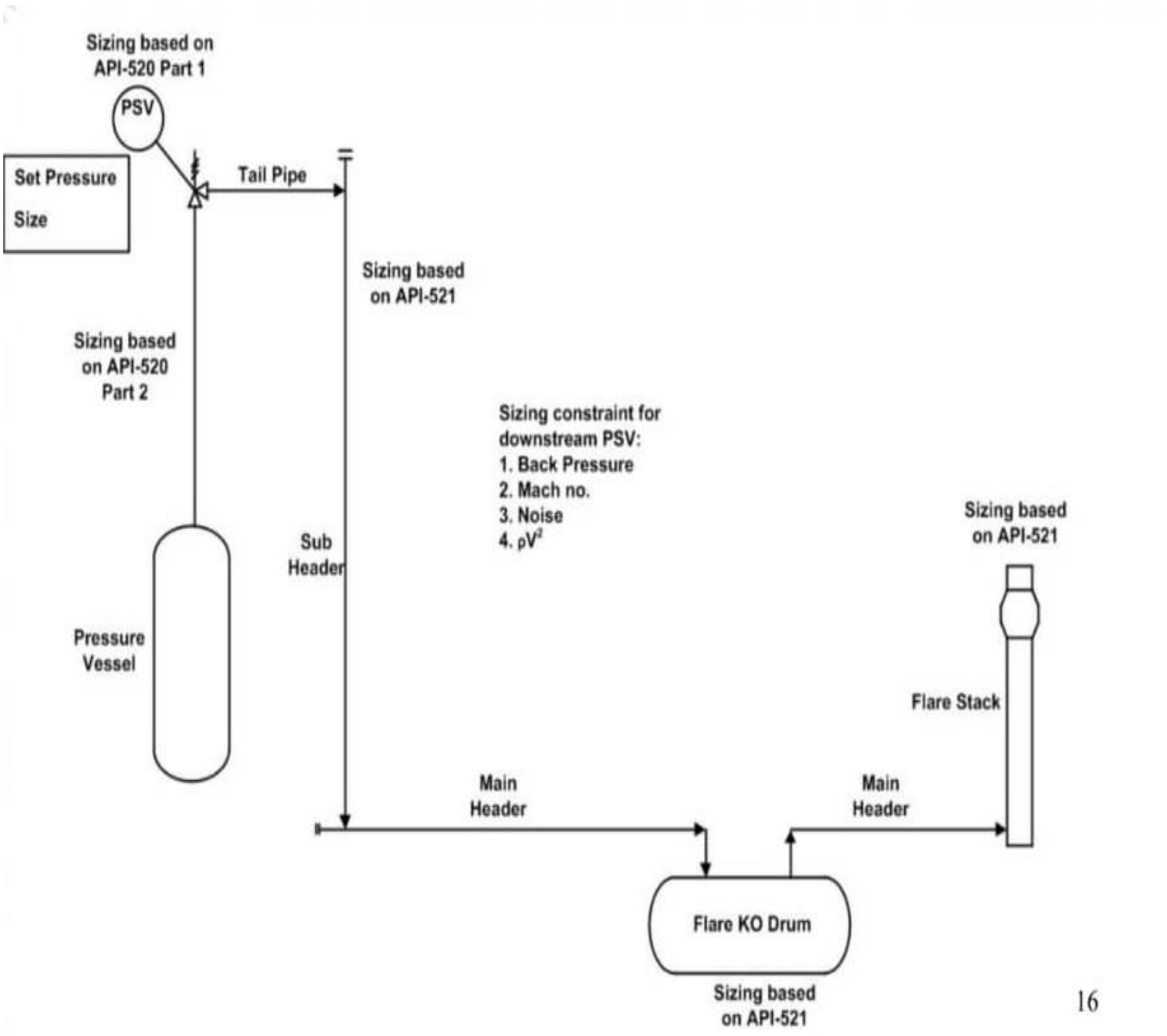
Education Institute for

Equipment & Process Design

PSV General Guideline


Sizing based on API-520 Part 1
PSV
Set Pressure
Size
Tail Pipe
Sizing based on API-521
Sizing based on API-520 Part 2
Sizing constraint for downstream PSV:
1. Back Pressure
2. Mach no.
3. Noise
4. ρV²
Sizing based on API-521
Sub Header
Pressure Vessel
Flare Stack
Main Header
Main Header
Flare KO Drum
Sizing based on API-521
16

Chapter 1

Definitions and Terms

Maximum allowable working pressure (MAWP)

The maximum gauge pressure permissible at the top of a completed vessel in its normal operating position at the designated coincident temperature specified for that pressure. The pressure is the least of the values for the internal or external pressure as determined by the vessel design rules for each element of the vessel using actual nominal thickness, exclusive of additional metal thickness allowed for corrosion and loadings other than pressure. The MAWP is the basis for the pressure setting of the pressure-relief devices that protect the vessel. The MAWP is normally greater than the design pressure but can be equal to the design pressure when the design rules are used only to calculate the minimum thickness for each element and calculations are not made to determine the value of the MAWP.

Design pressure

Pressure, together with the design temperature, used to determine the minimum permissible thickness or physical characteristic of each vessel component as determined by the vessel design rules. The design pressure is selected by the user to provide a suitable margin above the most severe pressure expected during normal operation at a coincident temperature. It is the pressure specified on the purchase order.

This pressure may be used in place of the MAWP in all cases where the MAWP has not been established. The design pressure is equal to or less than the MAWP. In most of the cases, however, the pressure relieving device is set at the design pressure and not at the M.A.W.P. because the latter is only known late in the design, when the detailed mechanical design of the vessel is completed.

Accumulation

The pressure increases over the MAWP of the vessel, expressed in pressure units or as a percentage of MAWP or design pressure. Maximum allowable accumulations are established by applicable codes for emergency operating and fire contingencies.

Blow-down:

for gas 5-7% and for 2-phase and liquid is 20%

Overpressure:

is the pressure increase over the set pressure of the primary relieving device during discharge. Overpressure is the same as accumulation only when the relieving device is set to open at the maximum allowable working pressure of the vessel

Backpressure

The pressure that exists at the outlet of a pressure-relief device as a result of the pressure in the discharge system. Backpressure is the sum of the superimposed and built-up backpressures.

Built-up backpressure

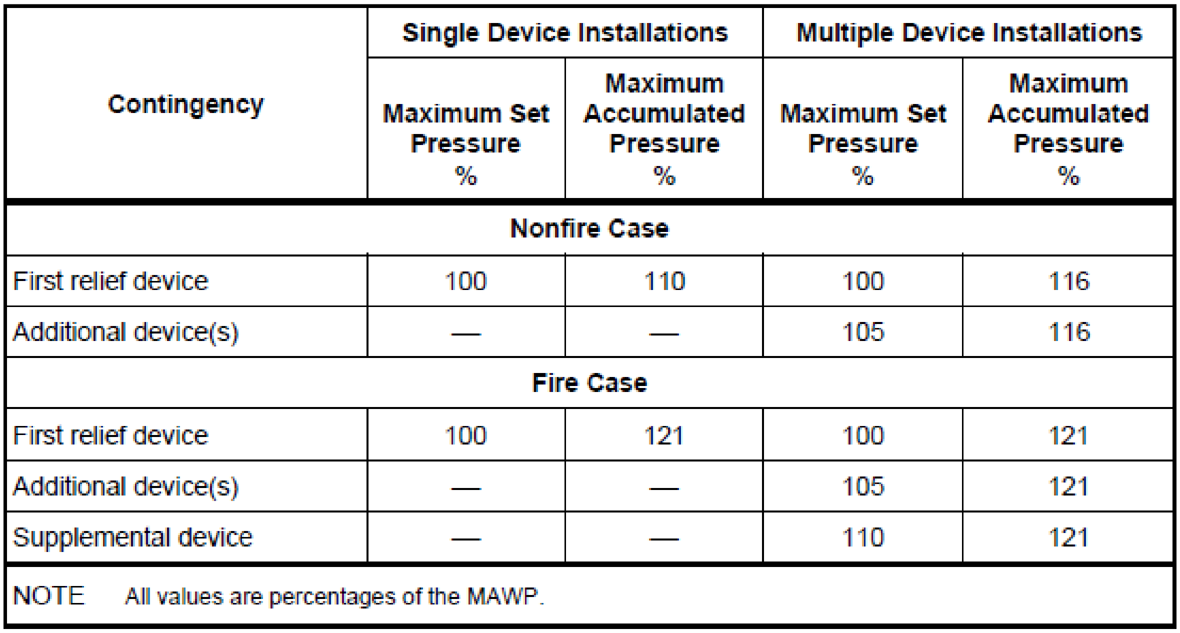
The increase in pressure at the outlet of a pressure-relief device that develops as a result of flow after the pressure-relief device opens.

Superimposed backpressure

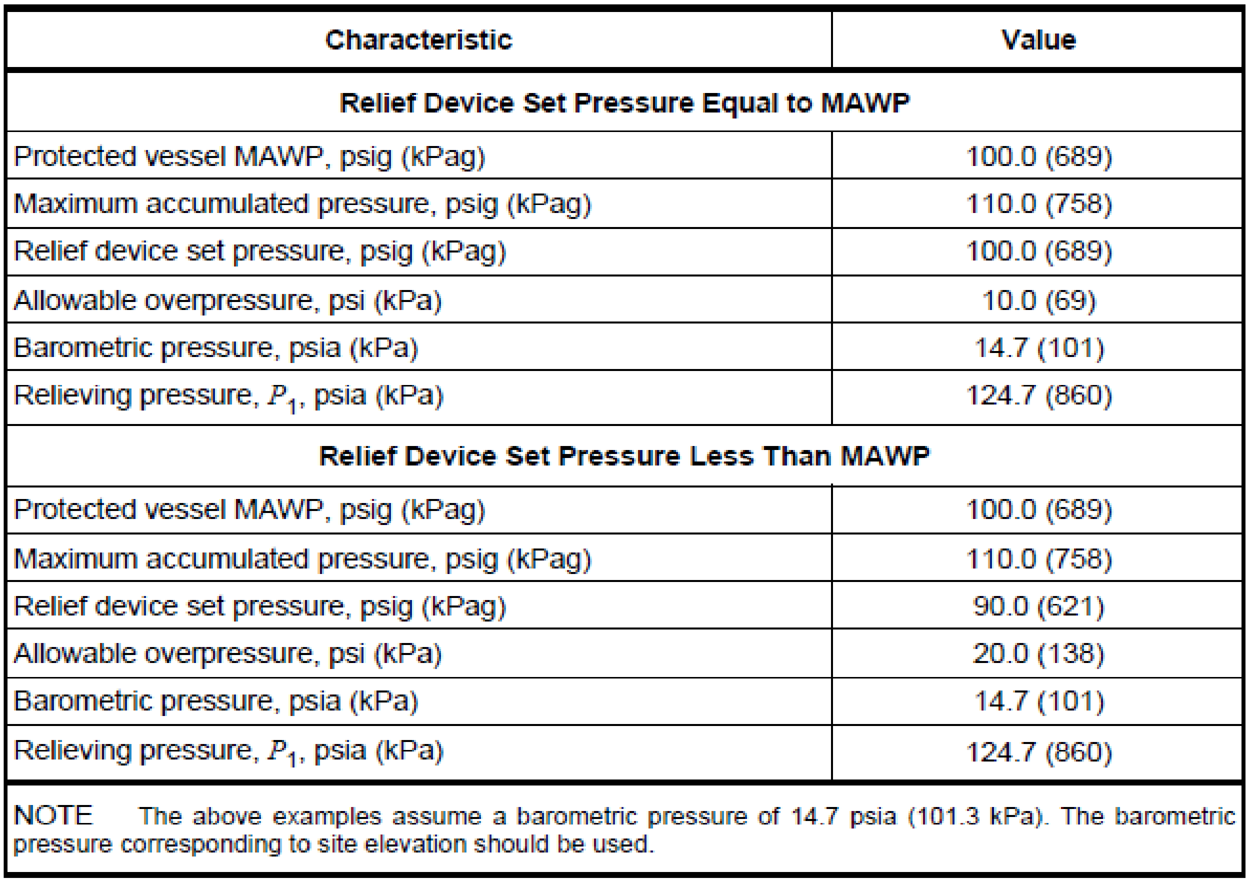
The static pressure that exists at the outlet of a pressure-relief device at the time the device is required to operate. Superimposed backpressure is the result of pressure in the discharge system coming from other sources and may be constant or variable.

Relieving conditions

Relieving pressure, shown as *P*1 in the various sizing equations, is the inlet pressure of the PRD at relieving conditions. The relieving pressure is the total of set pressure plus overpressure. The examples cited in this section for the determination of relieving pressure refer to PRVs; however, they are also applicable to non-reclosing PRDs (see Figure 15 and Figure 19 for pressure level relationships for these types of devices). The effects of inlet pressure drop on specification of relieving pressure for PRV sizing can be neglected if the inlet pressure drops does not exceed 3 % of set pressure.



Contingency	Single Device Installations		Multiple Device Installations	
	Maximum Set Pressure %	Maximum Accumulated Pressure %	Maximum Set Pressure %	Maximum Accumulated Pressure %
Nonfire Case				
First relief device	100	110	100	116
Additional device(s)	—	—	105	116
Fire Case				
First relief device	100	121	100	121
Additional device(s)	—	—	105	121
Supplemental device	—	—	110	121
NOTE All values are percentages of the MAWP.				



Characteristic	Value
Relief Device Set Pressure Equal to MAWP	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	110.0 (758)
Relief device set pressure, psig (kPag)	100.0 (689)
Allowable overpressure, psi (kPa)	10.0 (69)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	124.7 (860)
Relief Device Set Pressure Less Than MAWP	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	110.0 (758)
Relief device set pressure, psig (kPag)	90.0 (621)
Allowable overpressure, psi (kPa)	20.0 (138)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	124.7 (860)

NOTE The above examples assume a barometric pressure of 14.7 psia (101.3 kPa). The barometric pressure corresponding to site elevation should be used.

Notes

1.In general, restrictions, either a specially designed spool piece or a restriction orifice, should not be used as a means of limiting the capacity of a pressurization path.

2. When the increased operating condition will not exceed 10 hours at any one time or 100 hours per year, it is permissible to increase the pressure rating at the temperature existing during the increased operating condition, by a maximum of 33 %.

3. When the increased operating condition will not exceed 50 hours at any one time or 500 hours per year, it is permissible to increase the pressure rating at the temperature existing during the increased operating condition, by a maximum of 20 %.

Overall PSV Sizing Procedure

1.Determine the scenario, using API-521

2.Calculate the relief load, using API-520 Part1

3.Calculate the orifice area, using API-520 Part1

4.Select proper PSV type by checking backpressure

5.Use API-526 to determine the designation and the inlet and outlet sizing

6.Use API-521 Part2 to detail its construction

Chapter 2

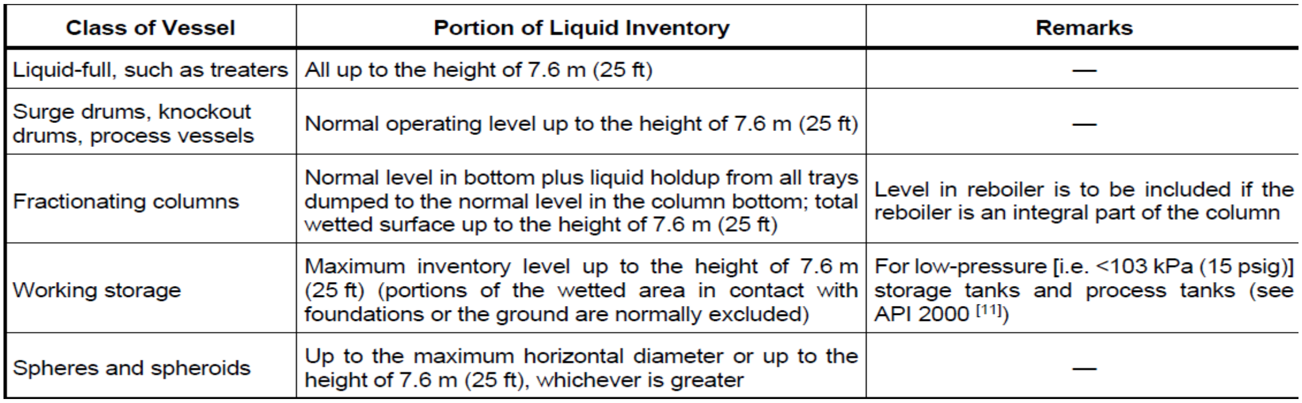
Individual Overpressure Causes and Their Relieving Rates

Fire Scenario

Fire exposure on equipment can result in overpressure due to vapor generation (boiling of liquid contents or decomposition reaction) and/or fluid expansion. Fire exposure can also cause overheating of the vessel walls resulting in a reduction in material strength. Either the vapor thermal-expansion-relief load or the boiling-liquid vaporization-relief load, but not both, should be used. It is a practice that has been used for many years. There are no known experimental studies where separate contributions of vapor thermal expansion versus boiling-liquid vaporization have been determined. When sizing the PRD for fire exposure, the contribution of vaporizing liquid compared with vapor expansion is generally governing unless, for example, the wetted surface has external insulation in accordance with 4.4.13.2.7 and the unwetted surfaces are not insulated.

