operation.

For preliminary sizing purposes, disregarding viscosity and backpressure effects, the graph in Figure 7.16j can be used.

Calculating the Discharge Area For more accurate sizing for liquid service PRVs, refer to Equations 7.16(12) and 7.16(13) below:

\[
A = \frac{Q}{(38K_dK_wK_cK_v)} \sqrt{SpG/(P_1 - P_2)} \quad \text{in US units}
\]

\[
A = \frac{11.78Q}{(K_dK_wK_cK_v)} \sqrt{SpG/(P_1 - P_2)} \quad \text{in SI units}
\]

where

\[A, K_c, P_1, P_2 = \text{as defined in connection with Equation 7.16(4)}\]

\[Q = \text{the relieving flow of liquid in GPM (l/min)}\]

\[K_d = \text{the effective coefficient of discharge, which should be obtained from the manufacturer (For preliminary sizing use } K_d = 0.65.)\]

\[K_v = \text{the variable or constant backpressure capacity correction factor, which is required only}\]

**FIG. 7.16j**

Approximate relief valve sizing chart for liquids.
7.16 Relief Valves

— Sizing, Specification, and Installation

1001

for bellows sealed PRV valves (Figure 7.16k) (For conventional or pilot-operated valves, or when the backpressure is atmospheric, use $K_w = 1.0$.)

$K_w =$ the capacity correction factor for viscosity, which can be obtained from Figure 7.16l or from Equation 7.16(14), in which $R$ is the Reynolds number

$$K_w = [0.9935 + (2.878/R^{0.5}) + (342.75/R^{1.5})]^{{-1.0}}$$

7.16(14)

$\text{SpG} =$ specify gravity of liquid at flowing conditions relative to water at $60^\circ F$

**Viscosity Correction** The factor $K_w$ accounts for the fact that the resistance to flow encountered when handling viscous liquids above 50 to 100 SSU may reduce the velocity and thus capacity enough to require a larger orifice size than the usual liquid capacity formula would indicate. Because the correction factor is a function of the flow conditions, and these in turn depend on the orifice diameter, a trial orifice is usually calculated based on no viscosity correction at all, based on Figure 7.16k.

Having determined this “nonviscous orifice size,” the next larger standard orifice is selected and used on the graph shown in Figure 7.16m to find the correction factor. This procedure is then repeated, using the corrected value as a trial value, until the corrected required orifice area is less than that of the standard orifice that was used to establish the $K_w$ factor.

**Sizing for Flashing Liquid Relief**

API RP 520 Appendix D (7th ed., 2000) describes a method for PRV sizing on two-phase service, but it is still a somewhat controversial subject. No sizing method has been validated by tests, nor is there any recognized procedure for certifying two-phase relief capacity. Problems associated with flashing include the possibility of autorefrigoration and ice formation, which might require the use of heat tracing or specially selected PRV materials.

While the actual sizing is discussed below, certain features of the valve discharge system can affect both valve sizing and the cost of the installation. Because the amount of flash is influenced by the discharge line size through the actual backpressure developed, the ability of discharge line sizing to suppress vapor generation should be considered. Based on limited experience and some calculation, it appears that the most economical valve size results at about 30% backpressure. Balanced safety valves are usually used in flashing flow to minimize the effects of the flashed vapors and of the resultant backpressure on valve operation and capacity.

In the absence of experience in a particular service, some manufacturers use an enthalpy balance (isenthalpic flash)
across the valve to calculate the expected volumetric rates of liquid and vapor downstream of the valve. The required discharge areas are then established independently for these two rates, which are treated as all liquid and all vapor, respectively. Both sizing calculations must be made at the same overpressure with the appropriate capacity correction factors applied as needed. The discharge area of the PRV is selected to be at least equal to the sum of these two calculated areas.

While this method is not theoretically refined, there have been no reported incidents in which this procedure led to an undersized valve. The method could conceivably lead to an oversized valve, which in turn can possibly result in valve chatter. However, it is probable that the valve plus its discharge piping will come to a stable condition of balance between the effects of flashing and the downstream pressure drop.

**Special Cases**

There are a number of special cases (such as relieving polymericizing materials, handling high-temperature water, Dowtherm® systems, super pressure steam system, cryogenic fluids, toxic materials relief, etc.) for which manufacturers have developed special designs of valves and sizing experience or special sizing methods. It is recommended that the reader avail himself of all available advice and assistance. Frequently, the recommendations of two manufacturers will not agree. The reader is thus alerted that he has a problem case and that further study may be warranted.

**SPECIFICATION AND SELECTION**

Pressure relief valves serve to provide relief from overpressure by opening a path for the excess process fluids flow to a safer location. After the excess pressure is relieved, they reclose, thereby not only preventing the further loss of process fluids but also returning the process to normal operation. A properly designed and installed PRV will perform these tasks automatically, reliably, economically, and efficiently.

The most commonly accepted means of providing this is to sense the rising pressure by some sort of force-balance mechanism that, when its set point is reached, opens the required relieving area for fluid flow. Usually, this force balance has the process pressure acting upon a given area on one side; on the other side, that force is compared against the force of springs or weights. The magnitude of the forces that are being balanced can be reduced, and thus their control improved, through the use of secondary devices such as pilot valves, solenoids, etc. Of the above-mentioned design options, the weight-loaded valves have largely disappeared from process plant services except in extremely low-pressure applications where their high accuracy and the absence of the “spring constant” effect caused by valve travel makes them advantageous.

Figure 7.16m shows a specification form that can be used to list the required features of pressure relief valves before they are sent out for bids by PRV manufacturers. Figure 7.16o provides some cost estimating information on a list price basis, which plant engineers can use if, based on their previous projects, they know their probable discount schedules.
### Pressure Relief Valves Specification Form

**FIG. 7.16n**

Pressure relief valve specification form.

```
<table>
<thead>
<tr>
<th>NO</th>
<th>BY</th>
<th>DATE</th>
<th>REVISION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GENERAL**

1. Tag Number
2. Service
3. Line No./Vessel No.
4. Full Nozzle/Semi Nozzle
5. Safety or Relief
7. Bonnet Type

**CONN.**

8. Size: Inlet | Outlet
9. Flange Rating or Screwed
10. Type of Facing

**MATERIALS**

11. Body and Bonnet
12. Seat and Disc
13. Resilient Seat Seal
14. Guide and Rings
15. Spring
16. Bellows

**OPTIONS**

17. Cap: Screwed or Bolted
18. Lever: Plain or Packed
19. Test Gag
20. 
21. 
22. 
23. 

**BASIS**

24. Code
25. Fire
26. 
27. 

**FLUID DATA**

28. Fluid and State
29. Required Capacity
30. Mol. Wt., Oper. sp. gr.
33. Constant
34. Back Pressure | Variable
35. Total
36. % Allowable Overpressure
37. Overpressure Factor
38. Compressibility Factor
39. Latent Heat of Vaporization
40. Ratio of Specific Heats
41. Operating Viscosity
42. Barometric Pressure
43. 
44. 
45. Calc. Area sq. in.
46. Selected Area
47. Orifice Designation
48. Manufacturer
49. Model No.

**Notes:**

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**Conventional PRVs**

As it is shown in Figure 7.16, the conventional PRV is a force balance device that is held closed by a spring when the inlet pressure is below its set pressure. When the set pressure is reached, the upward force overcomes that of the spring, and the valve opens. When the inlet pressure drops below the set pressure by some percentage (this difference is called blowdown), the valve recloses. The housing of the spring is vented to the outlet of the PRV, and therefore the operation of the valve is directly affected by the backpressure.

The main difference in the operation of a PRV on liquid relief service from that of a vapor relief valve is that it does not have “pop action.” This is because, on liquid service, the force that lifts the disc is generated by the reactive forces (the impact of the flowing liquid stream on the disc holder) to achieve full lift. These reactive forces build slowly during the initial 2 to 4% of overpressure, and only after that will the valve suddenly surge to full lift. The blowdown (the percentage by which the inlet pressure has to drop below the set pressure for the valve to close) on liquid service is much larger than on gas service—around 20%.

**PRV Bodies and Bonnets** The basic requisite for a direct spring-loaded pressure-relieving valve is a suitable valve body, which is usually an angle-type device, having an inlet connection that is suitable for the inlet pressure/temperature requirements under both normal and relieving conditions. The body,
the outlet, and the bonnet are usually designed for a lower pressure than the process pipeline or the inlet connection of the PRV. Body connections can be flanged, screwed, or welded.

The bonnet is sized to accommodate the spring for the maximum pressure rating of the valve. The bonnet is used when the discharging medium must be confined within the valve body and discharge piping. All bonnet-type valves have either caps over the adjusting bolt or lifting levers, either plain or packed.

Flanged valves for steam boilers usually have an open spring with a yoke in place of a closed bonnet. The spring is exposed on the steam valve, whereas the spring is totally enclosed on the bonnet type valve. Marine boiler valves are of the yoke type except that additional cover plates must be added and sealed to prevent tampering with the spring. The covers are vented (not pressure tight).

**Seat and Spring** The PRV inlet incorporates a valve seat with a disc for full closure of the inlet port. The disc is usually spring loaded, and the spring force is applied directly on the disc by means of a stem. The disc may be either disc guided or top guided. A bottom (disc)-guided valve has vanes or feathers for guiding in the valve bore (inlet port). Process valve are usually top guided (Figure 7.16p). Boiler valves and liquid relief valves are often disc guided.

The set pressure is determined by the selection of the proper spring and by adjusting the bolt that compresses the spring to the correct opening pressure. Springs are classed in different ranges so that the spring is never over stressed and so that proper clearance between the coils allows for full lift. The spring force at open position must not exceed the lifting force of the flowing medium when the valve is open. The spring setting may be adjustable in a narrow range. This adjustment can be 30% or more on low-range springs and 5% on higher-range springs. The manufacturer must be consulted for the acceptable range for a particular spring.

**Nozzles and Blowdown Rings** The inlet of the PRV may be described as a bushing, semi-nozzle, or full nozzle. The bushing is used on bottom-guided valves. The semi-nozzle is usually found in cast iron valves. Both are screwed into the PRV’s body. The full nozzle is utilized on steel valves and is the part of the valve that is designed for the pressure rating of the process line.

The seat, orifice, and flange facing is one piece. The flange of the valve is used for bolting force, which is to ASA standards. The nozzle flange construction is similar to a Van Stone-type flange. The discharge area or orifice of a nozzle type valve is smaller than the nominal inlet. The converging of the nozzle results in high velocity, which provides the high kinetic energy required to obtain high lift.

**Pop Action** The capacity of PRVs must be accurately calculated, and their action must be reliable and foolproof over the long run. Reliability is achieved by the maximum use of simple mechanisms such as springs and linkages, and so forth. Accuracy in relieving capacity is achieved by conservatism, by treating the relief device as an orifice, and by attempting to size and install it so that it can always release the process fluid (and thus energy).

In Figure 7.16p, one should note that there is an adjustable ring around the nozzle. Furthermore, the disc has either a fixed or adjustable deflecting lip. The purpose of this lip is to form a huddling chamber, which provides the pop action of these pressure relief valves. The inlet nozzle is used to efficiently generate the required velocity head (and thus capacity), while the lip and the ring on the nozzle form a secondary orifice and a device for reconversion of this velocity energy into static pressure to provide the pop action when sufficient vapor flow develops.