Effect of Fire on the Wetted Surface of a Vessel

To determine vapor generation, it is necessary to recognize only that portion of the vessel that is wetted by its internal liquid and is equal to or less than 7.6 m (25 ft) above the source of flame. Wetted surfaces higher than 7.6 m (25 ft) are normally excluded because pool fire flames are not likely to impinge for long durations above this height.



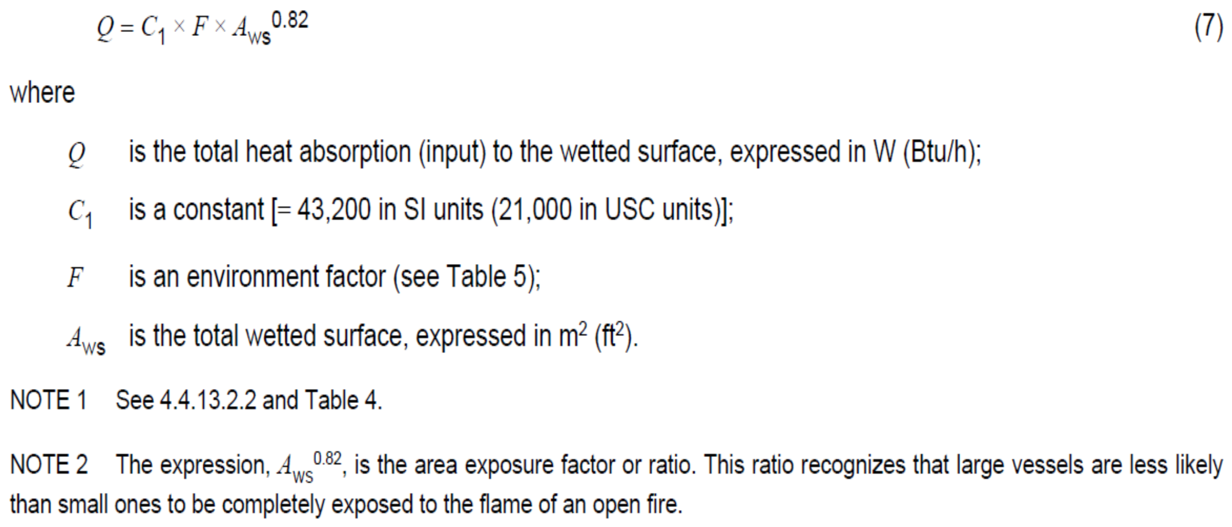
Class of Vessel	Portion of Liquid Inventory	Remarks
Liquid-full, such as treaters	All up to the height of 7.6 m (25 ft)	—
Surge drums, knockout drums, process vessels	Normal operating level up to the height of 7.6 m (25 ft)	—
Fractionating columns	Normal level in bottom plus liquid holdup from all trays dumped to the normal level in the column bottom; total wetted surface up to the height of 7.6 m (25 ft)	Level in reboiler is to be included if the reboiler is an integral part of the column
Working storage	Maximum inventory level up to the height of 7.6 m (25 ft) (portions of the wetted area in contact with foundations or the ground are normally excluded)	For low-pressure [i.e. <103 kPa (15 psig)] storage tanks and process tanks (see API 2000 [11])
Spheres and spheroids	Up to the maximum horizontal diameter or up to the height of 7.6 m (25 ft), whichever is greater	—

Effect of Fire on the Unwetted Surface of a Vessel

Unwetted wall vessels are those that have no liquid in contact with the internal vessel walls (e.g. internal walls are exposed only to a gas, vapor, or supercritical fluid or they are internally insulated regardless of the contained fluids). These include vessels that contain separate liquid and vapor phases under normal conditions but become single phase (above the critical) at relieving conditions. Vessels can be designed to have internal insulation (e.g., refractory) and such areas may be considered unwetted. A characteristic of a vessel with an unwetted internal wall is that heat flow from the wall to the contained fluid is low as a result of the heat transfer resistance of the contained fluid or any internal insulating material. Heat input from a fire to the bare outside surface of an unwetted or internally insulated vessel can, in time, be sufficient to heat the vessel wall to a temperature high enough to rupture the vessel.

Heat Absorption Equations for Vessels Containing Liquids

The amount of heat absorbed by a vessel exposed to an open fire is markedly affected by the type of fuel feeding the fire, the degree to which the vessel is enveloped by the flames (a function of vessel size and shape), the environment factor, firefighting, and drainage. Equation (7) is used to evaluate these conditions if there are Prompt firefighting efforts and drainage of flammable materials away from the vessels:



$$Q = C_1 \times F \times A_{ws}^{0.82} \qquad (7)$$

where

Q is the total heat absorption (input) to the wetted surface, expressed in W (Btu/h);

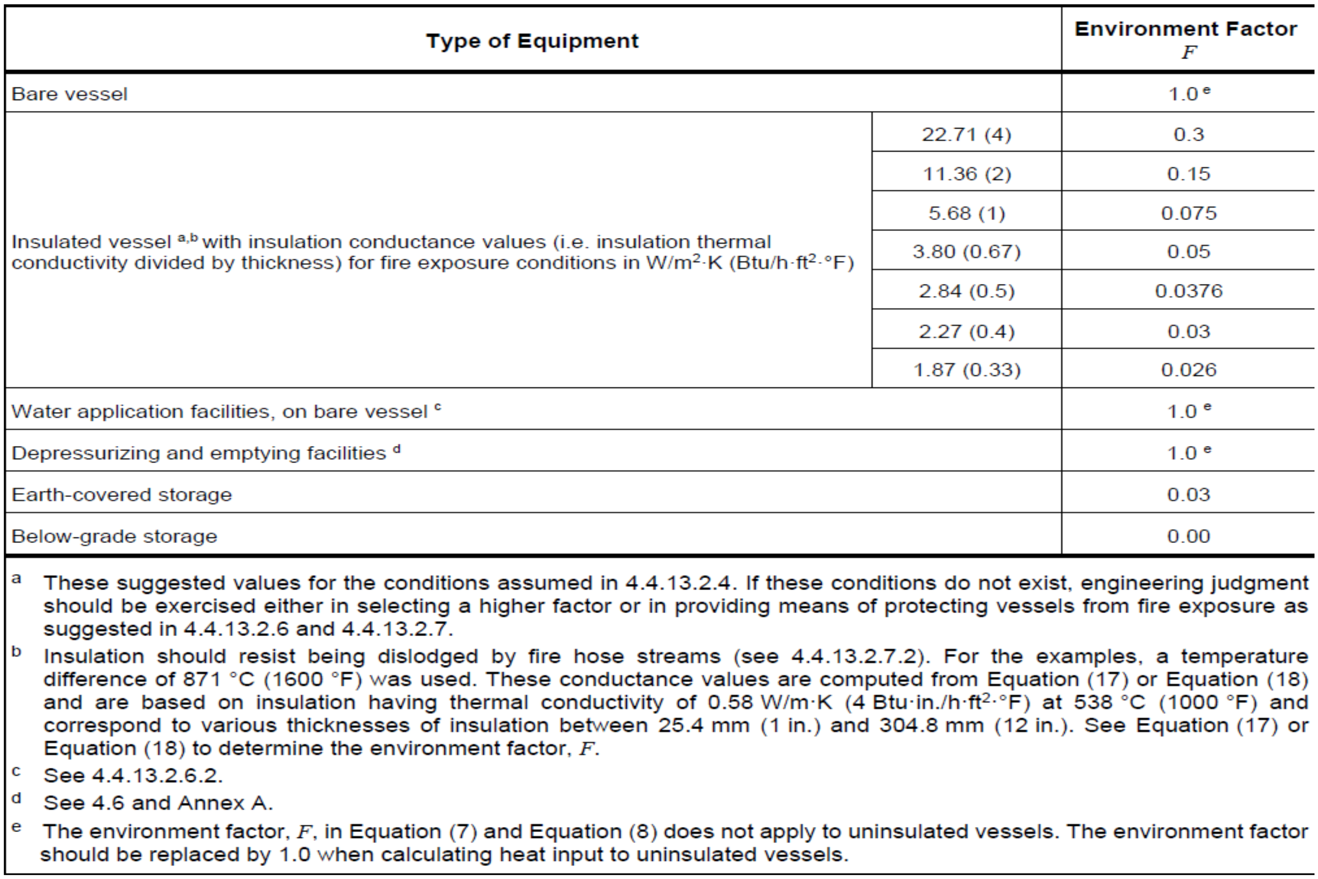
C_1 is a constant [= 43,200 in SI units (21,000 in USC units)];

F is an environment factor (see Table 5);

A_{ws} is the total wetted surface, expressed in m^2 (ft^2).

NOTE 1 See 4.4.13.2.2 and Table 4.

NOTE 2 The expression, $A_{ws}^{0.82}$, is the area exposure factor or ratio. This ratio recognizes that large vessels are less likely than small ones to be completely exposed to the flame of an open fire.



Type of Equipment		**Environment Factor** F
Bare vessel		1.0 [e]
Insulated vessel [a,b] with insulation conductance values (i.e. insulation thermal conductivity divided by thickness) for fire exposure conditions in W/m²·K (Btu/h·ft²·°F)	22.71 (4)	0.3
	11.36 (2)	0.15
	5.68 (1)	0.075
	3.80 (0.67)	0.05
	2.84 (0.5)	0.0376
	2.27 (0.4)	0.03
	1.87 (0.33)	0.026
Water application facilities, on bare vessel [c]		1.0 [e]
Depressurizing and emptying facilities [d]		1.0 [e]
Earth-covered storage		0.03
Below-grade storage		0.00

[a] These suggested values for the conditions assumed in 4.4.13.2.4. If these conditions do not exist, engineering judgment should be exercised either in selecting a higher factor or in providing means of protecting vessels from fire exposure as suggested in 4.4.13.2.6 and 4.4.13.2.7.

[b] Insulation should resist being dislodged by fire hose streams (see 4.4.13.2.7.2). For the examples, a temperature difference of 871 °C (1600 °F) was used. These conductance values are computed from Equation (17) or Equation (18) and are based on insulation having thermal conductivity of 0.58 W/m·K (4 Btu·in./h·ft²·°F) at 538 °C (1000 °F) and correspond to various thicknesses of insulation between 25.4 mm (1 in.) and 304.8 mm (12 in.). See Equation (17) or Equation (18) to determine the environment factor, F.

[c] See 4.4.13.2.6.2.

[d] See 4.6 and Annex A.

[e] The environment factor, F, in Equation (7) and Equation (8) does not apply to uninsulated vessels. The environment factor should be replaced by 1.0 when calculating heat input to uninsulated vessels.

Where adequate drainage and firefighting equipment do not exist, Equation (8) should be used

$$Q = C_2 \times F \times A_{\mathrm{WS}}^{0.82}$$

C_2 is a constant [= 70,900 in SI units (34,500 in USC units)].

Credit for thermal insulation is typically not taken because it usually does not meet the fire-protection insulation requirements. Thermal insulation not equal to fire proof insulation.

The designer should be certain that any system of insulating materials permits the basic insulating material to function effectively at temperatures up to 900 °C during a fire for up to 2 hr.

The value of thermal conductivity used in calculating the environmental factor credit for insulation should be the thermal conductivity of the insulation at the mean temperature between 904°C and the process temperature expected at relieving conditions. (Use of a conservative mean temperature of 1000°F (540°C) is suggested.)

For insulated vessels, the environment factor is given by:

$$F = \frac{k(904 - T_f)}{66\ 570\delta_{ins}}$$

k is the thermal conductivity of insulation at mean temperature, expressed in W/m·K (Btu·in/h·ft²·°F);

δ_{ins} is the thickness of insulation, expressed in metres (inches);

T_f is the temperature of vessel contents at relieving conditions, expressed in °C (°F).

Horizontal Drum

Up to 25 ft (7.6 m) above grade - Use total wetted vessel surface up to high liquid level.

Greater than 25 ft (7.6 m) above grade - Use the wetted area of the vessel surface to high liquid level or up to the vessel center line whichever is less.

Vertical Drums

The wetted vessel surface within 25 ft (7.6 m) of grade, based on high liquid level, is used. If the entire vessel is more than 25 ft (7.6 m) above grade, then only the surface of the bottom head need be included. For vessels supported on skirts that do not require fireproofing of their inside surface the surface of the bottom head need not be included in the wetted area regardless of elevation.

Vertical Vessels

A wetted = 1.089 D 2 + π D h

Use this equation when the liquid surface elevation SE < 7.6 m. If the surface elevation of liquid level is above 7.6 m, replace h by h - (SE – 7.6)

Fire Case Calculation by Software

Relief load calculation for single component:

Calculate Aw then calculate Q-fire then calculate landa then divide Q-fire to landa.

In order to calculate landa put Vf=0 and relieving pressure = 1.21pset + patm.

Relief load calculation for multi-component:

For multi-component systems, the latent heat of the residual liquid will change as the lighter components are vaporized and removed from the system. In general, such systems require a time-dependent analysis to determine the required relief area and the corresponding relief rate. The following approach is suggested.

Using the composition of the residual liquid inventory in the vessel, perform a bubble point flash at the accumulated pressure. In doing this flash, the flow rate of the feed stream to the flash can be set at initial mass on the equipment. m=ρ.V

m: initial liquid mass in the equipment

V: liquid volume in the equipment up to HLL

ρ: liquid mass density at normal operation.

For each flash, sufficient heat is applied to vaporize a nominal 10 wt% of liquid, the remaining liquid passing to the next flash.

An estimate of the time for each flash should be made.

time=required heat for each flash/calculated heat of fire.

A flash temperature of 400°C is obtained. The total vaporization time riches 2 hours**.** For each stage, a latent heat of vaporization should be calculated and data for the flashed vapor used to compute the value of a factor A’ which is indicative of the pressure relief valve orifice area required based on that stage of the vaporization of the original fluid.

A =1/Y sqr(ZT/M)

pressure relief valve orifice area parameter (not the orifice area)

λ latent heat of vaporization (kJ/kg)

z vapor compressibility

T vapor temperature (K)

M vapor molecular weigh

Two-phase relief-device sizing is not normally required for the fire case, except for unusually foamy materials or reactive chemicals.

If no accurate latent heat value is available for these hydrocarbons near the critical point, a minimum value of 115 kJ/kg (50 Btu/lb) is sometimes acceptable as an approximation

Horizontal Vessels:

Liquid level below centerline

$S=D \text{ Cos} - 1 ((r- h) / r)$

Liquid level above centerline

$S=D \{\pi\text{-Cos} - 1 ((h- r) / r)\}$

$A \text{ wetted}= (2.178D2+ \pi DL) (S/ \pi D)$

As with vertical vessels, these equations are directly useful when the liquid surface elevation S E < 7.6 m. If the surface elevation of liquid level is above 7.6 m, replace h by h - (S E – 7.6).

Trayed column

High liquid level in bottom plus liquid holdup from all trays. Level in reboiler is to be included if the reboiler is an integral part of the column. Total wetted surface up to the height of 7.6m. Vessel heads protected by support skirts with limited ventilation are not normally included as wetted surface area. Liquid hold-up on each tray shall be equal to the weir height plus 50mm.

Air-Coolers

It is not necessary to consider the bare area for air-cooled condensers, whether partial or total condensing, as long as both of the following conditions are satisfied:

1. The tubes are sloped so that they are self-draining.

2. There is no control valve or pump connected directly to the condenser

liquid outlet.

Heat Absorption Equations for Vessels Containing Only Gases, Vapors, or Supercritical Fluids

The discharge areas for PRDs on vessels containing supercritical fluids, gases or vapors exposed to open fires can be estimated using Equation (9). In certain cases, the normal operating pressure can be below the thermodynamic critical conditions but the relieving pressure is supercritical. In such cases, the guidance below can be used to size the relief device.

In the use of Equation (9), no credit has been taken for insulation:

The derivations of Equations (9), (10), (13), and (14) [53] are based on the physical properties of air and the perfect gas laws. The derivations assume that the vessel is uninsulated and has no mass, that the vessel wall temperature does not reach rupture stress temperature, and that there is no change in fluid temperature. These assumptions should be reviewed to ensure that they are appropriate for any particular situation. Insulation that meets the external insulation criteria outlined in 4.4.13.2.7 offers a mitigating benefit when gas-filled vessels are exposed to a fire by decreasing the rate at which the metal wall temperature rises.

The surface area potentially exposed to a fire should be used when determining the fire-relief requirements of gas-filled vessels.

$$A = \frac{F' \times A'}{\sqrt{p_1}} \tag{9}$$

where

A is the effective discharge area of the valve, expressed in mm^2 ($in.^2$);

A' is the exposed surface area of the vessel, expressed in m^2 (ft^2);

p_1 is the upstream relieving absolute pressure, expressed in kPa (psi);

NOTE p_1 is the set pressure plus the allowable overpressure plus the atmospheric pressure.