**Valve Lift and Capacity** Being spring-loaded, PRVs require some increase in force, because the movement of the spring occurs while the valve is opening. The amount of this force increase is determined by the spring constant and by the amount of valve lift required to achieve full capacity. Most PRVs reach their full capacity opening at about 3% above their set pressure. If the pressure rises further, the area of opening does not increase, so the increase in PRV capacity is the result only of increased valve pressure differential.

Therefore, at 3% overpressure, the valve has fully lifted. At this point, the curtain or cylinder area (huddling chamber) between nozzle and disc is greater than the cross-sectional area of the nozzle. The so-called low-lift valves gain more capacity at higher pressure, because they have not reached their limiting dimensions for the curtain area at the low overpressures. In such cases, it is not permitted under the ASME Code to calculate down-ratings for valves at lower pressure based on performance at a higher test pressure, although up-rating above test pressure is permitted, because it will always tend to be quite conservative.

In contrast to gas or vapor PRVs, liquid service relief valves generally do not reach their full capacity dimensions until their full nominal rating overpressure of 10% is reached. In liquid PRVs designed prior to 1980, this overpressure was 25%. Down-rating to lower pressures is permitted and provided by all manufacturers. It is important to understand and design for this up-rating and down-rating, especially when considering actual flow during maximum relief. This can affect pressure losses in inlet and outlet piping.

**Balanced PRVs**

Two of the most common means of eliminating the effect of backpressure on the set pressures of a PRV’s set pressure are the use of bellows seals and of a balancing piston design. Figure 7.16q describes both of these devices. The balanced disc, which is operated by a vented piston, is shown on the left, and the bellows sealed designs are on the right. Note that these devices may or may not provide a true balance, depending on how well they match the nozzle area.
The backpressure effect on the PRV’s set pressure has already been discussed in connection with Figure 7.16c. This figure illustrated several valve designs and four different means of remedying this effect. On the lower right, Figure 7.16c illustrates a PRV that is provided with vented bellows seals. In this design, if the bellows area (A_B) is the same as the nozzle area (A_N) of the PRV, the valve will be balanced, and the backpressure will have no effect on the pressure set point at which the valve opens. Such a balanced PRV is shown on the upper right of Figure 7.16q.

If the bellows area (A_B) is not the same as the nozzle area (A_N), the valve will be unbalanced, and the backpressure will affect the set point. Even among balanced bellows designs, there are differences among the K_b correction factors of different manufacturers (Figure 7.16r). These variations are a function of the specific valve design.

Equations 7.16(4) and 7.16(5) should be used when sizing balanced bellows PRVs for gas or vapor service. In these equations, the backpressure correction factor K_b serves to correct for the loss in capacity resulting from subcritical flow and for the condition when the valve disc does not lift fully. For preliminary sizing estimates, Figure 7.16b can be used to obtain a K_b correction factor, but, because each manufacturer’s PRV design is a little different, the actual value of K_b should be eventually obtained from the selected manufacturer.

When sizing the PRV for liquid service, it is common practice to use the minimum pressure drop in the standard formula [Equation 7.16(12) or 7.16(13)], which includes the K_v factor for backpressure correction. For liquid applications as well, there is variation in this factor among vendors.

As was shown by Equation 7.16(14), viscous materials adversely affect the capacity of relief valves. Because the required correction depends on the Reynolds number, the point at which a correction is required will be a function of orifice size, flow rate, and flowing viscosity (Figure 7.16i). There is reasonably good agreement among manufacturers as to the viscosity correction, and there is also general agreement that viscosities below 50 to 100 SSU do not require correction.

**Pilot-Operated PRVs**

The pilot-operated PRV shown in Figure 7.16s consists of an unbalanced floating piston type main valve and an external or integral pilot. During normal operation, because the area of the piston is larger on the top than on the bottom, and because both are exposed to the same process pressure, the resulting net force holds the PRV tightly closed. As the process pressure rises, the seating force increases with it. This feature is an advantage in applications in which the maximum operating pressure is close to the relief set pressure and it is important to prevent leakage.

When the set point is reached, the pilot vents the pressure from the top of the piston, and the piston lifts. When the process pressure drops below the set point of the pilot, it closes its vent, which, in turn, reseats the piston.

The pilot can be pop-action or modulating and can be flowing or nonflowing. The modulating design can save expensive process fluids and can shorten the system recovery time by relieving only as much process fluid as needed to lower the pressure below its set point. For most services except for inert gases, the nonflowing designs are preferred.
7.16 Relief Valves—Sizing, Specification, and Installation

Integral or External Pilot The PRV on the right of Figure 7.16s utilizes an integrally mounted conventional safety valve that, based on the relationship between the process pressure and its set point, sends the process pressure to the top of the main piston or vents it. The external pilot design on the left permits adjustment of blowdown without a need for entering the valve proper and uses an external sensing line to the pilot.

There are also pilot-operated PRVs in which the blowdown and relief settings are independently adjustable through the pilot valves mounted on top of the main piston or disc chamber. Most of these designs have not received wide acceptance because of the large number of static and moving seals they require for proper functioning and because of the small clearances and potentials for plugging in the pilot mechanisms.

Advantages Where operating pressures approach the set pressure, and where the process fluids are toxic and thus present hazardous leakage problems, pilot-operated valves present special economic and safety advantages.

1. The probability of leakage is reduced when the operating pressure approaches the set pressure because, as the process pressure increases, the forces that are holding the piston closed also increase. In contrast, in the spring-operated valves, the differential pressure on the seat decreases under these conditions, causing simmering near the set pressure.
2. Flexibility is provided by the potential for remote operation.
3. Because nozzles are not needed to generate the velocity for pop action, the capacity is larger. The potential increase in capacity over the largest nozzle orifice for a given body size ranges from 150% for smaller sizes to about 120% for the larger sizes.
4. There is improved operability at up to 98% of set pressure due to lower blowdown. Figure 7.16t shows these advantages.
5. There is a reduction in the loss of product, downtime, and maintenance.

Disadvantages
1. There is increased potential for failure due to the large number of static and moving parts.

FIG. 7.16s
Pilot-operated relief valve designs showing the external (left) and integral pilot versions (right).
2. Small clearances exist in pilot mechanisms that can be plugged by dirty process fluids.
3. The lead lines between the process and the pilot valve and between pilot and main valve are small in size and therefore have a higher potential for plugging.

### Modulating Pilot-Operated Valves

The modulating pilot-operated relief valve is especially useful where some degree of oversizing is necessary or desirable, because this valve design helps to eliminate chattering. The main feature of the modulating pilot-operated relief valve is that it has a zero blowdown, which allows the main valve to modulate while being approximately at the set pressure.

On gas or vapor service, this valve is at full lift when the overpressure is about 3%, and when it is about 10% on liquid service. Due to the variable orifice feature, the modulating PRV valve opens only to relieve the overpressure and hence reduces both the noise and the upset to the downstream process. **Figure 7.16u** shows the lift of the valve piston as a function of the process pressure during modulation. It can be seen that this PRV valve changes its lift (opening) as the rate of discharge is surging, thus avoiding chatter.

### When to Consider Pilot-Operated PRVs

When the following conditions exist, it is justified to consider the use of pilot-operated PRVs (POPRVs):

1. The expected PRV inlet losses are significant.
2. The margin between the operating pressure and the set pressure is less than 10%.
3. The operating pressure is less than 15 PSIG.
4. The lighter weight of the POPRV is a consideration.

---

**FIG. 7.16t**

Comparing the operating ranges of conventional spring-loaded PRVs to the ranges of pilot-operated ones.

<table>
<thead>
<tr>
<th>Process Operating Pressure</th>
<th>Spring Loaded Valve</th>
<th>Pilot Servo Safety Valve</th>
<th>Pilot Servo Safety Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.22 × Po</td>
<td>Set at Usual Pressure</td>
<td>Set at a Lower Pressure</td>
<td></td>
</tr>
<tr>
<td>1.20 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.18 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.16 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.14 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.12 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.10 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.08 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.06 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.04 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.02 × Po</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **5** Cut Product Losses
- **6** Reduce Down-Time
- **7** Cut Maintenance
- **8** Increased Safety when Sized at 1.02 × Po
- **9** 9% Increased Throughput
- **10** Min. Valve Size Set Here

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5. If the required orifice size is larger than "P," both cost and operating performance favor the consideration of using POPRVs.

6. A depressuring system is needed.

   In connection with "depressuring," it should be noted that such units should be used only as backups in addition to regular pressure-relieving systems. These backup systems should be sized to lower the process pressure from the set pressure to 50% of design pressure within 15 min. They are considered when the response time of the regular PRVs is insufficient on reactors with potential for runaway reactions, on gas filled tanks exposed to fire, on high-pressure fluid applications in the event of major leakage, and in the reduction of hydrogen partial pressure to minimize the potential for exothermic reactions.

**Specification and Selection Checklist**

In addition to selecting a particular pressure relief valve for a specific service, it is advisable to review the following checklist of the most frequent PRV system problem areas:

1. Make sure that, from among ASME Section I and VIII, API, NFPA, etc., the right codes have been followed.

2. Specify both maximum and minimum normal operating temperatures and design the PRV for those and not for the temperatures that might be reached during fire relief conditions. Evaluate the high-temperature effects on the seat and seal of the PRV, check for temperature causing disc warpage or spring set-point change.

3. Make sure that the set pressure of the PRV is equal to or less than the tank design pressure. If the PRV protects several vessels, make sure that the hydrostatic head of liquids is considered in selecting its set point so that the design pressure, even at the lowest point, will not be exceeded.

4. Make sure that the inlet and outlet line losses are consistent with the code limits, and consider the use of POPRVs with remote pressure detection when high inlet loss is unavoidable.

5. Select a safe discharge point for the PRV if the process fluid is toxic, corrosive, or flammable to protect both the operators and the environment.

6. Consider the possible process upsets as well as start-up and shut-down conditions when selecting the operating margin (difference between set pressure and operating pressure) for the PRV; if the process fluid is toxic, corrosive, or very valuable, make that margin large.

7. Consider galling or seizing problems in guiding or other close clearance areas, which can be caused by bad materials selection, foreign matter entry, or deposit buildup.

8. Check for atmospheric corrosion effects on the discharge portion of the valve bonnet and other portions of the discharge header system. Check, in particular, the effect on high-stressed elements such as springs. Consider the use of diaphragm seals and bellows seals.

9. Consider the possibility of polymer or other material buildup in throats of valve or operating mechanism after or during relief, which could impair valve action. Consider the use of various seals.

10. Consider the resistance of the PRV valve assembly to vibration.
11. Provide the valve designs that will minimize chatter on pulsating services.
12. Consider the probable condition of the valve and its seating after exposure to external fire.
13. Evaluate whether the inlet, outlet, and/or the PRV itself requires thermal tracing, because winter temperatures can cause freezing of the process fluid. Evaluate the need for steam jacketing to prevent tendencies of solidification or crystallization within the valve. Check, in particular, the degree of steam jacketing required.