F' can be determined using Equation (10). If calculated using Equation (10) and the result is less than 182 in SI units (<0.01 in USC units), then use a recommended minimum value of $F' = 182$ in SI units ($F' = 0.01$ in USC units). If insufficient information is available to use Equation (10), then use $F' = 821$ in SI units ($F' = 0.045$ in USC units).

$$F' = \frac{C_9}{C \times K_D} \left[\frac{(T_W - T_1)^{1.25}}{T_1^{0.6506}} \right] \tag{10}$$

where

C_9 is a constant [= 0.2772 in SI units (0.1406 in USC units)];

K_D is the coefficient of discharge (obtainable from the valve manufacturer);

NOTE A K_D value of 0.975 is typically used for preliminary sizing of PRVs (see API 520, Part 1).

T_W is the maximum wall temperature of vessel material, expressed in K (°R);

T_1 is the gas absolute temperature, at the upstream relieving pressure, determined from Equation (12), expressed in K (°R).

The coefficient, C, is given by Equation (11):

$$C = C_{10}\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{11}$$

where

C_{10} is a constant {= 0.0395 (kg-mole-K)$^{0.5}$/(mm^2-kPa-h) in SI units [520 (lb-mole-°R)$^{0.5}$/(lbf-h) in USC units]};

k is the ideal gas specific heat ratio (C_p/C_v) of gas or vapor at relieving temperature.

$$T_1 = \frac{p_1}{p_n}\times T_n \tag{12}$$

where

p_n is the normal operating gas absolute pressure, expressed in kPa (psia);

T_n is the normal operating gas absolute temperature, expressed in K (°R).

The recommended maximum vessel wall temperature, T_w, for the usual carbon steel plate materials is 593 °C (1100 °F). If vessels are fabricated from alloy materials, the value for T_w should be based on the stress rupture data for that material. See 4.4.13.2.3, 4.4.13.2.6, 4.6.1, and Annex A for guidance on the potential for vessel failure from overtemperature due to fire exposure.

If $F' \geq 182$ in SI units ($F' \geq 0.01$ in USC units), the relief load, $q_{m,\text{relief}}$, expressed in kg/h (lb/h), can be calculated directly by rearranging the critical vapor equation and substituting Equation (9) and Equation (10), which results in Equation (13):

$$q_{m,\text{relief}} = C_{12}\sqrt{M\times p_1}\left[\frac{A'(T_w - T_1)^{1.25}}{T_1^{\,1.1506}}\right] \tag{13}$$

where

M is the relative molecular mass of the gas;

C_{12} is a constant [= 0.2772 in SI units (0.1406 in USC units)].

The minimum relief load recommended for sizing where $F' < 182$ in SI units ($F' < 0.01$ in USC units) is calculated by setting $F' = 182$ in SI units ($F' = 0.01$ in USC units), which results in Equation (14):

$$q_{m,\text{relief}} = C_{13}CA'\sqrt{\frac{Mp_1}{T_1}} \tag{14}$$

where

C_{13} is a constant [= 182 in SI units (0.01 in USC units)].

NOTE To derive Equation (13) and Equation (14), Z, K_b, and K_c in API 520, Part 1, Equation (3) have each been assumed to have a value of 1. For Equation (14), K_D is conservatively assumed to have a value of 1.

Failure of Automatic Controls Scenario

Inadvertent Valve Opening

The inadvertent opening of any valve from a source of higher pressure, such as high-pressure steam or process fluids, should be considered. Administrative controls can be used to prevent inadvertent valve opening, subject to 4.2.1 and 4.2.2. The relief load should be determined using the maximum operating pressure upstream of the valve and the relieving pressure on equipment downstream of the valve. If the pressure source is a pipeline or a production well, the pressure upstream of the valve may reach the maximum shut-in pressure of the source after a shutdown. The user should determine whether inadvertent valve opening combined with maximum shut-in pressure in upstream system is a credible relief case. There can be single or multiple inlet lines fitted with control devices. The scenario to consider is that one inlet valve is in a fully opened position regardless of the control valve failure position. Opening of this control valve can be caused by instrument failure or misoperation. If the system has multiple inlets, the position of any control device in those remaining lines shall be assumed to remain in its normal operating position. Therefore, the required relieving rate is the difference between the maximum expected inlet flow and the normal outlet flow, adjusted for relieving conditions and considering unit turndown, assuming that the other valves in the system are still in operating position at normal flow (i.e., normally open, normally closed, or throttling.

The following applies when a manual or actuated valve is inadvertently opened, causing pressure buildup in a vessel. The vessel should have a PRD large enough to pass a rate equal to the flow through the open valve; credit may be taken for the flow capacity of vessel outlets that can reasonably be expected to remain open. The manual or actuated valve should be considered as passing its capacity at a full-open position with the pressure in the vessel at relieving conditions. Volumetric or heat-content equivalents may be used if the manual or actuated valve admits a liquid that flashes or a fluid that causes vaporizing of the vessel contents.

An important consideration is the effect of having a manual bypass on the inlet control valve(s) at least partially open. If, during operation, the bypass valve is opened to provide additional flow, then this total flow (control valve wide open and bypass valve normal position) shall be considered in the relieving scenario. The potential for the bypass valve to be inadvertently opened (e.g. during normal operations, control valve maintenance, start-up, shutdown, or special operations) while the control valve is operating (both bypass and control valve wide open) should also be considered. Administrative controls can be used to prevent inadvertent opening of the bypass valve. The user is cautioned that some systems can have unacceptable risk due to failure of administrative controls and resulting consequences due to loss of containment. In these cases, limiting the overpressure to the normally allowable overpressure can be more appropriate. Note that the entire system, including all of the auxiliary devices (e.g. gasketed joints, instrumentation), should be considered for the overpressure during the failure of administrative controls.

Other situations can arise where problems involved in evaluating relief requirements after the failure of an inlet control device are more complex and of special concern (e.g. a pressure vessel operating at a high pressure where liquid bottoms are on level control and discharge into a lower-pressure system).

Usually, when the liquid is let down from the high-pressure vessel into

the low-pressure system, only the flashing effect is of concern in the event that the low-pressure system has a closed outlet. However, the designer should also consider that vapors flow into the low-pressure system if loss of liquid level occurs in the vessel at higher pressure. In this case, if the volume of the source of incoming vapors is large compared with the volume of the low-pressure system or if the source of vapor is unlimited, serious overpressure can rapidly develop. When this occurs, it can be necessary to size relief devices on the low-pressure system to handle the full vapor flow through the liquid control valve. The loss of liquid level followed by high-pressure vapor flow is commonly referred to as “vapor breakthrough” or “gas blowby.

Closed Outlets

The inadvertent closure of a valve on the outlet of pressure equipment while the equipment is on stream can expose the equipment to a pressure that exceeds the MAWP. Every valve (i.e. manual, control, or remotely operated) should be considered as being subject to inadvertent operation. If closure of an outlet valve can result in pressure in excess of that allowed by the design code, a PRD is required. If the equipment is designed to the maximum source pressure, then closure of an outlet valve will not result in overpressure, so a PRD is not required for the closed outlet scenario. Additional Considerations Involving Pumps: The system does not require relief protection for the closed outlet (i.e. shut-in) scenario if the pump, piping, and other equipment downstream of a centrifugal pump (which can be exposed to the shut-in pressure of the pump, e.g. closed block valve in the discharge system) are designed to withstand the maximum shut-in pressure of the pump or other pressure source such as a start-up or warm-up line. For positive displacement pumps, pressure-relief protection is usually required to protect the pump itself and downstream equipment against shut-in conditions.

In the case of a manual valve, administrative controls can be used to prevent the closed outlet scenario unless the resulting pressure exceeds the maximum allowed by the pressure design code [usually the corrected hydrotest pressure is exceeded.

Liquid Overfill

Liquid overfills of a vessel results in a closed outlet case. As an alternative to providing an adequacy sized pressure relief valve, the following alternative options are available for preventing overpressure:

1) Increase the system design pressure and/or pressure relief valve set pressure within code allowances.

2) Provide a safety instrument system (HIPS) to isolate the inflow on increasing vessel inventory.

3) Rely on operator intervention to prevent overfill from occurring. Where liquid overfill is

eliminated on the basis of operator intervention, at least one additional and independent alarm shall be provided to indicate that the situation has not yet been brought under control. This alarm may monitor a parameter other than level (e.g.differential pressure)

Sizing Procedure for Gases

Determine if it is in critical flow:

$$\frac{P_{cf}}{P_1} = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}}$$

where

P_{cf} is the critical flow nozzle pressure;

P_1 is the upstream relieving pressure;

k is the ratio of specific heats (C_p/C_v) for an ideal gas at relieving temperature.

If so, then:

$$A = \frac{W}{C K_d P_1 K_b K_c}\sqrt{\frac{TZ}{M}}$$

where

A is the required discharge area of the device, in.^{2} (mm^2) (see 5.2);

W is the required flow through the device, lb/h (kg/h);

C is a function of the ratio of the ideal gas specific heats ($k = C_p/C_v$) of the gas or vapor at inlet relieving temperature.

The coefficient, C, is determined as follows.

In USC units [for use in Equation (6) through Equation (8) only]:

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}} \qquad (12)$$

In SI units [for use in Equation (9) through Equation (11) only]:

$$C = 0.03948\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}} \qquad (13)$$

K_d is the coefficient of discharge; for preliminary sizing, use the following effective values:

- 0.975, when a PRV is installed with or without a rupture disk in combination;
- 0.62, when a PRV is not installed and sizing is for a rupture disk in accordance with 5.12.1.2;

P_1 is the upstream relieving pressure, psia (kPa); this is the set pressure plus the allowable overpressure (see 5.4) plus atmospheric pressure;

K_b is the capacity correction factor due to backpressure; this can be obtained from the manufacturer's literature or estimated for preliminary sizing from Figure 31. The backpressure correction factor applies to balanced bellows valves only. For conventional and pilot-operated valves, use a value for K_b equal to 1.0 (see 5.3). See 5.6.4 for conventional valve applications with backpressure of a magnitude that will cause subcritical flow;

K_c is the combination correction factor for installations with a rupture disk upstream of the PRV (see 5.12.2);

- equals 1.0 when a rupture disk is not installed;
- equals 0.9 when a rupture disk is installed in combination with a PRV and the combination does not have a certified value;

T is the relieving temperature of the inlet gas or vapor, °R(°F + 460) [K(°C + 273)];

Z is the compressibility factor for the deviation of the actual gas from a perfect gas, evaluated at inlet relieving conditions;

M is the molecular weight of the gas or vapor at inlet relieving conditions; various handbooks carry tables of molecular weights of materials, but the composition of the flowing gas or vapor is seldom the same as that listed in tables. This value should be obtained from the process data. Table 10 lists values for some common fluids, lbm/lb-mole (kg/kg-mole);

V is the required flow through the device, SCFM (Nm^3/min);

G_v is the specific gravity of gas at standard conditions referred to air at standard conditions (normal conditions); in other words, $G_v = 1.00$ for air at 14.7 psia and 60 °F (101.325 kPa and 0 °C).

If it is subcritical flow, then use the following equation for conventional or pilot type

$$A = \frac{17.9 \times W}{F_2 K_d K_c} \sqrt{\frac{TZ}{M \times P_1 (P_1 - P_2)}}$$

where

A is the required discharge area of the device, in.^{2} (mm^2) (see 5.2);

W is the required flow through the device, lb/h (kg/h);

F_2 is the coefficient of subcritical flow; see Figure 36 for values, or use Equation (22).

$$F_2 = \sqrt{\left(\frac{k}{k-1}\right) r^{\left(\frac{2}{k}\right)} \left[\frac{1 - r^{\left(\frac{k-1}{k}\right)}}{1 - r}\right]}$$

k is the ratio of the specific heats (C_p/C_v) for an ideal gas at relieving temperature; the ideal gas specific heat ratio is independent of pressure. Most process simulators can provide real gas specific heats, which should not be used in Equation (22) because the real gas specific heat ratio does not provide a good representation of the isentropic expansion coefficient (see Annex B);

r is the ratio of backpressure to upstream relieving pressure, P_2/P_1;

K_d is the coefficient of discharge; for preliminary sizing, use the following effective values:

- 0.975, when a PRV is installed with or without a rupture disk in combination;
- 0.62, when a PRV is not installed and sizing is for a rupture disk in accordance with 5.12.1.2;

K_c is the combination correction factor for installations with a rupture disk upstream of the PRV (see 5.12.2); use the following values for the combination correction:

- 1.0, when a rupture disk is not installed;
- 0.9, when a rupture disk is installed in combination with a PRV and the combination does not have a certified value;

T is the relieving temperature of the inlet gas or vapor, °R(°F + 460) [K(°C + 273)];

Z is the compressibility factor for the deviation of the actual gas from a perfect gas, evaluated at relieving inlet conditions;

M is the molecular weight of the gas or vapor; various handbooks carry tables of molecular weights of materials, but the composition of the flowing gas or vapor is seldom the same as that listed in the tables; this value should be obtained from the process data; Table 10 lists values for some common fluids, lbm/lb-mole (kg/kg-mole);

P_1 is the upstream relieving pressure, psia (kPa); this is the set pressure plus the allowable overpressure (see 5.4) plus atmospheric pressure;

P_2 is the backpressure, psia (kPa);

V is the required flow through the device, SCFM (Nm^3/min);

G_v is the specific gravity of gas at standard conditions referred to air at standard conditions (normal conditions), i.e. $G_v = 1.00$ for air at 14.7 psia and 60 °F (101.325 kPa and 0 °C).

k

Hydraulic Expansion

Hydraulic expansion is the increase in liquid volume caused by an increase in temperature (see Table 2). It can result from several causes, the most common of which are the following.

a) Piping or vessels are blocked in while they are filled with cold liquid and are subsequently heated by heat tracing, coils, ambient heat gain, or fire.

b) A heat exchanger is blocked in on the cold side with flow in the hot side.

Caution—Block valves have the potential to leak, thereby admitting either cold or hot fluid into a heat exchanger that is intended to be blocked in, resulting in a potential overpressure.

c) Piping or vessels are blocked in while they are filled with liquid at near-ambient temperatures and are heated by direct solar radiation.

Where the system under consideration for thermal relief consists of piping only (does not contain Pressure vessels or heat exchangers), a PRD might not be required to protect piping from thermal expansion if any of the following:

a) the piping always contains a pocket of noncondensing vapor, such that it can never become liquid-full; or Caution—Small vapor or gas pockets can disappear upon heating due to compression and/or solubilization. In contrast, multicomponent mixtures with a wide boiling range can always have sufficient vapor present to preclude becoming completely liquid-full. The liquid-volume change upon solar heating, heat tracing, heating to ambient temperature, or heat from another source should be estimated to determine if the volume of the vapor pocket is sufficient for liquid expansion.

b) the piping is in continuous use (i.e. not batch or semicontinuous use) and drained after being blocked in using well supervised procedures or permits; or

c) the fluid temperature is greater than the maximum temperature expected from solar heating [usually approximately 60 °C to 70 °C (approximately 140 °F to 160 °F)] and there are no other heat sources such as heat tracing (note that fire is generally not considered when evaluating pressure-relief requirements for piping);

d) the estimated pressure rise from thermal expansion is within the design limits of the equipment or piping.

Sizing and Set Pressure

Since every application is for a relieving liquid, the required relieving rate is small; specifying an oversized device is, therefore, reasonable. A nominal diameter (DN) 20 × DN 25 (NPS 3/4 × NPS 1) relief valve is commonly used.

If there is reason to believe that this size is not adequate, the procedure in 4.4.12.3 can be applied. The thermal-relief pressure setting should never be above the maximum pressure permitted by the weakest component in the system being protected. However, the PRD should be set high enough to open only under hydraulic expansion conditions. If thermal-relief valves discharge into a closed system, the effects of backpressure should be considered.

Two general applications for which thermal-relieving devices larger than a DN 20 × DN 25 (NPS 3/4 × NPS 1) valve can be required are long pipelines of large diameter in uninsulated, aboveground installations and large vessels or heat exchangers operating liquid-full. Long pipelines can be blocked in at or below ambient temperature; the effect of solar radiation raises the temperature at a calculable rate. If the total heat transfer rate and thermal expansion coefficient for the fluid are known, a required relieving rate can be calculated. See Parry [135] for additional information on thermal relief

$$q = \frac{\alpha_V \times \phi}{1000 d \times c} \qquad (2)$$

where

q is the volume flow rate at the relieving conditions, expressed in m^3/s;

α_V is the cubic expansion coefficient for the liquid at the relieving conditions, expressed in 1/°C;

NOTE This information is best obtained from the process design data; however, Table 2 shows typical values for hydrocarbon liquids and water at 15.6 °C.

ϕ is the total heat transfer rate, expressed in watts;

NOTE For heat exchangers, this can be taken as the maximum heat exchanger duty during operation.

d is the relative density referred to water (d = 1.00 at 15.6 °C), dimensionless;

NOTE Compressibility of the liquid is usually ignored.

c is the specific heat capacity of the trapped fluid, expressed in J/kg·K;

1000 is the density of water at 15.6 °C, expressed in kg/m^3.