14. Make sure the features are provided to accurately guide the disc.
15. Check the need for valve position indicating devices.
16. Check the availability and desirability of augmenting normal disc seating forces or keeping them constant until the valve set point is reached so as to minimize leakage.
17. Select seat and seal materials that are compatible with, and are not dissolved by, the process fluids. On H2S service, make sure that the valve materials are selected in compliance with NACE MR0175. Also, make sure that the seat will reseat tightly after relieving on specific service.
18. Make sure that the proper design features are selected for countering the effects of all types of backpressures and the resulting variations in set point and blowdown.
19. Evaluate the consequences of, and provide the ability to detect, bellows rupture.
20. Consider open-spring vs. bonneted-spring designs.
21. Evaluate the degree of blowdown needed and answer questions such as: Does blowdown have to be adjustable? Can pop action be destroyed in adjusting blowdown?
22. Evaluate the need for special service valves such as chlorine service, toxic material, LPG storage tank, ICC approved, Coast Guard approved, etc.
23. Evaluate the need for various auxiliary features such as test gags, lifting levers open or packed, screwed vs. bolted adjusting nut caps, etc.
24. Evaluate the level of noise produced and its effect on discharge piping.

**PRV OPERATION AND PERFORMANCE**

The topics of blowdown, PRV chatter, valve tightness or leakage, and discharge system considerations are discussed in the following paragraphs.

**Blowdown**

The phenomenon of blowdown is caused by the use of springs in PRVs. The relieving system, when in operation, is a kinetic system in which the PRV is at a point of high kinetic energy in contrast to the equipment that it is protecting. The valve spring balances against a pressure that equals the pressure in the protected tank minus the kinetic effects.

When the PRV is closed, the system is a static one, with no kinetic effects. Therefore, the pressure at the point of spring balance is equal to that in the protected tank. When the PRV is open, its inlet pressure is less than the pressure in the protected vessel because of the inlet pressure drop. This discrepancy between relieving and static conditions requires the allowance for blowdown.

Blowdown is the amount by which the protected tank’s pressure has to drop below the PRV’s set pressure for the valve to reseat. This pressure difference is needed to ensure that the valve satisfies its force balance once it closes. The normal blowdown of a PRV is between 2 and 7% of set pressure. Pilot-operated PRVs can reduce the blowdown to about 2%, and engineers should always consult the supplier of a particular PRV design for the actual percentage of their design.

Section I of the ASME code for fired boilers requires that the PRVs reach their full lift at a pressure not greater than 3% over their set point and reclose within the maximum blowdown values given in Table 7.16v. Section VIII of the ASME code for unfired vessels does not provide a blowdown requirement, and the industrial practice is about 7%, which means that the normal operating pressure must be under 93% of set pressure.

**Setting the Blowdown** The position of the adjustable ring on the PRV nozzle (Figure 7.16p) controls the blowdown. This position establishes a secondary orifice area as the valve opens and closes. Blowdown is set by first bringing this ring all the way up to the disc (this corresponds to the maximum blowdown position) and then lowering it a number of turns as recommended by the vendor. This is necessary because most test facilities have limited supplies of gas, and the set pressure is usually tested at zero blowdown.

For process PRVs, the percent blowdown per turn is usually based on methane. A 5% blowdown setting established by using methane can represent about 11% when the valve is handling butane. Very few manufacturers can provide or have published data on this.

If blowdown is an important consideration, field tests usually must be made after the PRV is installed. Even then, it is nearly impossible to simulate actual, desired, or design relieving conditions. Pilot-operated valves are much less subject to these considerations, because they can usually be set for smaller blowdowns. Three percent is fairly standard for a POPRV, and as little as 1% can be achieved in some cases.

**TABLE 7.16v**

Blowdown Recommendations by ASME for Fired Boilers and Associated Tanks Operating at up to 375 PSIG

<table>
<thead>
<tr>
<th>Pressure Relief Valve Set Pressure in PSIG</th>
<th>Maximum Blowdown Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;67</td>
<td>4 PSI</td>
</tr>
<tr>
<td>&lt;67 to &lt;250</td>
<td>6% (of set pressure)</td>
</tr>
<tr>
<td>&gt;250 to &lt;375</td>
<td>15 PSI</td>
</tr>
</tbody>
</table>
PRV Chatter

Energy losses in the inlet piping to the PRV and the protected tank (as well as an oversized valve) can lead to a condition known as chatter. Under these conditions, the PRV valve repeatedly cycles between its open and closed positions. Variations in backpressure exceeding about 10% while a conventional PRV is relieving will also produce an unstable force balance condition and chatter.

Section II of API RP-520 endorses the widely used limit of 3% of set pressure as the maximum limit for the pressure loss in the inlet piping of a PRV. If, during relief, there are losses much higher than 3%, they can drop the pressure at the PRV seat to the reseating value. When this happens, the valve closes, but as soon as it does, it is immediately subjected to a pressure rise, because closure has eliminated the kinetic effects. This rise in pressure can be enough to cause the PRV to reopen, and the cycle repeats.

Oversized valves can also cause this same condition, because a spring-loaded valve needs to have about 20 to 30% of its maximum flow to establish a stable force relationship to maintain a stable disc position. Chatter has at least two detrimental effects. One is that the valve’s seating condition will cause leakage. The other detrimental effect is that allows failure can be expected if the disc chatters or flutters.

Chatter and Inlet Line Loss in POPRVs

Pilot-operated valves are not subject to chatter to the same extent, because they are open or closed and cannot “throttle down” to flows in the 20 to 30% range. Thus, if they are oversized, repeated openings and closings may be needed to hold the system pressure, and the net result is an action approaching chatter. Modulating pilot-operated relief valves overcome the basic problem of oversizing and inlet pressure losses that are the causes of chatter.