In order to calculate the orifice area use the following equation:

$$A = \frac{11.78 \times Q}{K_d K_w K_c K_v} \sqrt{\frac{G_l}{P_1 - P_2}}$$

where

A is the required discharge area, in.^{2} (mm^2);

Q is the required relieving capacity at the flowing temperature, U.S. gal/min (L/min);

K_d is the coefficient of discharge; for preliminary sizing, an effective coefficient of discharge can be used as follows:

- 0.65, when a PRV is installed with or without a rupture disk in combination;
- 0.62, when a PRV is not installed and sizing is for a rupture disk in accordance with 5.12.1.2.2;

K_w is the correction factor due to backpressure; if the backpressure is atmospheric, use a value for K_w of 1.0. Balanced bellows valves in backpressure service will require the correction factor determined from Figure 32. Conventional and pilot-operated valves require no special correction (see 5.3);

K_c is the combination correction factor for installations with a rupture disk upstream of the PRV (see 5.12.2); use the following values for the combination correction factor:

- 1.0, when a rupture disk is not installed;
- 0.9, when a rupture disk is installed in combination with a PRV and the combination does not have a certified value;

K_v is the correction factor due to viscosity; where the liquid has a viscosity of 100 cP (0.1 Pa-s) or less, the viscosity correction factor can be set to 1. For viscosities greater than 100 cP (0.1 Pa-s), the factor should be determined from Figure 38 or from Equation (34). This equation is applicable for $Re_L \geq 80$:

$$K_v = \left(\frac{170}{Re_L} + 1 \right)^{-0.5} \tag{34}$$

where

G_l is the specific gravity of the liquid at the flowing temperature referred to water at standard conditions;

P_1 is the upstream relieving pressure, psig (kPag); this is the set pressure plus allowable overpressure;

P_2 is the total backpressure, psig (kPag).

Notes:

When a PRV is sized for viscous liquid service, it should first be sized as if it were for a non-viscous type application (i.e. *K*v = 1.0) so that a preliminary required discharge area, *A*R, can be obtained from Equation (32) or Equation (33). The user is cautioned that the equations presented here may not be applicable for non-Newtonian applications (see 5.10). From the list of API 526 standard orifice sizes or the manufacturer's listing, the next orifice size, *A* selected, larger than *A*R should be chosen to calculate the Reynolds number, Re, from either of the following relationships

$$\mathrm{Re} = \frac{Q(18{,}800 \times G_{\mathrm{l}})}{\mu\sqrt{A_{\text{selected}}}}$$

where

Re	is the Reynolds number;
Q	is the required relieving capacity at the flowing temperature in U.S. gal/min (L/min);
G_{l}	is the specific gravity of the liquid at the flowing temperature referred to water at standard conditions;
μ	is the absolute viscosity at the flowing temperature, centipoise;
A_{selected}	is the smallest standard orifice area that exceeds the preliminary area A_{R}, in.^{2} (mm^2); standard orifice sizes from API 526 or the manufacturer's table should be used;
U	is the viscosity at the flowing temperature in Saybolt universal seconds.

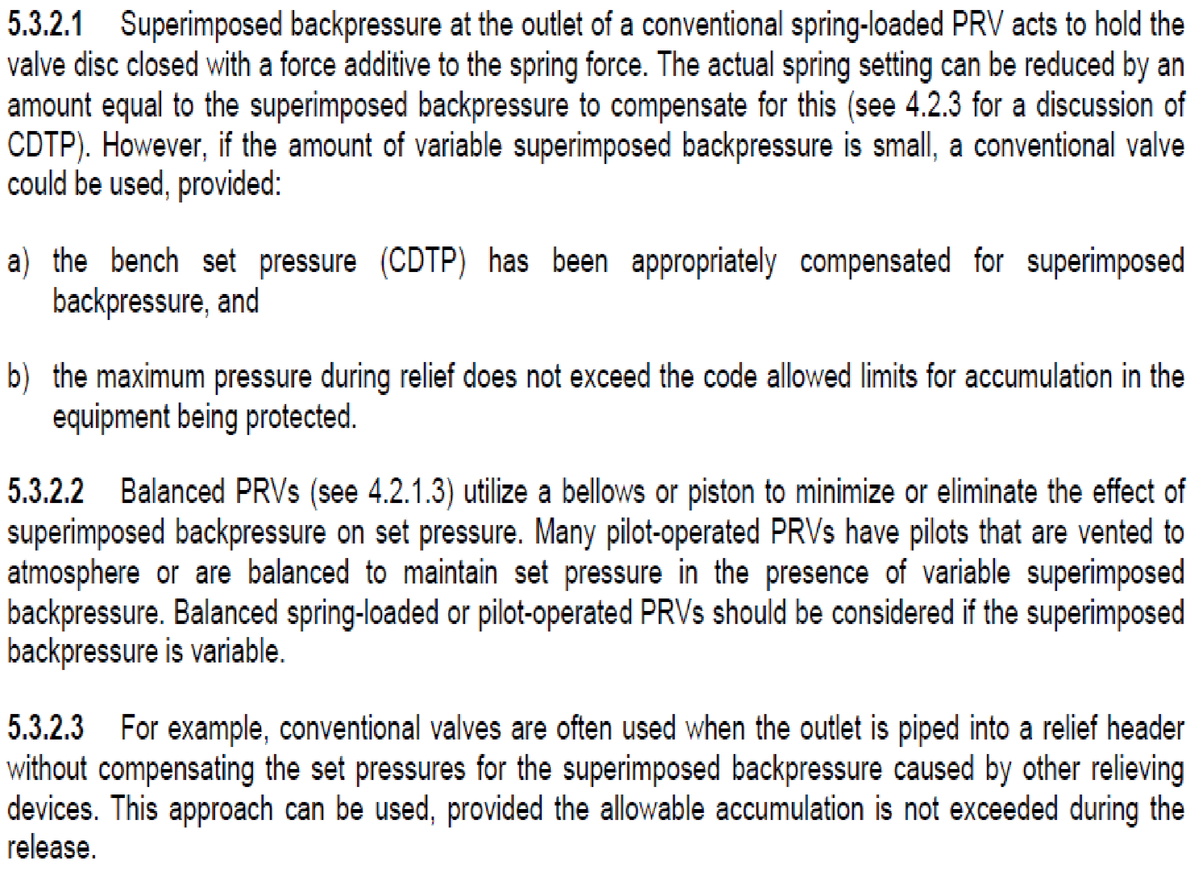
After the Reynolds number, Re, is determined, the factor *K*v is obtained and applied in Equation (32)or Equation (33) to correct the preliminary required discharge area, *A*R. If the corrected area exceeds the chosen standard orifice area, *A* selected, the Reynolds number should be recalculated using the next larger standard orifice size and the value of *K*v updated accordingly.

Designation	Effective Orifice Area (in.^{2})
D	0.110
E	0.196
F	0.307
G	0.503
H	0.785
J	1.287
K	1.838
L	2.853
M	3.60
N	4.34
P	6.38
Q	11.05
R	16.00
T	26.00

Selecting PSV Type based on Backpressure

Regardless of whether the valve is vented directly to atmosphere or the discharge is piped to a collection system, the backpressure may affect the operation of the PRV. Effects due to backpressure may include variations in opening pressure, reduction in flow capacity, instability, or a combination of all three. backpressure can be constant if the valve outlet is connected to a process vessel or system that is held at a constant pressure. In most cases, however, the superimposed backpressure will be variable as a result of changing conditions existing in the discharge system.

Effects of Superimposed Backpressure on Pressure-relief Valve Opening



5.3.2.1 Superimposed backpressure at the outlet of a conventional spring-loaded PRV acts to hold the valve disc closed with a force additive to the spring force. The actual spring setting can be reduced by an amount equal to the superimposed backpressure to compensate for this (see 4.2.3 for a discussion of CDTP). However, if the amount of variable superimposed backpressure is small, a conventional valve could be used, provided:

a) the bench set pressure (CDTP) has been appropriately compensated for superimposed backpressure, and

b) the maximum pressure during relief does not exceed the code allowed limits for accumulation in the equipment being protected.

5.3.2.2 Balanced PRVs (see 4.2.1.3) utilize a bellows or piston to minimize or eliminate the effect of superimposed backpressure on set pressure. Many pilot-operated PRVs have pilots that are vented to atmosphere or are balanced to maintain set pressure in the presence of variable superimposed backpressure. Balanced spring-loaded or pilot-operated PRVs should be considered if the superimposed backpressure is variable.

5.3.2.3 For example, conventional valves are often used when the outlet is piped into a relief header without compensating the set pressures for the superimposed backpressure caused by other relieving devices. This approach can be used, provided the allowable accumulation is not exceeded during the release.

5.3.3 Effects of Backpressure on Pressure-relief Valve Operation and Flow Capacity

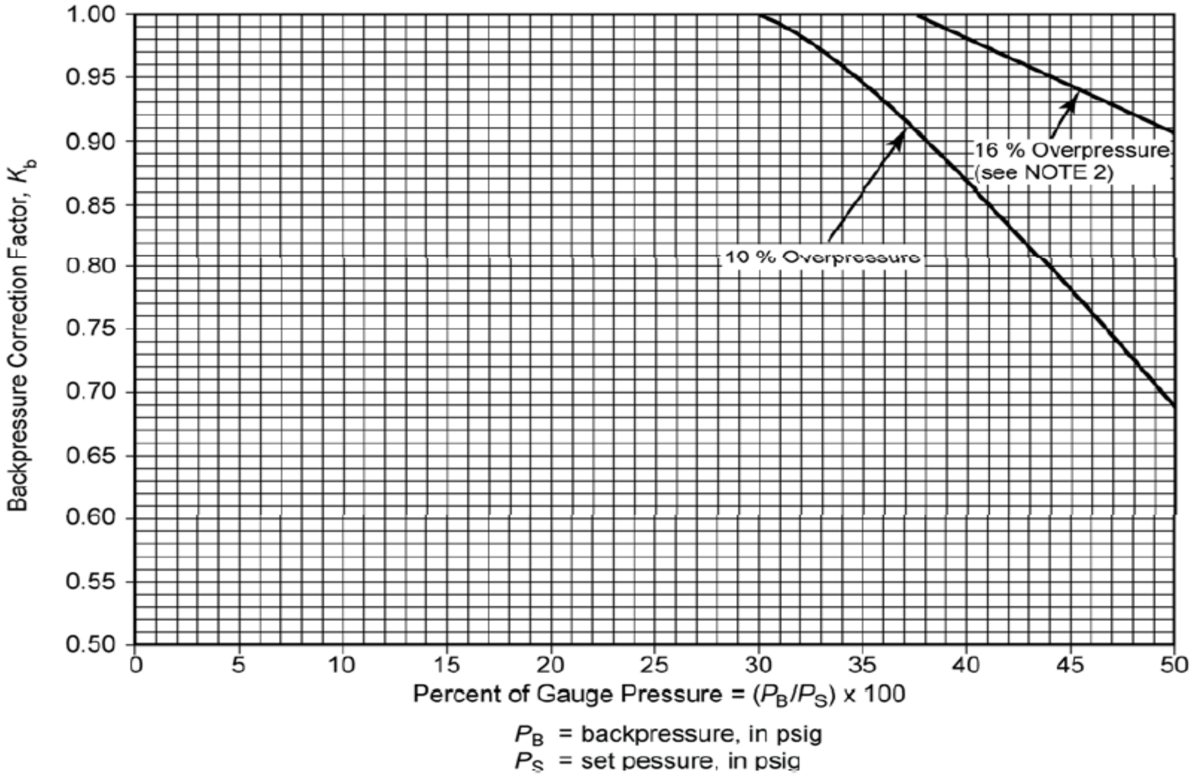
5.3.3.1 Conventional Pressure-relief Valves

5.3.3.1.1 Conventional PRVs show unsatisfactory performance when excessive backpressure develops during a relief incident, due to the flow through the valve and outlet piping. The built-up backpressure opposes the lifting force that is holding the valve open.

5.3.3.1.2 Excessive built-up backpressure can cause the valve to operate in an unstable manner. This instability may occur as flutter or chatter. Chatter refers to the abnormally rapid reciprocating motion of the PRV disc where the disc contacts the PRV seat during cycling. This type of operation may cause damage to the valve and interconnecting piping. Flutter is similar to chatter except that the disc does not come into contact with the seat during cycling.

5.3.3.2 Balanced Pressure-relief Valves

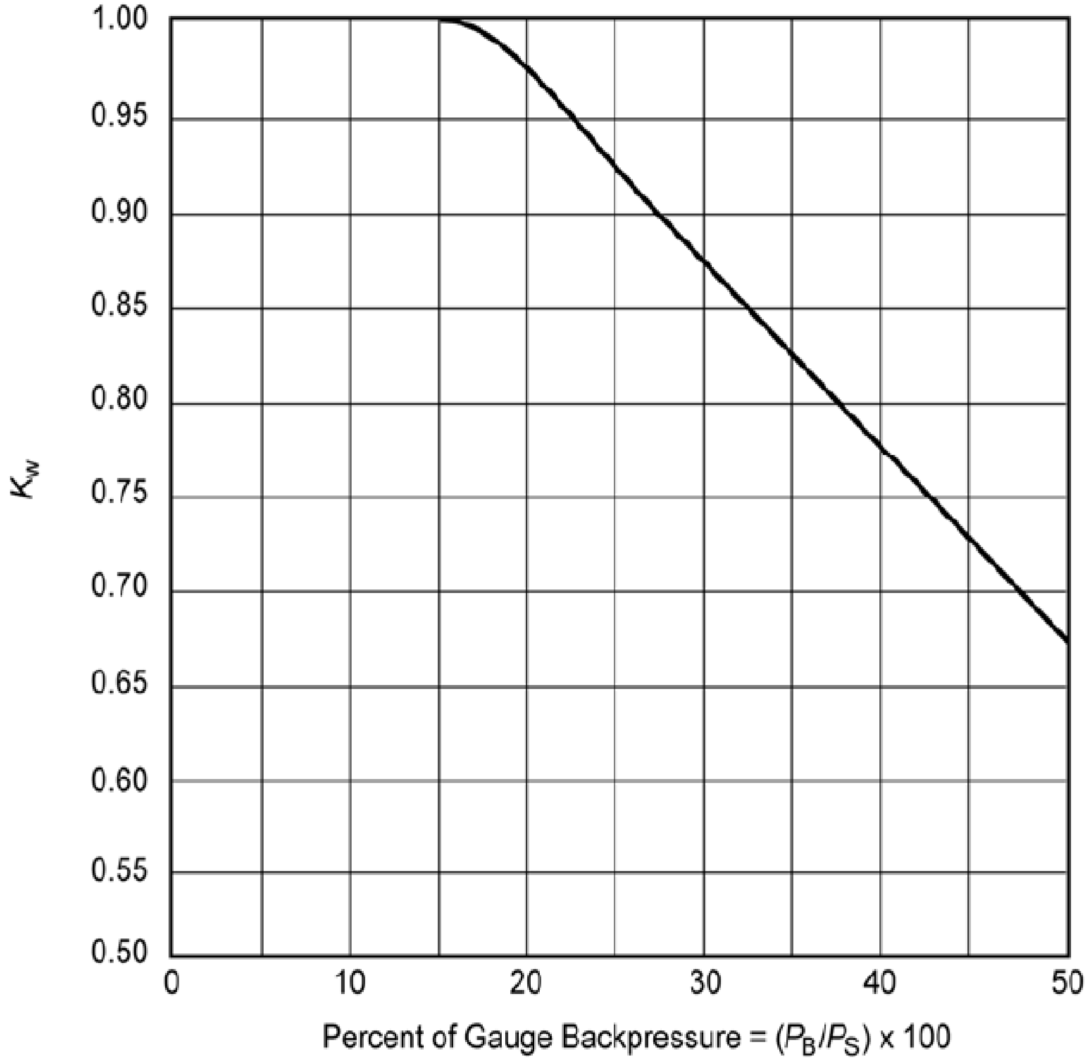
5.3.3.2.1 A balanced PRV should be used where the built-up backpressure is too high for conventional PRVs or where the superimposed backpressure varies widely compared to the set pressure. Balanced valves can typically be applied where the total backpressure (superimposed plus built-up) does not exceed approximately 50 % of the set pressure. The specific manufacturer should be consulted concerning the backpressure limitation of a particular valve design. With a balanced valve, high backpressure will tend to produce a closing force on the unbalanced portion of the disc. This force may result in a reduction in lift and an associated reduction in flow capacity. Capacity correction factors, called backpressure correction factors, are provided by manufacturers to account for this reduction in flow. Typical backpressure correction factors may be found for compressible fluid service in Figure 31 and for incompressible fluid (liquid) service in Figure 32. For liquid service applications, the factor shown in Figure 32 is applicable for all overpressures. For compressible fluid service, however, the factor may vary depending on whether the allowable overpressure is 10 %, 16 %, or 21 %.