As far as their set pressure is concerned, POPRVs can have more than 3% pressure drop in their inlet line if they are using a remote sensor (Figure 7.16s shows a local pressure pilot line). In such situations, the inlet line loss will still limit the relieving capacity of the valve. Therefore, the inlet line loss should always be considered before the POPRV is sized. If this is not done, when the inlet loss is calculated, it might be found that a larger valve needs to be used. Naturally, in all high line loss cases, one should consider the relocation of the POPRV to the point where the remote pilot line detects the process pressure.

Chatter on Liquid Service

The subject of chatter is of special interest when relief valves are mounted on vessels that are full of liquid. In the past, conventional valves designed for vapor service were also used in liquid service, and this had catastrophic results. This is because, in a liquid system, the pressure profile immediately upstream of the PRV valve can change rapidly when the valve “pops open,” especially if there is a significant length of inlet piping between the valve and the vessel being protected. In that case, when the valve opens rapidly, an immediate reduction in pressure (at the inlet to the valve) can make the PRV valve close prematurely. The pressure then builds back up again quickly, the valve must open again, and the cycle repeats; thus, chatter ensues.

Most manufacturers offer a liquid-service trim designed specifically to overcome this problem. The piping between the inlet to the valve and the process being protected should be kept to a minimum. Direct connection of the valve to the process vessels is preferred, if practical. Another potential solution is to use a pilot-operated or modulating pilot-operated PRV valve that is provided with a remote sense line, depending on the process conditions and type of process liquid.

PRV Tightness and Leakage

If fire is the only potential cause of overpressure, the valve tightness in spring-loaded valves can be markedly improved by taking advantage of the 20% accumulated pressure that the ASME Code allows for this condition (Table 7.16w).

If one valve is set for 109% of maximum allowable working pressure (MAWP), and 10% accumulation is allowed, this results in the same size valve as one set at 100% allowing 20% accumulation. However, if the operating pressure is at or near 90% of the maximum allowable, the first valve will have about twice the force keeping the seat tight at the operating pressure as that available in the case of the second valve (Figure 7.16x).

Using Two PRVs

Another way to reduce leakage in some installations is to use two PRVs. This is a possibility if, in a particular application, there is a large fire load but relatively

<table>
<thead>
<tr>
<th>PRV Installation</th>
<th>Single Set%</th>
<th>Single Accumulated%</th>
<th>Multiple Set%</th>
<th>Multiple Accumulated%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Fire Case, 1st PRV</td>
<td>100%</td>
<td>110%</td>
<td>100%</td>
<td>116%</td>
</tr>
<tr>
<td>Non-Fire Case, Additional PRV</td>
<td>N/A</td>
<td>N/A</td>
<td>105%</td>
<td>116%</td>
</tr>
<tr>
<td>Fire Case, 1st PRV</td>
<td>100%</td>
<td>121%</td>
<td>100%</td>
<td>121%</td>
</tr>
<tr>
<td>Fire Case, Additional PRV</td>
<td>N/A</td>
<td>N/A</td>
<td>105%</td>
<td>121%</td>
</tr>
<tr>
<td>Fire Case, Supplemental PRV</td>
<td>N/A</td>
<td>N/A</td>
<td>110%</td>
<td>121%</td>
</tr>
</tbody>
</table>
small operating load. In such a case, the small valve is set at 100% and sized for 10% accumulation at the operating load, but it will accumulate to 20% under fire conditions. The large PRV is set at 109% and is sized to handle the fire load 10% overpressure. Such a combination of two PRVs will generally reduce leakage quantities (Figure 7.16y).

The use of a pair of PRVs becomes even more attractive if company policy requires the use of two PRVs. Similarly, on low-pressure tall towers, if the API recommendation is followed and therefore the PRV inlet loss is limited to 3% of set pressure, the use of two valves becomes attractive.

**Seat Designs, O-Rings, and Temperature**   Greatly influencing valve tightness are the factors of seating design, cleanliness of the process fluid handled, and installation practices. In the area of seating closure design, some of the mechanical containment designs of the nozzle, disc, and guiding moving parts have been claimed to pay off handsomely in terms of trouble-free service.

The so-called soft seat designs and the O-ring seats do much to prevent leakage as long as the PRV does not relieve. However, it is good practice to check the design and question the vendor about what the leakage will be after the PRV

---

**FIG. 7.16x**

Characteristics of a single safety relief valve used to protect a pressure vessel having the listed requirements.

<table>
<thead>
<tr>
<th>PRESSURE VESSEL REQUIREMENTS</th>
<th>VESSEL PRESSURE</th>
<th>TYPICAL SAFETY RELIEF VALVE CHARACTERISTICS SET AT M.A.W.P., SIZED FOR 10% O.P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX. ALLOWABLE ACCUMULATED</td>
<td>120</td>
<td>ALTERNATE UPSTREAM PRESSURE (FLOWING PRESSURE) UNDER FIRE CONDITIONS</td>
</tr>
<tr>
<td>PRESSURE (FIRE EXPOSURE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX. ALLOWABLE ACCUMULATED</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>PRESSURE (OTHER THAN FIRE EXPOSURE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAX. ALLOWABLE SET PRESSURE</td>
<td>110</td>
<td>MAX. SET PRESS. (POP)</td>
</tr>
<tr>
<td>(SUPPLEMENTAL VALVES ONLY,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER THAN FIRE EXPOSURE)</td>
<td></td>
<td>MAX. ALLOWABLE WORKING PRESS.</td>
</tr>
<tr>
<td>MAX. ALLOWABLE WORKING PRESS.</td>
<td>105</td>
<td>ALTERNATE OVERPRESSURE (AVG. SET)</td>
</tr>
<tr>
<td>MAX. ALLOWABLE SET PRESS.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(OTHER THAN FIRE EXPOSURE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RECOMMENDED MARGIN 25 PSI OR</td>
<td>100</td>
<td>OVERPRESSURE (FIRE EXPOSURE)</td>
</tr>
<tr>
<td>172.5 kPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORMAL OPERATING PRESS.</td>
<td>90</td>
<td>MAX. ALLOWABLE ACCUMULATED PRESSURE</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>(FIRE EXPOSURE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAX. ALLOWABLE ACCUMULATED PRESSURE (OTHER THAN FIRE EXPOSURE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ALTERNATE OVERPRESSURE (AVG. SET)</td>
</tr>
</tbody>
</table>

NOTE: ABOVE VALVE WOULD MEET THE REQUIREMENTS OF UG-125 (c), UG-125(d) AND UG-133(a), ASME UNFIRED PRESSURE VESSEL CODE.
resends. In some designs, the O-ring is actually expected to be shredded or destroyed during relief. Therefore, until the ring is replaced, the PRV will only provide a metal-to-metal secondary seal after the first relief.

Temperature probably provides the most serious limitation on soft seal or O-ring materials. In addition to soft seat sealing, the flexible seat has been well received in some services outside the temperature limits of synthetic seating materials. The knife-edge seat is perhaps the most desirable for services where icing or similar deposits can form on the seat during relief. The knife-edge seat has also been used on liquid services containing fine solids in suspension.

**Flatness and Cleanliness**
Most process service valves as tested and shipped by the manufacturer have a seat finish of less than 5 µin. with a flatness deviation of less than 5 to 15 µin. (0.13 to 0.38 µm). For this reason, even nozzle deformation caused by bolting stresses is a concern.

The method of holding the nozzle in the pressure-containing body to minimize the effects of bolting forces is one of the distinguishing features of some PRV designs. Other design goals include minimizing piping reactions that would tend to deform the nozzle, applying the spring load to the disc, and various disc designs that act to compensate for differential expansion effects. These are refinements that

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**FIG. 7.16**
Illustrating the various pressures in a case where a supplemental valve has been installed to handle the fire load.
manufacturers have developed as users demanded tighter, longer-lasting valves while the PRV service conditions grew progressively more severe.

The influence of fluid cleanliness on PRV performance is illustrated by contrasting the refinery or chemical industry practices to those of missile service. In a number of refinery and chemical plant applications, experience has shown that the valve will leak once it has opened and reseated. In many plants, it is accepted that you may just as well take it down, clean and lap it, reset it, and reinstall it.

Contrast this with the shop inspection requirements on some missile service PRVs where 200 successive cyclings on clean, high-pressure nitrogen must still leave the valve virtually bubble tight. This requirement is regularly met on a production basis.

**PRV INSTALLATION**

The inlet and outlet line losses of the individual PRVs are calculated on the basis of their rated capacity, not on their required relieving capacity. This approach should also be used as the basis for sizing PRV manifolds so as to minimize built-up backpressure and PRV chattering.

**PRV Location**

Pressure relief valves should be placed close to the tank or equipment they are protecting to minimize their inlet pressure losses. Their location should also be selected with the goal of avoiding unstable flow patterns and minimizing inlet turbulence. Therefore, a minimum distance of ten pipe diameters should be provided between such fittings as orifices, elbows, valves, and flow nozzles and the PRV.

Relief valves should be located with full consideration given to the need for convenient maintenance access. Easy and safe access is a very important element in making sure that inspection and testing is regularly performed. If there is no convenient natural access to the valve, the installation of a platform should be considered. PRVs should not be located at the end of long and stagnant horizontal pipes.

**PRV Mounting**

Vapor relief valves should be mounted on the top of the protected tank and should be connected to its vapor space above the liquid level or to piping that is connected to the vapor space. Liquid service PRVs should be connected below the normal liquid level in the tank. All PRVs should always be mounted vertically, not only because horizontal mounting can adversely affect their operation but also because horizontal mounting violates the ASME code and the API recommended practice.

Pressure relief valves should not be mounted close to vibration or turbulence sources such as orifice plates or positive displacement pumps/compressors. This is because the pressure spikes can cause premature relieving, and the pulsation can alter the PRV’s set pressure.

PRVs should not be mounted at the end of horizontal pipes, either. This is because, when the PRV opens, debris such as welding slag, pipe scale, and foreign objects that are present in the horizontal pipe will be transported into the valve and will either cause leaking after the PRV recloses or require immediate maintenance to be performed on the valve.

**PRV Inlet Piping**

The inlet pipe to all PRVs should be as short and direct as possible and should be the same size or larger than the inlet connection of the valve. The inlet pipe should not connect to locations in the process where unstable or turbulent flow patterns exist. When the PRV is relieving vapors, it should be sloped upward to the PRV so that liquid entrainment would be minimal. If the line has a low point, it should be drained.

If the process is such that the inlet pipe can be plugged, it is recommended to provide a clean, nonreactive liquid purge to keep the inlet line clean. If plugging of the inlet line can be caused by low temperatures, such as generated by the cooling of high-viscosity polymers or by ice formation at ambient temperatures, the PRV inlet line should be heat traced.

**PRV Outlet Piping**

The outlet pipe size should be the same as or larger than the PRV outlet connection. The outlet pipe should be sized to limit the backpressure when the PRV is relieving so that this backpressure will neither shift the set pressure nor prevent the PRV from operating at its full rated capacity. In case of conventional spring-loaded PRVs, the maximum limit for built-up backpressure is 10% of the set pressure. For PRVs with balanced bellows, it is between 30 and 50%. For pilot-operated PRVs, it is 50% of the set pressure.

The outlet pipe should always be properly drained. The preferred choice is to provide self-draining. When that is not possible, a low-point drain with shut-off valve should be provided, and the drain should be piped to a closed system.

In selecting the materials of construction for the outlet pipe, design engineers should evaluate the possibility of autorefrigeration occurring during PRV relieving. If that is the case, the expected low temperatures should be calculated, and suitable pipe materials should be selected to protect against fracturing the brittle metal.

When the PRV discharges to the atmosphere, long-radius elbows should be used, and both the weight of the outlet pipe and the reaction forces should both be considered in designing the pipe supports. The tail pipes should be angle-cut to reduce both the relieving noise level and the reaction force. Local bylaws should be consulted in setting the allowable noise level, which should be calculated on the basis of API RP 521, Section 5.4.4.3.4, in the 1997 edition.
The discharge location should be selected so that, if steam, hot water, or nitrogen is being discharged, it will not injure the operators. The tip of the atmospheric outlet pipe should be provided with both a screen and a weather cap.