NOTE 1 The curves above represent a compromise of the values recommended by a number of relief valve manufacturers and may be used when the make of the valve or the critical flow pressure point for the vapor or gas is unknown. When the make of the valve is known, the manufacturer should be consulted for the correction factor. These curves are for set pressures of 50 psig and above. They are limited to backpressure below critical flow pressure for a given set pressure. For set pressures below 50 psig or for subcritical flow, the manufacturer must be consulted for values of K_b.

NOTE 2 See 5.3.3.

NOTE 3 For 21 % overpressure, K_b equals 1.0 up to P_B/P_S = 50 %.



K_W = correction factor due to backpressure
P_B = backpressure, in psig
P_S = set pressure, in psig

NOTE The curve above represents values above recommended by various manufacturers. This curve may be used when the manufacturer is not known. Otherwise, the manufacturer should be consulted for the applicable correction factor.

Figure 32—Capacity Correction Factor, K_w, Due to Backpressure on Balanced Spring-loaded Pressure-relief Valves in Liquid Service

5.3.3.2.2 In most applications, the allowable overpressure is 10 % and the backpressure correction factor for 10 % overpressure shall be used. In the special case of multiple valve installations, the low set valve may operate at overpressures up to 16 %. A backpressure correction factor for 16 % overpressure may be used for that low set valve. The high set valve is actually operating at a maximum overpressure of 10 % (assuming the high set valve is set at 105 % of the MAWP), however, and the backpressure correction factor for 10 % overpressure shall be used for that high set valve. A supplemental valve used for an additional hazard created by exposure to fire (see 5.4.3.4) may be set to open at 10 % above MAWP. In this case, the backpressure correction factor for 10 % overpressure shall be used because the valve is actually operating at 10 % overpressure, even though the accumulation is at 21 %. When calculating the rated capacity for the first (nonfire) valve at 21 % overpressure, a backpressure correction factor of 1.0 may be used for backpressures up to 50 % of set pressure (see Figure 31, NOTE 3).

5.3.3.2.3 The backpressure correction factors specified in Figure 31 and Figure 32 are applicable to balanced spring-loaded PRVs with backpressures up to 50 % of set pressure.

5.3.3.2.4 When backpressures in compressible fluid applications (does not include multiphase applications) exceed approximately 50 % of set pressure, the flow is subcritical. Nonetheless, the critical flow equations found in 5.6.3 should be used. The PRV manufacturer should be consulted when backpressures exceed approximately 50 % of set pressure to obtain backpressure correction factors or any special limitations on valve operation.

5.3.3.3 Pilot-operated Pressure-relief Valves

For pilot-operated PRVs, the valve lift is not affected by backpressure. For compressible fluids at critical flow conditions, a backpressure correction factor of 1.0 should be used for pilot-operated PRVs.

5.3.4 Effects of Backpressure and Header Design on Pressure-relief Valve Sizing and Selection

5.3.4.1 For conventional PRVs connected to a flare header, there are several considerations that affect PRV sizing and selection. The PRV discharge line and flare header shall be designed so that the built-up backpressure does not exceed the allowable limits as specified in 5.3.3. In addition, the flare header system shall be designed in order to ensure that the superimposed backpressure, caused by venting or relief from another source, will not prevent PRVs from opening at a pressure adequate to protect equipment per the ASME *Code* or applicable code. Once the superimposed, built-up, and total backpressures are calculated based on a pressure drop analysis of the discharge system, they should be specified on the datasheet for the PRV under consideration.

5.3.4.2 Total backpressure may affect the capacity of the PRV. Sizing a balanced PRV is a two-step process. The PRV is sized using a preliminary backpressure correction factor, K_b. The correction factor could either be set initially equal to 1.0 or can be based on an assumed total backpressure. Once a preliminary valve size and capacity is determined, the discharge line and header size can be determined based on pressure drop calculations. The final size, capacity, backpressure, and backpressure correction factor, K_b, can then be calculated. The backpressure should be included on the datasheet for the PRV under consideration.

5.3.4.3 For a pilot-operated PRV, neither the set pressure nor the capacity is typically affected by backpressure, for compressible fluids at critical flow conditions. Tail pipe and flare header sizing are typically based on other considerations.

A pilot-operated PRV consists of the main valve, which normally encloses a floating unbalanced piston assembly, and an external pilot (see Figure 10 through Figure 14). The piston is designed to have a larger area on the top than on the bottom. Up to the set pressure, the top and bottom areas are exposed to the same inlet operating pressure. Because of the larger area on the top of the piston, the net force holds the piston tightly against the main valve nozzle. As the operating pressure increases, the net seating force increases and tends to make the valve tighter. This feature allows most pilot-operated valves to be used where the maximum expected operating pressure is higher than the percentage shown in Figure 15. At the set pressure, the pilot vents the pressure from the top of the piston; the resulting net force is now upward causing the piston to lift, and process flow is established through the main valve. After the overpressure incident, the pilot will close the vent from the top of the piston, thereby re-establishing pressure, and the net force will cause the piston to reseat. The pilots may be either a flowing or nonflowing type. The flowing type allows process fluid to continuously flow through the pilot when the main valve is open; the nonflowing type does not. The nonflowing pilot type is generally recommended for most services to reduce the possibility of hydrate formation (icing) or solids in the lading fluid affecting the pilot’s performance.

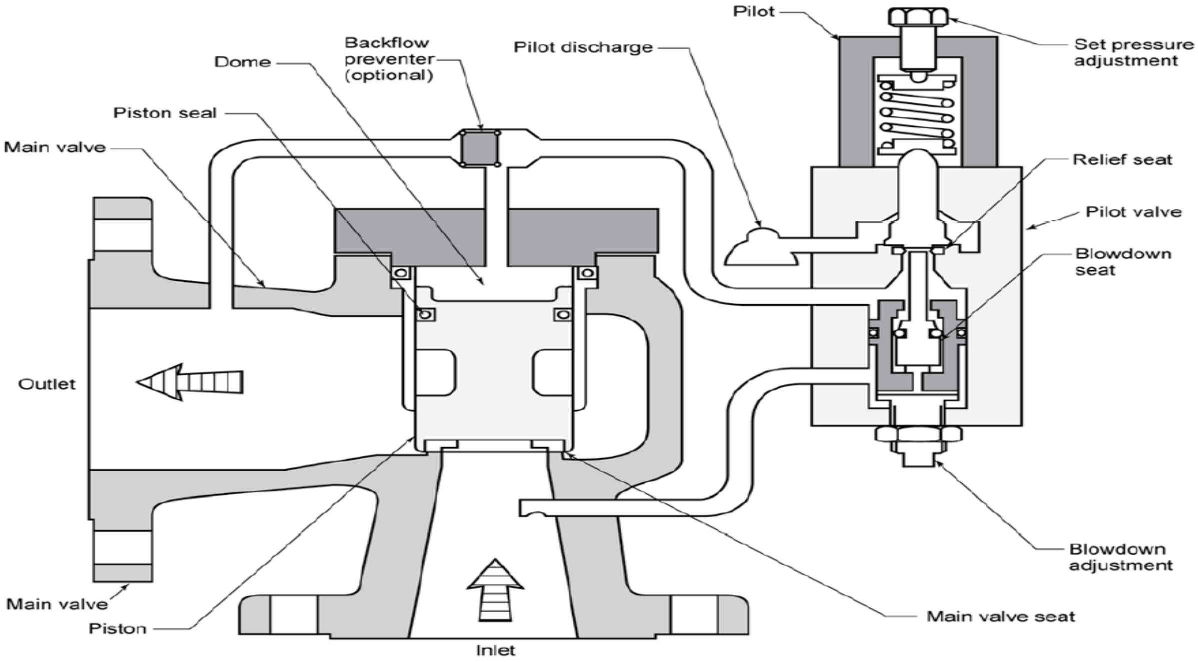


Figure 11—Pop-action Pilot-operated Valve (Nonflowing Type)

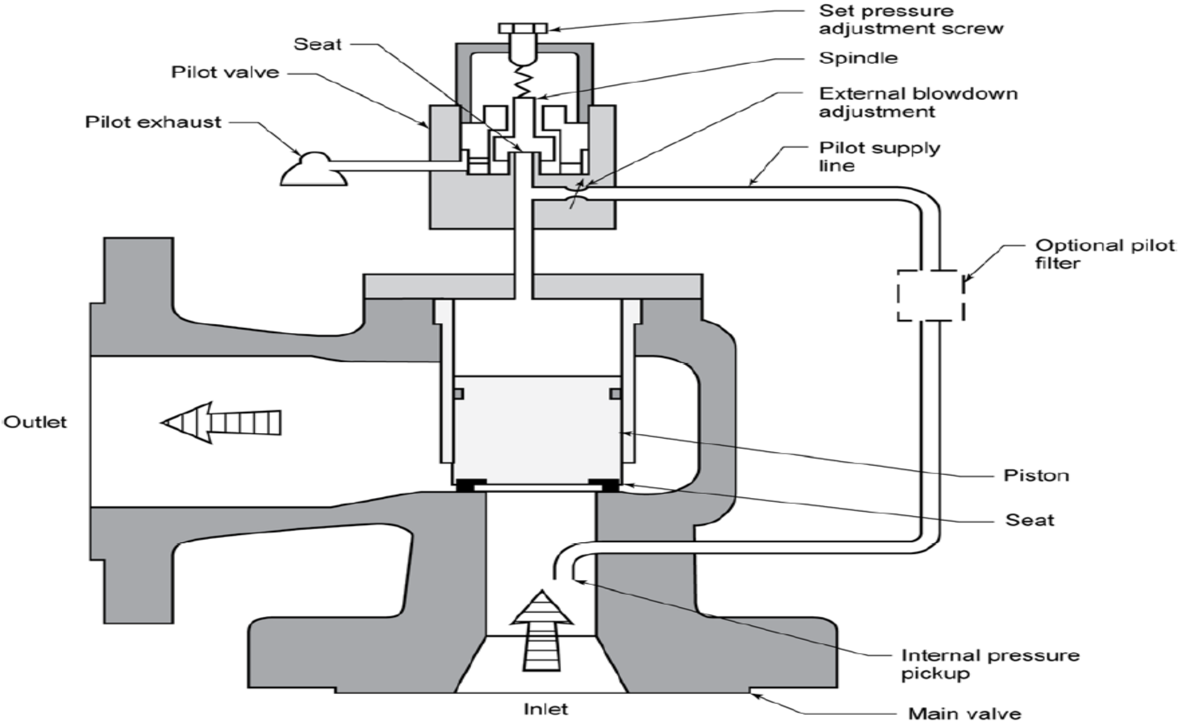


Figure 10—Pop-action Pilot-operated Valve (Flowing Type)

The modulating pilot, as shown in Figure 17, opens the main valve only enough to satisfy the required relieving capacity and can be used in gas, liquid, or two-phase flow applications. A modulating pilot-operated valve, in contrast to a pop-action valve, limits the amount of relieving fluid to only the amount required to prevent the pressure from exceeding the allowable accumulation. Since a modulating pilot only releases the required relieving rate, the calculation of built-up backpressure may be based on the required relieving rate instead of the rated capacity of the valve corrected for the actual overpressure. The modulating pilot valve also can reduce interaction with other pressure control equipment in the system during an upset condition, reduce unwanted atmospheric emissions, and reduce the noise level associated with discharge to the atmosphere.

PRV Instability

PRV Cycling

PRV Flutter

PRV Chatter

Chattering is where the PRV opens and closes at a very high frequency (on the order of the natural frequency of the valve’s spring/mass system). Spring-loaded PRVs are spring/mass devices and consequently are susceptible to dynamic interaction with the system. The primary concern is loss of containment (loosening of flange bolts or failure of piping components due to fatigue) caused by pressure pulsation or impact loading from rapid hammering of the valve disk onto the valve seat. Chattering may lead to significantly reduced PRV flow capacity. As a secondary effect, the chattering can cause valve seat damage and mechanical failure of valve internals (galling and bellows failure). Spring-loaded PRVs and pop action pilot valves can experience chatter. Modulating pilot-operated or remote sensing pop-action pilot PRVs are less likely to chatter). The damaging forces on piping associated with fluid pressure and velocity changes associated with chatter are much more severe in liquid service as compared to vapor service due to the higher densities associated with liquids. This is supported by analysis that shows that the pressure change as a result of fluid acceleration is typically small in inlet piping applications in vapor service.

Potential Causes of PRV Instability

1.Excessive PRV Inlet Pressure Loss

2. Excessive Built-up Backpressure

3. Acoustic Interaction

4. Retrograde Condensation

5. Improper Valve Selection

6. Oversized PRVs

PRD Location

If other factors permit, the PRD should normally be placed close to the protected equipment or system of equipment so that the pressure in the protected equipment stays within code allowable limits and to avoid PRV instability. The PRD should not be located where there are pressure fluctuations large enough to result in relief valve simmering/activation or rupture disk fatigue. On installations that have pressure fluctuations that peak close to the set pressure of the PRV or burst pressure of a rupture disk, the PRD should be located farther from the source and in a more stable pressure region.

— locations close to control valves, other valves, and other appurtenances;

— locations close to orifice plates and flow nozzles;

— locations close to other fittings, such as short radius elbows;

— locations close to the discharge of positive displacement pumps or compressors.

The potential effect of pressure fluctuations on the relief device may be reduced by the following

— locating the PRD 10 or more pipe diameters from any areas as described above;

— providing a well-rounded, smooth branch connection where the relief device inlet piping joins the main piping run.

— providing a larger branch connection (relative to the size of the PRV inlet).

The PRD inlet and outlet piping should be free-draining (no pockets) away from the PRD.

The nominal size of the inlet piping and fittings shall be the same as or larger than the nominal size of the pressure-relief valve inlet connection.

Horizontal lines are generally regarded as self-draining. However, avoid the installation of a PRV at the end of a long horizontal inlet pipe through which there is normally no flow. Solids, such as rust or scale, may accumulate, or liquid may be trapped, creating interference with the valve's operation or requiring more frequent valve maintenance.

Auto-refrigeration during discharge can cool the outlet of the PRD and the discharge piping to the point that brittle fracture can occur. Piping design, including material selection, shall consider the expected discharge temperature.

Note that the rated capacity corrected for the actual overpressure can vary depending on the overpressure scenario common relief header piping in closed discharge systems can be sized using the protected system's required relieving capacity.

For a modulating pilot-operated PRV, the discharge piping can be sized using the required relieving capacity of the system that the valve is protecting.

Whenever the atmospheric vent, discharge piping, or common relief header piping is sized using the system's required relieving capacity instead of the rated capacity of the valve corrected for the actual overpressure, the backpressure should be re-checked whenever changes are made to the process that affect the required relieving capacity of the system the valve is protecting. The discharge piping from thermal relief valves designed solely to protect against liquid hydraulic expansion due to ambient heating (including solar radiation) typically does not need to be sized to meet the built-up backpressure limits provided in API 520, Part I and as discussed in 6.3.1. The reason for this is that the capacity of these PRVs is typically larger by an order of magnitude (>10 times) than the required relief rate and the flow in the discharge line never reaches a steady state flow at the capacity. Superimposed backpressure that exceeds the inlet pressure of a pilot-operated PRV can cause the main valve to open, allowing reverse flow through the main valve.

PRV Inlet Pressure Drop Limitations

1.Confirm the inlet pressure losses do not significantly affect the capacity of the PRV.

2.Confirm the PRV is set to open at or below the maximum allowable working pressure for all equipment being protected.

3.Limit the pressure to the maximum allowable accumulation for all equipment being protected

4.Provide reasonable assurance that the inlet pressure losses are unlikely to result in destructive instability of the PRV.

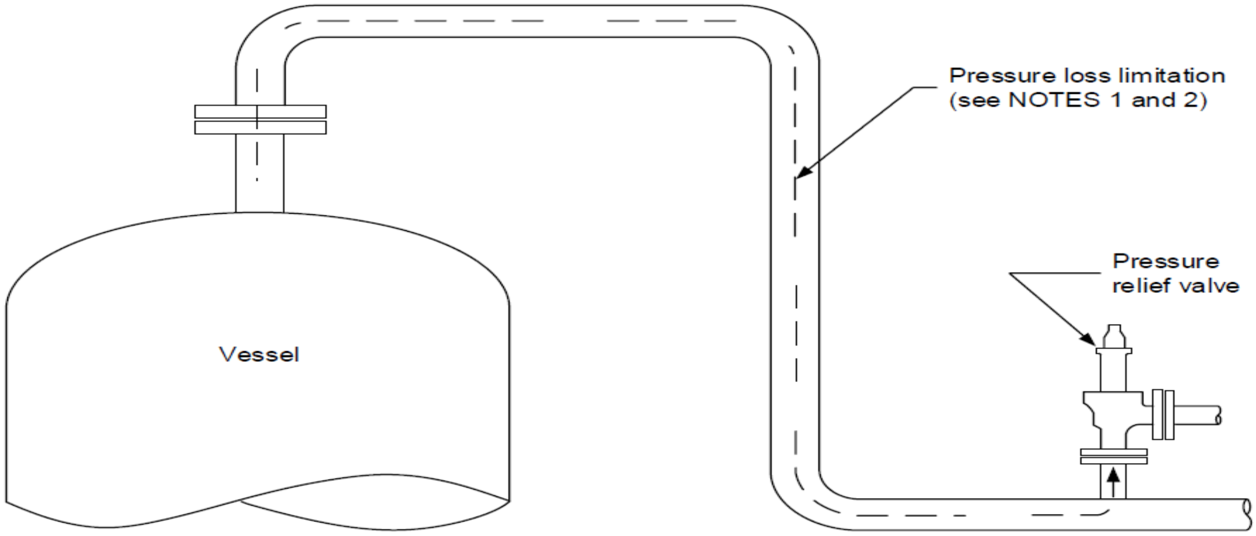
PRV Inlet Pressure Loss Criteria

The total nonrecoverable pressure loss between the protected equipment and the pressure-relief valve should not exceed 3 % of the PRV set pressure, except as noted below:

— thermal relief valves
— remotely sensed pilot-operated relief valves
— an engineering analysis is performed for the specific installation.

Note that keeping the pressure loss below 3 % becomes progressively more difficult at low pressures and/or as the orifice size of a PRV increases. In certain applications, it is difficult to meet the 3 % criterion for the largest API 526 [2] orifice size for a given inlet flange diameter (e.g., 2J3, 4P6, 6R8, etc.). There are some non-API 526 valves that also exhibit this behavior.

When a pressure-relief valve is installed on a normally flowing process line, the 3 % limit should be applied to the sum of the loss in the normally nonflowing PRV inlet pipe and the incremental pressure loss in the process line caused by the flow through the PRV.



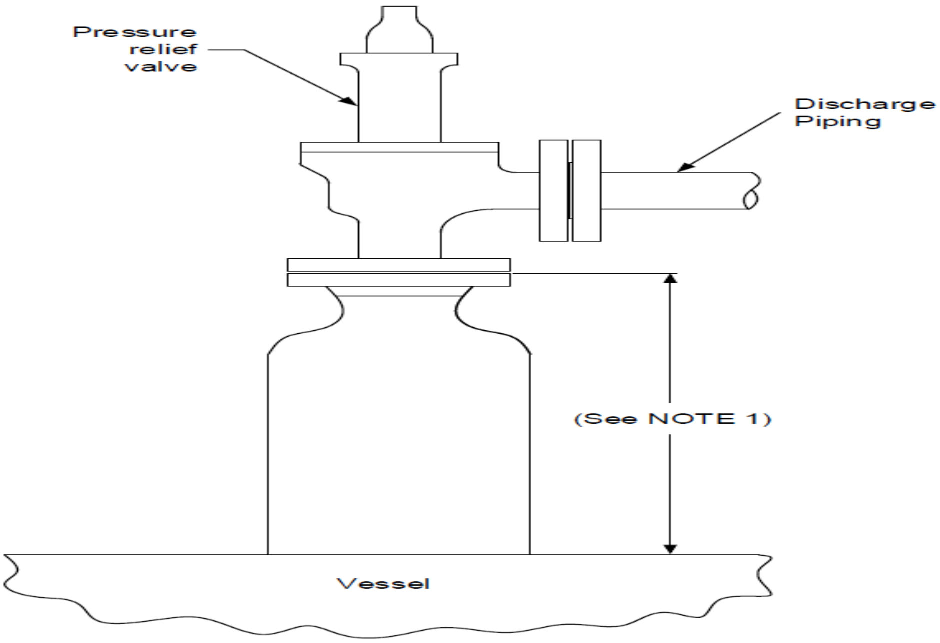
NOTE 1 See 7.3 for PRV inlet pressure drop limitations.
NOTE 2 See 7.3.7.3 for pressure loss limitations when the PRV is installed on normally flowing process piping.

7.3.7.5 Design Options to Address High Inlet Pressure Drop

Pressure losses can be reduced by making modifications to the system design, including but not limited to the following:

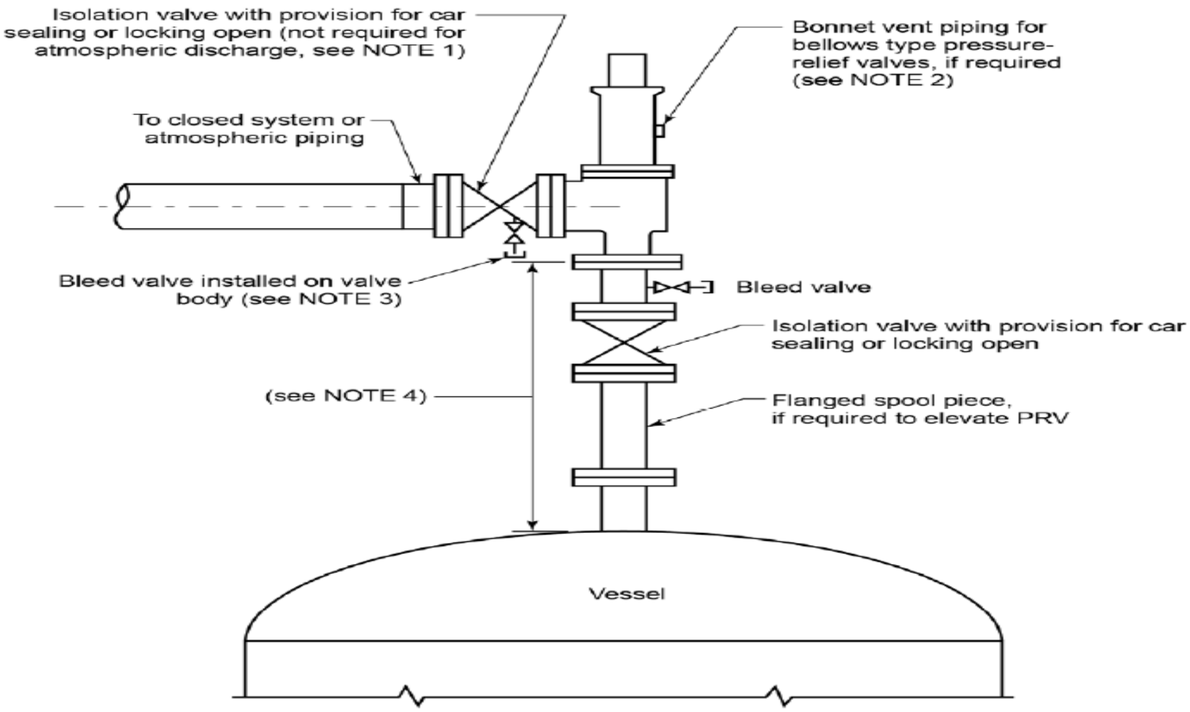
- rounding the entrance to the inlet piping;
- reducing the inlet line length;
- reducing the number of fittings;
- installing a different type of fitting (i.e. lower equivalent length);
- increasing the diameter of the inlet piping (see Figure 8);
- ensuring that the relief capacity is well-matched to the required rate; one option is to use a restricted lift PRV (consult manufacturer) to reduce rated capacity of the valve [26]; or
- using multiple PRVs; provide one smaller valve with independent inlet piping for low-flow contingencies.

An option for mitigating excessive inlet losses is to use a pilot-operated relief valve with remote sensing (see 7.3.9) if the application permits.



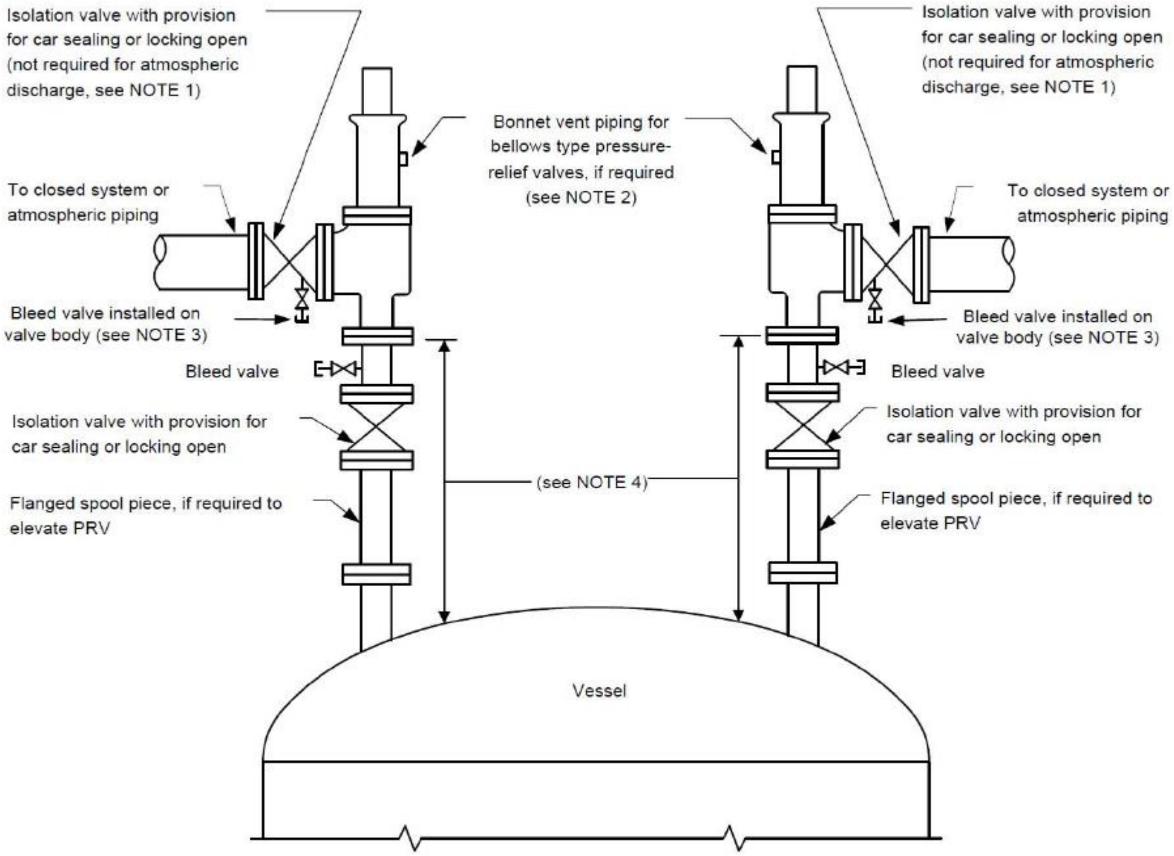
Isolation Valve Requirements

Isolation (stop) valves are allowed upstream and/or downstream of the pressure-relieving device for the purpose of inspection, testing, and repair of the pressure-relieving device or discharge header isolation. For outlet isolation valves, to help minimize the built-up backpressure, the flow area in the outlet isolation valve should be equal to or greater than the outlet area of the PRV. Typically, the inlet isolation valves for spare relief devices are closed and the outlet isolation valves are open. The outlet isolation valve for spare relief devices can be closed during operation if exposure to the fluid is a concern; however, the pressure temperature rating of the PRD outlet, the outlet isolation valve, and intervening piping should be suitable for the conditions upstream of the relief device in case of leakage. Protection of the PRD from discharge system fluids without closing the outlet isolation valve can also be achieved either by providing a purge or by installing a discharge rupture disk.



NOTE 1 See Section 8 for the use of isolation valves in pressure-relief system piping.
NOTE 2 See Section 10.
NOTE 3 Alternatively, a pipe spool with bleed may be provided.
NOTE 4 See 7.3 for PRV inlet pressure drop limitations.

Figure 10—Typical PRD Installation with an Isolation Valve



NOTE 1	See Section 8 for the use of isolation valves in pressure-relief system piping.
NOTE 2	See Section 10.
NOTE 3	Alternatively, a pipe spool with bleed may be provided.
NOTE 4	See 7.3 for detailed discussion on inlet pressure drop.

Figure 11—Typical PRD Installation for 100% Spare Relieving Capacity

Rupture Disk

Rupture disk devices are non-reclosing PRDs used to protect vessels, piping, and Other pressure-containing components from excessive pressure and/or vacuum. Rupture disks are used in single and multiple relief device installations. They are also used as redundant PRDs. With no moving parts, rupture disks are simple, reliable, and faster acting than other PRDs. Rupture disks react quickly enough to relieve some types of pressure spikes. Because of their light weight, rupture disks can be made from high alloy and corrosion resistant materials that are not practical in PRVs.

Rupture disks can be specified for systems with vapor (gas) or liquid pressure-relief requirements. Also, rupture disk designs are available for highly viscous fluids. The use of rupture disk devices in liquid service should be carefully evaluated to ensure that the design of the disk is suitable for liquid service. The user should consult the manufacturer for information regarding liquid service applications.

Rupture disk devices often have different opening characteristics as a function of the fluid state against the disk at the time of bursting. To account for the resulting differences in the resistance to flow, certified *K*r values are stated in terms of *K*rg (gas), *K*rl (liquid), or *K*rgl (gas or liquid). In application, use the following guidelines.

1.When the fluid initiating rupture (in contact with rupture disk) is compressible, rupture disks rated with *K*rg or *K*rgl should be used.

2.When the fluid initiating rupture (in contact with rupture disk) is incompressible, rupture disks rated with *K*rl or *K*rgl should be used.

The rupture disk is also a temperature-sensitive device. Burst pressures can vary significantly with the temperature of the rupture disk device. This temperature may be different from the normal fluid operating temperature. As the temperature at the disk increases, the burst pressure usually decreases. Since the effect of temperature depends on the rupture disk design and material, the manufacturer should be consulted for specific applications. For these reasons, the rupture disk shall be specified at the pressure and temperature the disk is expected to burst.

Application of Rupture Disks

Rupture disks can be used in any application requiring overpressure protection where a non-reclosing device is suitable. This includes single, multiple, and fire applications as specified in UG-134 of the ASME *Code*.

Rupture Disk Device at the Inlet of a Pressure-relief Valve

Rupture disks are used upstream of PRVs to seal the system to meet emissions standards, to provide corrosion protection for the valve, and to reduce valve maintenance.

When a rupture disk device is installed at the inlet of a PRV, the devices are considered to be close coupled, and the specified burst pressure and set pressure should be the same nominal value.

When installed in liquid service, it is especially important for the disk and valve to be close coupled to reduce shock loading on the valve The space between the rupture disk and the PRV shall have a free vent, pressure gauge, trycock, or suitable telltale indicator as required in UG-127 of the ASME *Code.* Users are warned that a rupture disk will not burst in tolerance if backpressure builds up in a nonvented space between the disk and the PRV, which will occur should leakage develop in the rupture disk due to corrosion or other cause (

Rupture Disk Device at the Outlet of a Pressure-relief Valve

A rupture disk device may be installed on the outlet of a PRV to protect the valve from atmospheric or downstream fluids. Consideration should be given to the valve design so that it will open at its proper pressure setting regardless of any backpressure that may accumulate between the valve and rupture disk.

Types of Rupture Disks

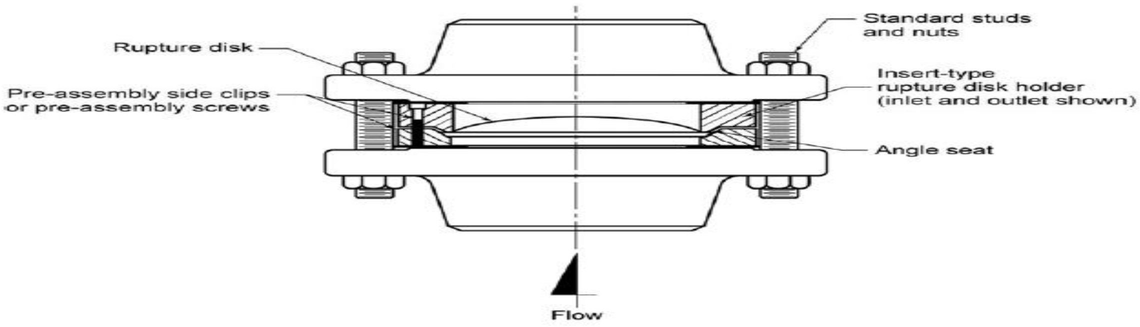
There are three major rupture disk types

1. Forward-acting, tension-loaded
2. Reverse-acting, compression-loaded;
3. Graphite, shear-loaded.

Forward-acting Solid Metal Rupture Disks

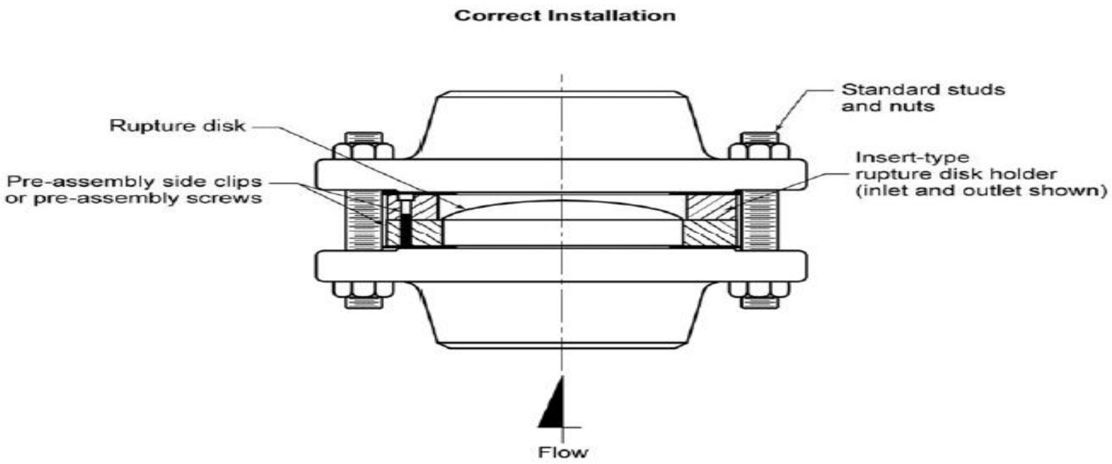
A forward-acting rupture disk is a formed (domed), solid metal disk designed to burst at a rated pressure applied to the concave side (see Figure 21). This rupture disk typically has an angular seat design and provides a satisfactory service life when operating pressures are up to 70 % of the marked burst pressure of the disk (70 % operating ratio). Consult the manufacturer for the actual recommended operating ratio for the specific disk under consideration. If vacuum or backpressure conditions are present, the disk can be furnished with a support to prevent reverse flexing. These disks have a random opening pattern and are considered fragmenting designs that are not suitable for installation upstream of a PRV.