**Calculating the Reaction Force**

Large reaction forces generated by the large volumes and high velocities of discharged fluids as the discharging stream makes a 90° turn at the PRV can overload supports, distort manifolds, and cause leakage related accidents—even fire. When the PRV discharges directly to the atmosphere, the outlet piping should be brace supported and, in case of very large valves, even dual outlets should be considered to balance the reaction forces. The reaction force of an open PRV discharge can be calculated using Equation 7.16(15).

\[
F = \left(\frac{W}{366}\right)\sqrt{\frac{k}{(k + 1)M_w}} + A_o P_2
\]

where
- \(F\) = the reaction force in lb
- \(W\) = the required relief capacity of the PRV in lb/hr
- \(k\) = the ratio of specific heats of the relieved gases (Table 7.15a)
- \(A_o\) = the area of the outlet of the discharge pipe at the point of discharge, in.\(^2\)
- \(T\) = the flowing temperature of the relieved vapors at the inlet of the PRV in °R
- \(M_w\) = the relieved gas or vapor
- \(P_2\) = the pressure inside the discharge pipe at the point of discharge in PSIG

When the PRV discharge is sent into a closed system, only at points of sudden expansion is it likely that significant reaction forces will exist. The manifold supports in such cases should be designed on the basis of detailed calculations.

**PRV Block Valves**

Section I of the ASME Boiler and Pressure Vessel Code does not allow the use of block valves at all. In contrast, PRVs protecting nonfired pressure vessels are permitted to be isolated on both their inlets and outlets if off-line maintenance is impossible. In that case, block valves are permitted if they are provided with a spare PRV and if the service they are in has a history of leakage, plugging, or other causes of frequent maintenance.

When isolating valves are used around PRVs, they must be distinguished by special tagging, and the plant operations should be such that only authorized personnel can operate them. It is also important that the open and closed positions be visible and clearly identified. The plant’s operating manual should clearly state the required position of these block valves and should also state the reasons why they are locked open or closed. The operating manual should require not only the periodic checking of PRV isolation valve positions but also the checking of their condition.

**Multiple PRVs**

One situation in which the use of a small and a large PRV is justified on the same tank or equipment is when the process can have two vastly different relieving capacities. In such a case, the smaller valve is needed, because a single large one would chatter when relieving small flows. The other case, when multiple valves of identical size can be used, is when the total relieving area required is more than that of a “P” orifice (Figure 7.16g). Whenever multiple valves are installed, one PRV should be set at the set pressure and the other(s) at 105% of that pressure, as listed in Table 7.16w.

The use of multiple PRVs can extend their life spans and make it easier to keep their inlet line losses below 3% of set pressure. Another advantage can be the reduction of the PRV inventory of the plant, if the use of multiple valves reduces their variety in the plant.

Among the multiple valves, each should have its own nozzle or other direct connection to the protected vessel or equipment. No tree branching of several PRVs from the same main inlet line should be used.

**Spare PRVs**

PRVs on critical equipment or processes that cannot be shut down should be provided with spares so that the processing operation can continue even when the PRV fails. The installation of a spare PRV is also recommended if the maintenance history of a particular valve is such that it needs maintenance more often than at regular service intervals.

Spare PRVs are also needed on applications in which the valve needs immediate servicing after each time it relieves because the process fluid is corrosive, fouling, or contains solids. Spares are also recommended if the PRVs operate near their extreme design limits, such as at very low or very high temperatures.

Whenever a PRV is spared, the spare valve must be provided with full-bored isolation valves on both its inlets and outlets. Car seal open (CSO) valve designs are required for these applications, because these block valves must be locked open when the spare PRV is in service.

**TEST, INSPECTION, AND AUDIT**

There are three levels of continuous status maintenance and reviews of pressure safety systems. Periodic testing serves to make sure that the performance of each PRV is within specifications. The purpose of inspections is to check on the quality and reliability of the testing program, whereas the main purpose of the audits is to make sure that the design of the safety systems has been adopted to the various changes that are always occurring in operating plants.
PRV Testing

All PRVs should be tested before their installation, after each fire event or case of relieving dirty process fluids, and at the frequency of the service intervals set by the plant. Certified technicians are required to perform the PRV tests. Testing is performed either in a test workshop or, if the PRVs are provided with field test connections, in situ.

During the test, technicians should look for signs of tampering, process-related damage, leakage, wear, and corrosion. They should also test the set pressure, blowdown, overpressure, and seat tightness of each PRV and make the required adjustment, if any. To test the tightness of the seat, they should follow API Standard 527.

After the testing is done, the staff should prepare a test report for each PRV and mark the PRV tag with the date and test pressure that was checked.

PRV Inspection

The purpose of the inspection is to ensure that the testing was properly performed and that no foreign objects, welding beads, or rust was left inside the PRVs. The inspector will also check for signs of tampering, leakage, erosion, wear, and corrosion and verify that the PRV flanges are clean and in good condition.

The inspectors will also make sure that the PRV’s tag is the same one that appears on the P&ID flow sheet and that it is securely tied to the valve. Finally, the inspectors should also make sure that the performance data obtained during testing and reported in the test report are acceptable for the particular PRV application.

PRV Audit

The audit evaluates the pressure safety of a complete processing unit. The main goal of the audit is to confirm that the tasks in the action list of the previous audit have been performed, and the maintenance strategy of the plant has been properly followed. Any process changes that have occurred since the last audit are carefully evaluates in terms of their effects on the pressure safety systems.

If, because of the process changes, PRVs can be removed, or previously acceptable ones have become oversized or undersized, the audit should reveal that. The final product of an audit is a prioritized new action list that will serve to further improve the operating safety of the plant.

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