Correct Installation



Forward-acting Scored Rupture Disks

The scored forward-acting rupture disk is a formed (domed) disk designed to burst along scored lines at a rated pressure applied to the concave side (see Figure 22). Some designs provide satisfactory service life when operating pressures are up to 85 % to 90 % of the marked burst pressure of the disk (85 % to 90 % operating ratio). Most designs withstand vacuum conditions without a vacuum support. If backpressure conditions are present, the disk can be furnished with a support to prevent reverse flexing. Because the score lines control the opening pattern, this type of disk can be manufactured to be nonfragmenting and is acceptable for installation upstream of a PRV. The scored,forward-acting rupture disk is manufactured from thicker material than nonscored designs with the same burst pressure, and it provides additional resistance to mechanical damage.



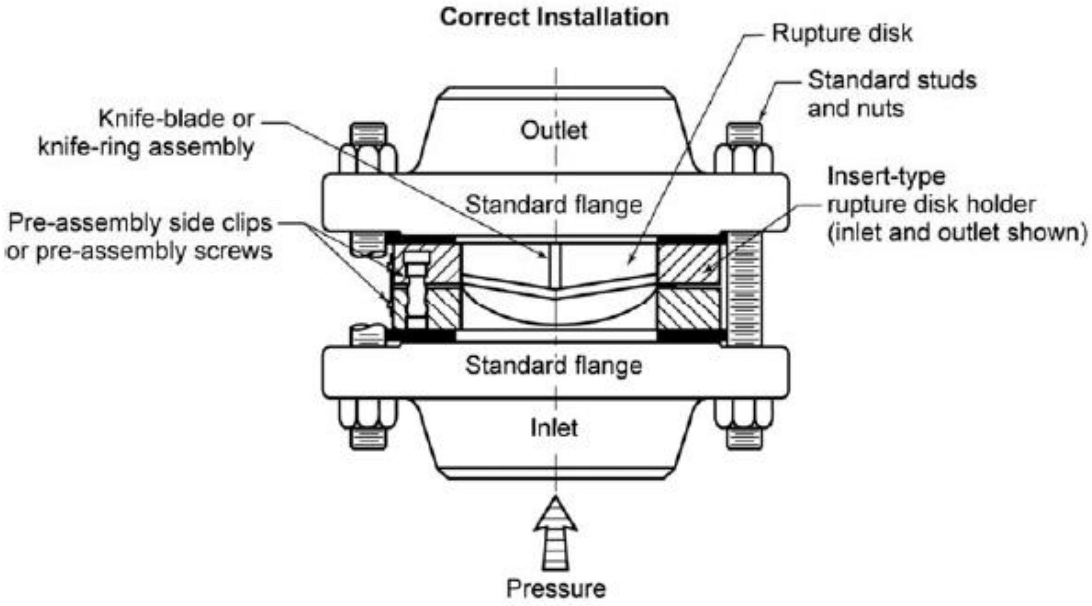
Forward-acting Scored Rupture Disks

A forward-acting composite rupture disk is a flat or domed multipiece construction disk (see Figure 23). The domed composite rupture disk is designed to burst at a rated pressure applied to the concave side. The flat composite rupture disk may be designed to burst at a rated pressure in either or both directions. Some designs are nonfragmenting and acceptable for use upstream of a PRV. A flat composite rupture disk is available for the protection of low-pressure vessels or the isolation of equipment such as exhaust headers or the outlet side of a PRV. This disk usually comes complete with gaskets and is designed to be installed between companion flanges rather than within a specific rupture disk holder. Flat composite rupture disks generally provide satisfactory service life when operating pressures are 50 % or less of the marked burst pressure (50 % operating ratio). The slits and tabs in the top section provide a predetermined opening pattern for the rupture disk. If vacuum or backpressure conditions are present, composite disks can be furnished with a support to prevent reverse flexing (see Figure 23). A domed, composite rupture disk generally provides satisfactory service life when the operating pressure is 80 % or less of the marked burst pressure (80 % operating ratio).

A flat composite rupture disk is available for the protection of low-pressure vessels or the isolation of equipment such as exhaust headers or the outlet side of a PRV. This disk usually comes complete with gaskets and is designed to be installed between companion flanges rather than within a specific rupture disk holder. Flat composite rupture disks generally provide satisfactory service life when operating pressures are 50 % or less of the marked burst pressure (50 % operating ratio).

Reverse-acting Rupture Disks

A reverse-acting rupture disk typically is a formed (domed) solid metal disk designed to reverseand burst at a rated pressure applied on the convex side. Reverse-acting rupture disks are designed to open by such methods as shear knife blades, tooth rings, or scored lines Reverse-acting rupture disks may be manufactured as nonfragmenting and are suitable for installation upstream of PRVs. These disks provide satisfactory service life when operating pressures are 90 % or less of marked burst pressure (90 % operating ratio). Some types of reverse-buckling disks are designed to be exposed to pressures up to 95 % of the marked burst pressure. Consult the manufacturer for the actual recommended operating ratio for the specific . disk under consideration. Because a reverse acting rupture disk is operated with pressure applied on the convex side, thicker disk materials may be used, thereby lessening the effects of corrosion, eliminating the need for vacuum support, and providing longer service life under pressure/vacuum cycling conditions and pressure fluctuations



Graphite Rupture Disks

Graphite rupture disks are typically machined from a bar of fine graphite that has been impregnated with a sealing compound to seal the porosity of the graphite matrix (see Figure 26). The disk operates on a pressure differential across the center diaphragm or web portion of the disk. Graphite rupture disks provide a satisfactory service life when operating pressures are up to 80 % of the marked burst pressure (80 % operating ratio) and can be used in both liquid and vapor service.

If vacuum or backpressure conditions are present, the disk can be furnished with a support to prevent reverse flexing. These disks have a random opening pattern and are considered fragmenting designs that are not suitable for installation upstream of a PRV. A metallic ring called armoring is often added to the outside diameter of the disk to help support uneven piping loads and minimize the potential for cracking of the outer graphite ring and blowout of process fluid.

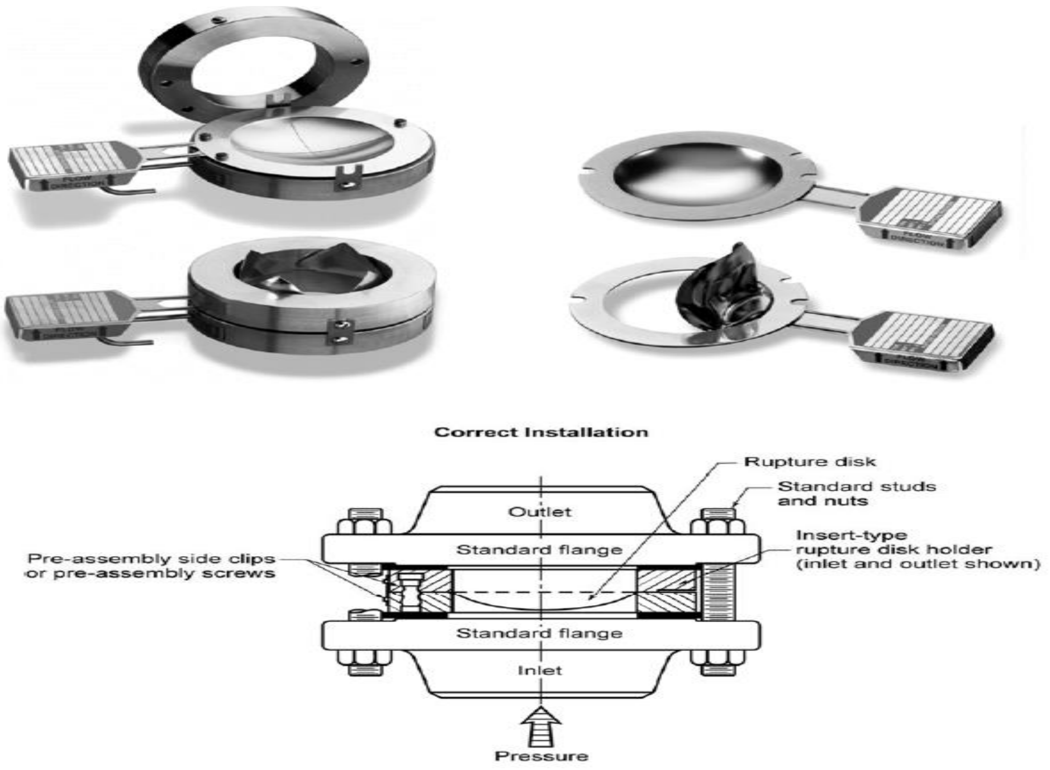
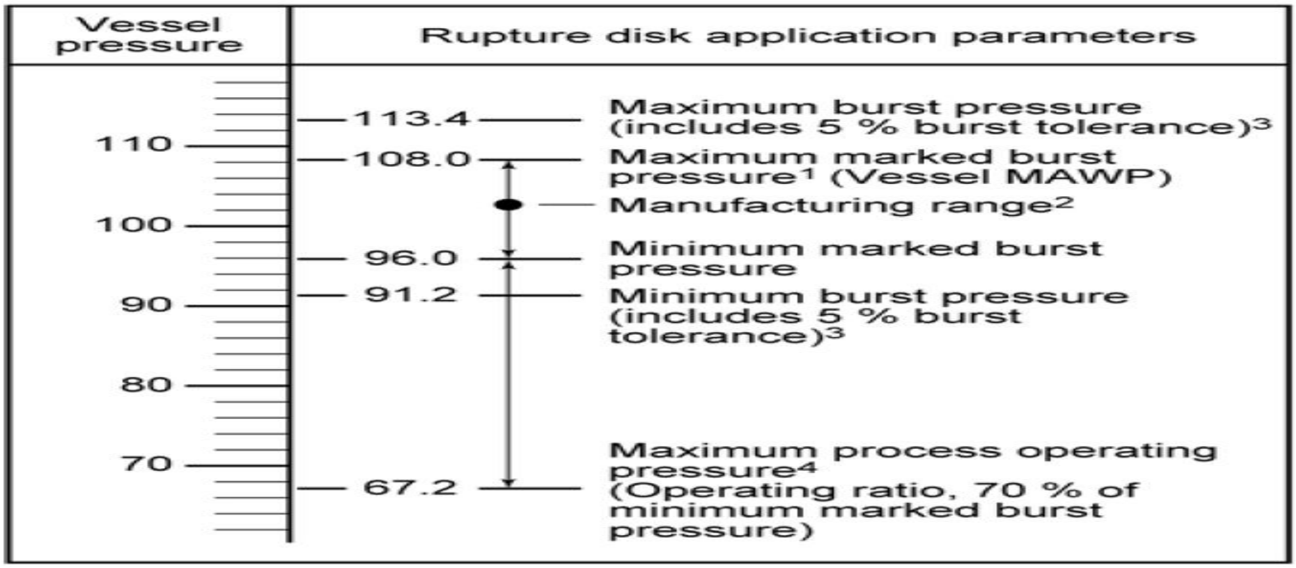


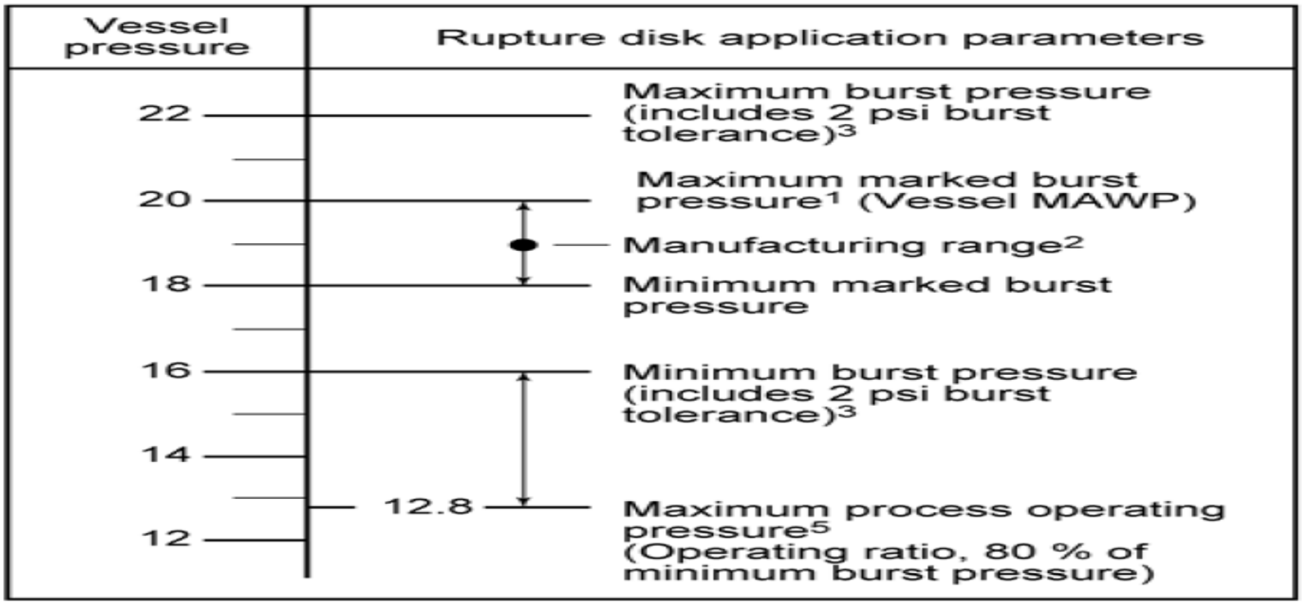
Figure 25—Reverse-acting Scored Rupture Disk

Rupture Disk Selection

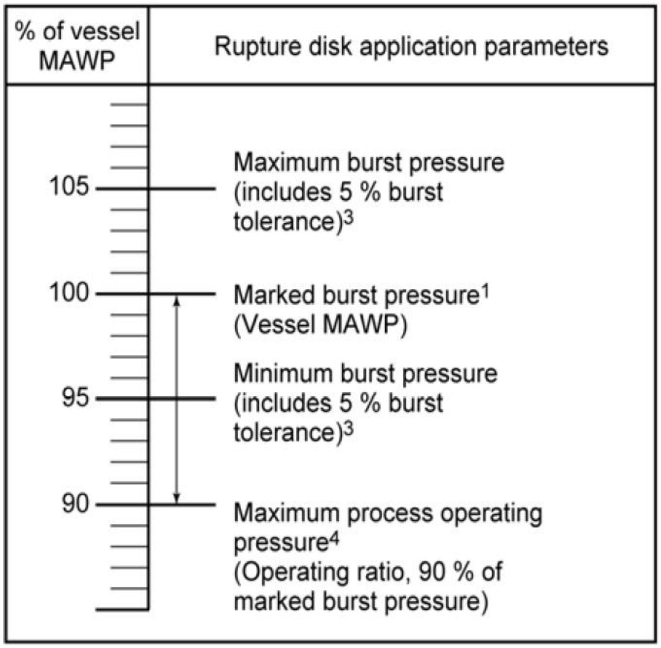
the user is cautioned to make sure that the upper limit of the manufacturing design range does not exceed the MAWP of the equipment being protected.



A. Example of a rupture disk with a specified burst pressure of 100 psig, manufacturing range of +8/–4 %, burst tolerance of ±5 %, and a 70 % operating ratio.



C. Example of a rupture disk with a specified burst pressure of 20 psig, manufacturing range of +0/–10 %, burst tolerance of ± 2 psig, and an 80 % operating ratio.



B. Example of a rupture disk with a specified burst pressure of 100 psig, zero manufacturing range, burst tolerance of ±5 %, and a 90 % operating ratio.

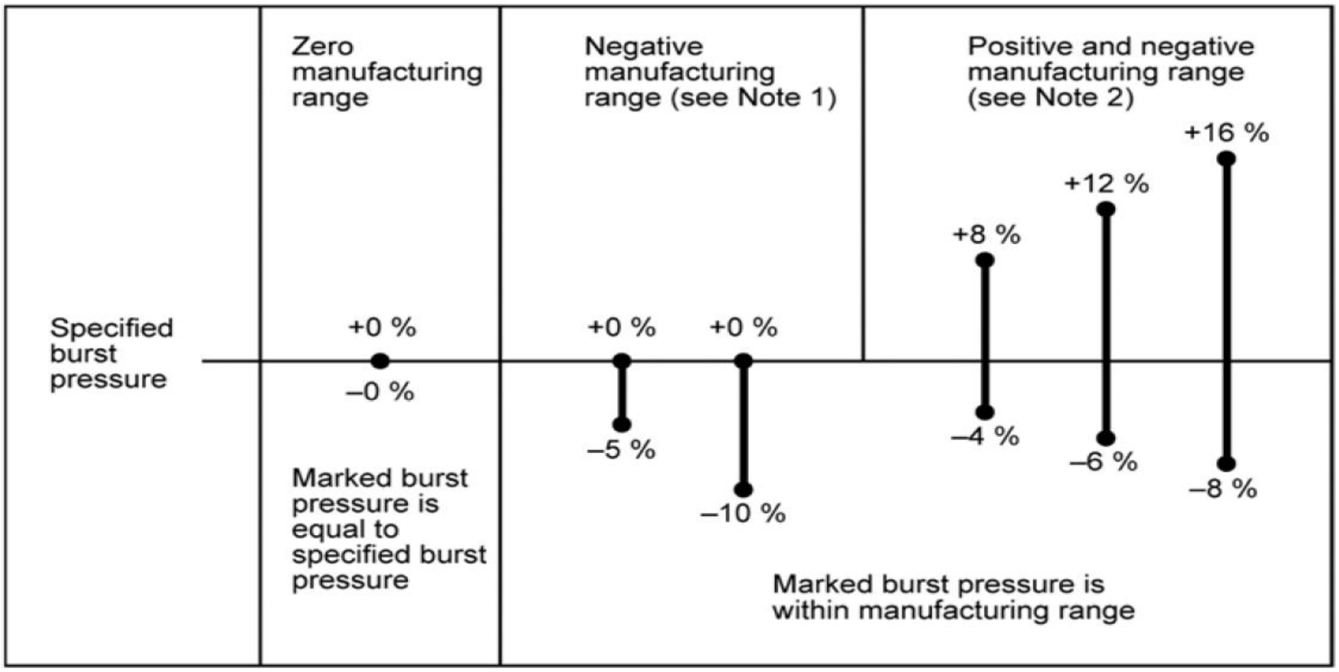
NOTE 1 See Figure 19 for limits on marked burst pressure.

NOTE 2 Marked burst pressure may be any pressure within the manufacturing range, see Figure 28.

NOTE 3 For marked burst pressures above 40 psig, the burst tolerance is ±5 %. For marked burst pressures at 40 psig and below, the burst tolerance is ±2 psi.

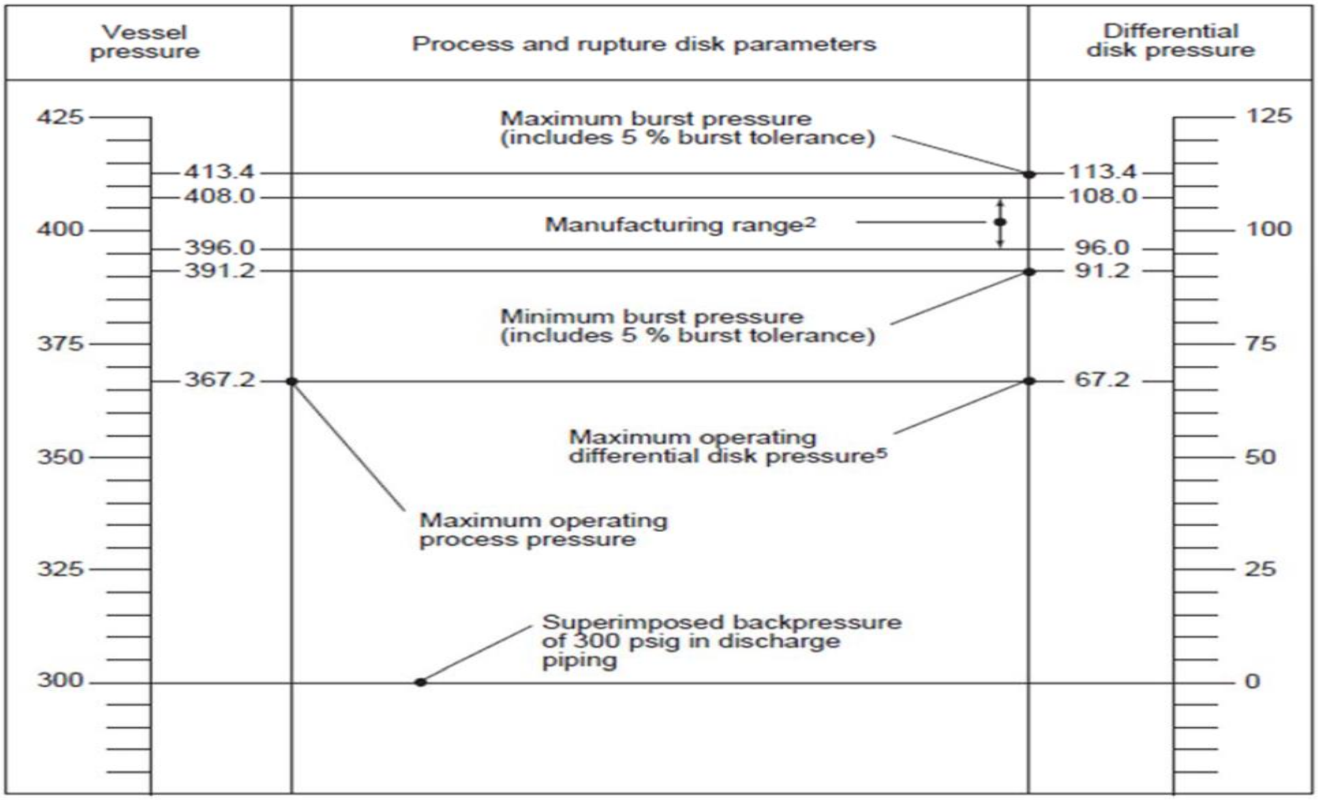
NOTE 4 For marked burst pressures above 40 psig, the maximum process operating pressure is calculated by multiplying the minimum marked burst pressure by the operating ratio.

NOTE 5 For marked burst pressures at 40 psig and below, the maximum process operating pressure is calculated by subtracting the burst tolerance from the minimum marked burst pressure, then multiplying the difference by the operating ratio.

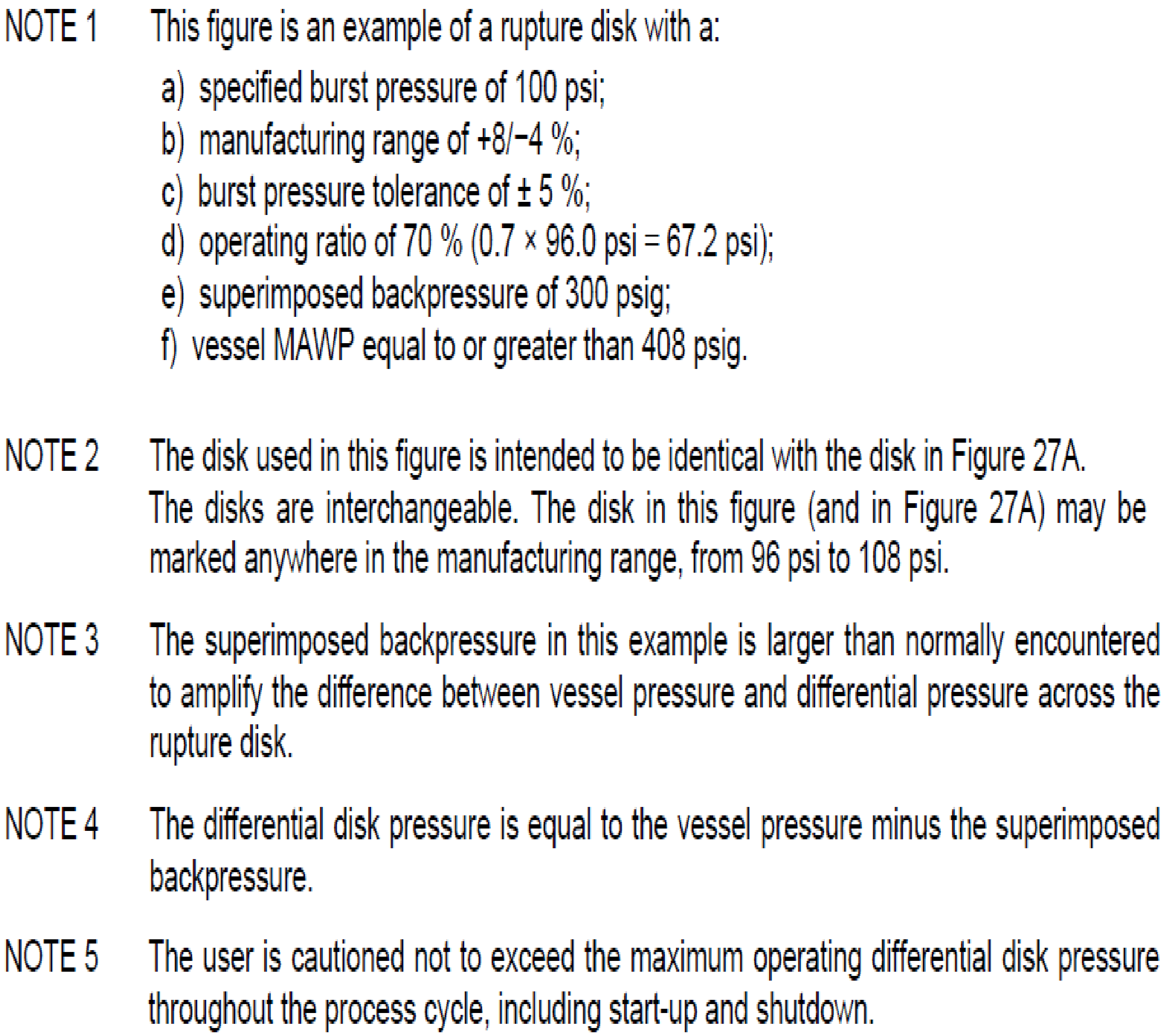


NOTE 1 The marked burst pressure will not exceed the specified burst pressure.

NOTE 2 Positive manufacturing range may result in a marked burst pressure exceeding the specified burst pressure.


Vessel pressure
Process and rupture disk parameters
Differential disk pressure
425
400
375
350
325
300
413.4
408.0
396.0
391.2
367.2
125
100
75
50
25
0
113.4
108.0
96.0
91.2
67.2
Maximum burst pressure (includes 5 % burst tolerance)
Manufacturing range2
Minimum burst pressure (includes 5 % burst tolerance)
Maximum operating differential disk pressure5
Maximum operating process pressure
Superimposed backpressure of 300 psig in discharge piping

Selection Procedure



NOTE 1 This figure is an example of a rupture disk with a:

a) specified burst pressure of 100 psi;
b) manufacturing range of +8/−4 %;
c) burst pressure tolerance of ± 5 %;
d) operating ratio of 70 % (0.7 × 96.0 psi = 67.2 psi);
e) superimposed backpressure of 300 psig;
f) vessel MAWP equal to or greater than 408 psig.

NOTE 2 The disk used in this figure is intended to be identical with the disk in Figure 27A. The disks are interchangeable. The disk in this figure (and in Figure 27A) may be marked anywhere in the manufacturing range, from 96 psi to 108 psi.

NOTE 3 The superimposed backpressure in this example is larger than normally encountered to amplify the difference between vessel pressure and differential pressure across the rupture disk.

NOTE 4 The differential disk pressure is equal to the vessel pressure minus the superimposed backpressure.

NOTE 5 The user is cautioned not to exceed the maximum operating differential disk pressure throughout the process cycle, including start-up and shutdown.

Sizing Procedure

a) Step 1—Determine required information:

- — MAWP = 100 psig;
- — P_1 = relieving pressure = 110 % = 124.7 psia;
- — T_1 = relieving temperature = 200 °F + 460 °F = 660 °R;
- — Z_1 = relieving compressibility = 1.0;
- — M = molecular weight = 20;
- — P_2 = backpressure = 14.7 psia.

b) Step 2—Determine overall piping resistance factor, K, from Table E.1.

c) Step 3—Determine Y_{sonic} and $\frac{dP_{\text{sonic}}}{P_1}$ based on total system K.

The charts on page A-22 of Crane 410 [16] can be used to obtain Y_{sonic} and $\frac{dP_{\text{sonic}}}{P_1}$. From the chart where, k (C_p/C_v) = 1.4, the following values are determined:

$$Y_{\text{sonic}} = 0.653$$

$$\frac{dP_{\text{sonic}}}{P_1} = 0.70$$

As an alternate to the chart method, curve fit equations for obtaining Y_{sonic} and $\frac{dP_{\text{sonic}}}{P_1}$ have been provided as Equation (E.1) through Equation (E.4).

For $\frac{dP_{\text{sonic}}}{P_1}$:

$$\text{If } 1.2 < K \leq 10, \text{ then } \frac{dP_{\text{sonic}}}{P_1} = 0.1107\ln(K) + 0.5352 \tag{E.1}$$

$$\text{If } 10 < K \leq 100, \text{ then } \frac{dP_{\text{sonic}}}{P_1} = 0.0609\ln(K) + 0.6513 \tag{E.2}$$

For Y_{sonic}:

If $1.2 < K \leq 20$, then $Y_{\text{sonic}} = 0.0434\ln(K) + 0.5889$ (E.3)

If $20 < K \leq 100$, then $Y_{\text{sonic}} = 0.710$ (E.4)

Based on $K = 4.04$:

$$\frac{dP_{\text{sonic}}}{P_1} = 0.69$$

$$Y_{\text{sonic}} = 0.65$$

d) Step 4—Compare $\frac{dP_{\text{sonic}}}{P_1}$ to $\frac{dP_{\text{actual}}}{P_1}$.

$$\frac{dP_{\text{actual}}}{P_1} = \frac{(124.7 - 14.7)}{124.7} = 0.88$$

Since $\frac{dP_{\text{sonic}}}{P_1} < \frac{dP_{\text{actual}}}{P_1}$, the flow will be sonic (critical).

Use Y_{sonic} and $\frac{dP_{\text{sonic}}}{P_1}$ and skip to Step 6 (if subsonic, proceed to Step 5).

e) Step 5—Evaluate Y_{actual} (subsonic cases only).

Using the Crane 410—Chart A-22 Method to obtain Y_{actual}:

1) at $\frac{dP_{\text{actual}}}{P_1}$ and K determine Y_{actual} from Chart A-22;

2) use $\frac{dP_{\text{actual}}}{P_1}$ and Y_{actual} in Step 6.

Using the Curve Fit Method for obtaining Y_{actual}:

1) calculate Y_{actual} from the Equation (E.5):

$$Y_{\text{actual}} = 1 - \frac{(1 - Y_{\text{sonic}})}{dP_{\text{sonic}}/P_1}\left(\frac{dP_{\text{actual}}}{P_1}\right) \tag{E.5}$$

2) use $\frac{dP_{\text{actual}}}{P_1}$ and Y_{actual} in Step 6 in place of $\frac{dP_{\text{sonic}}}{P_1}$ and Y_{sonic}.

f) Step 6—Calculate capacity based on Crane 410—Equation (3-20):

$$W = 0.9\left(1891 \times Y \times d^2 \sqrt{\frac{dP}{K \times V_1}}\right) \tag{E.6}$$

g) Step 7—Using the Chart Method values and Equation (E.6):

1) $Y = Y_{\text{sonic}} = 0.65$;

2) d = pipe ID (in.) = 3.068 in.;

3) $dP = \left(\frac{dP_{\text{sonic}}}{P_1}\right)(P_1) = 87.3$ psi;

4) K = overall resistance = 4.04;

5) V_1 = vapor specific volume = 2.84 ft³/lb (obtained using ideal gas law and compressibility).

6) $W = 0.9\left(1891 \times 0.65 \times 3.068^2 \sqrt{\frac{87.3}{4.04 \times 2.84}}\right) = 28{,}700$ lb/h.

h) Step 8—Using the Curve Fit Method values from Figure E.2 and Equation (E.6):

1) $Y = Y_{\text{sonic}} = 0.65$;

2) d = Pipe ID (in.) = 3.068 in.;

3) $dP = (dP_{\text{sonic}}/P_1)(P_1) = 86.0$ psi;

4) K = Overall resistance = 4.04;

5) V_1 = vapor specific volume = 2.84 ft^3/lb (obtained using ideal gas law and compressibility).

6) $W = 0.9\left(1891 \times 0.65 \times 3.068^2 \sqrt{\dfrac{86.0}{4.04 \times 2.84}}\right) = 28{,}508$ lb/h.