Instructions to Voters/Comments on API 520 Part I Ballot – "Kb for Pilot-Operated PSVs"

1. Your comments should be limited to the **red-line portions** of the ballot only.
2. This ballot provides a back pressure correction factor, Kb for pilot operated PSVs.
3. **This ballot addresses 520 Action Item 2019-19.**
4. If you are voting negative, please indicate which of your comment or comments are the reason for your negative vote. API's Balloting system will categorize all of your comments as Negative.

Thank you to Matt Byers and his work group for developing this ballot.

Phil Henry
API 520 Task Force Chair

Sizing, Selection, and Installation of Pressure-relieving Devices

Part I—Sizing and Selection

API STANDARD 520, PART I
TENTH EDITION, OCTOBER 2020

5.3 Backpressure

5.3.1 General

5.3.1.1 Pressure existing at the outlet of a PRV is defined as 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.

5.3.1.2 Backpressure that is present at the outlet of a PRV when it is required to operate is defined as superimposed backpressure. This 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.

5.3.1.3 Backpressure that develops in the discharge system after the PRV opens is defined as built-up backpressure. Built-up backpressure occurs due to pressure drop in the discharge system as a result of flow from the PRV. Short tail pipes that vent directly to the atmosphere typically result in lower built-up backpressures than long discharge systems. However, choked flow can occur at the outlet of even short tail pipes vented directly to atmosphere, resulting in a high built-up backpressure. For this reason, the built-up backpressure shall be evaluated for all systems, regardless of the outlet piping configuration.

5.3.1.4 The magnitude of the backpressure that exists at the outlet of a PRV, after it has opened, is the total of the superimposed and the built-up backpressure.

5.3.2 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.

5.3.3.1.3 In a conventional PRV application, the allowable built-up backpressure is equal to the allowable overpressure. Both of these values are referenced to the PRV's set pressure, not to its CDTP. See Equation (1).

$$P_{B,Allowable} = \mathrm{AOP} = \mathrm{MAWP} \times (1 + \%AA) - P_{set} \tag{1}$$

where

$P_{\mathrm{B,Allowable}}$ is the allowable built-up backpressure, psi; AOP is the allowable overpressure, psi;

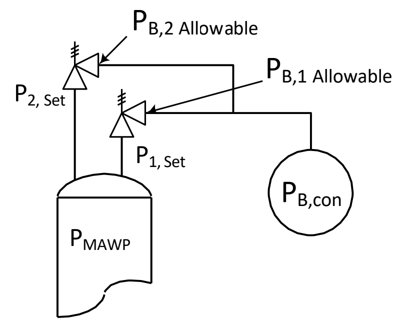
MAWP is the maximum allowable working pressure, psig;

%AA is the allowable accumulation (%);

P_{set} is the PRV set pressure, psig.

5.3.3.1.4 An example of the allowable backpressures for a multiple relief device installation, where the PRV is set lower than the MAWP and compensated for constant superimposed backpressure, is provided in Table 3.

Table 3—Example of Allowable Backpressures for a Multiple Conventional Pressure-relief Valve Installation



		Scenarios	
		Nonfire	Fire
$P_{B,CON}$	psig	25	25
$CDTP_1$	psig	70	70
$CDTP_2$	psig	75	75
$P_{1,set}$	psig	95	95
$P_{2,set}$	psig	100	100
%AA		16.0 %	21.0 %
MAWP	psig	100	100
AOP_1	psi	21	26
AOP_2	psi	16	21
$P_{B,1\ Allowable}$	psi	21.0	26.0
$P_{B,2\ Allowable}$	psi	16.0	21.0

Nomenclature:

— $P_{B,CON}$ = constant superimposed backpressure

— CDTP = cold differential test pressure (no temperature correction included in the example)

— P_{set} = set pressure

— %AA = % allowable accumulation

— MAWP = maximum allowable working pressure

— AOP = allowable overpressure

— $P_{B,Allowable}$ = allowable built-up backpressure (excluding constant superimposed backpressure)

5.3.3.1.5 When the downstream piping is designed within the above backpressure criteria, no backpressure capacity correction (K_b = 1.0) is required in the valve sizing equations, for gases at critical flow or for liquids. When the backpressure is expected to exceed these specified limits, a balanced or pilot-operated PRV should be specified.

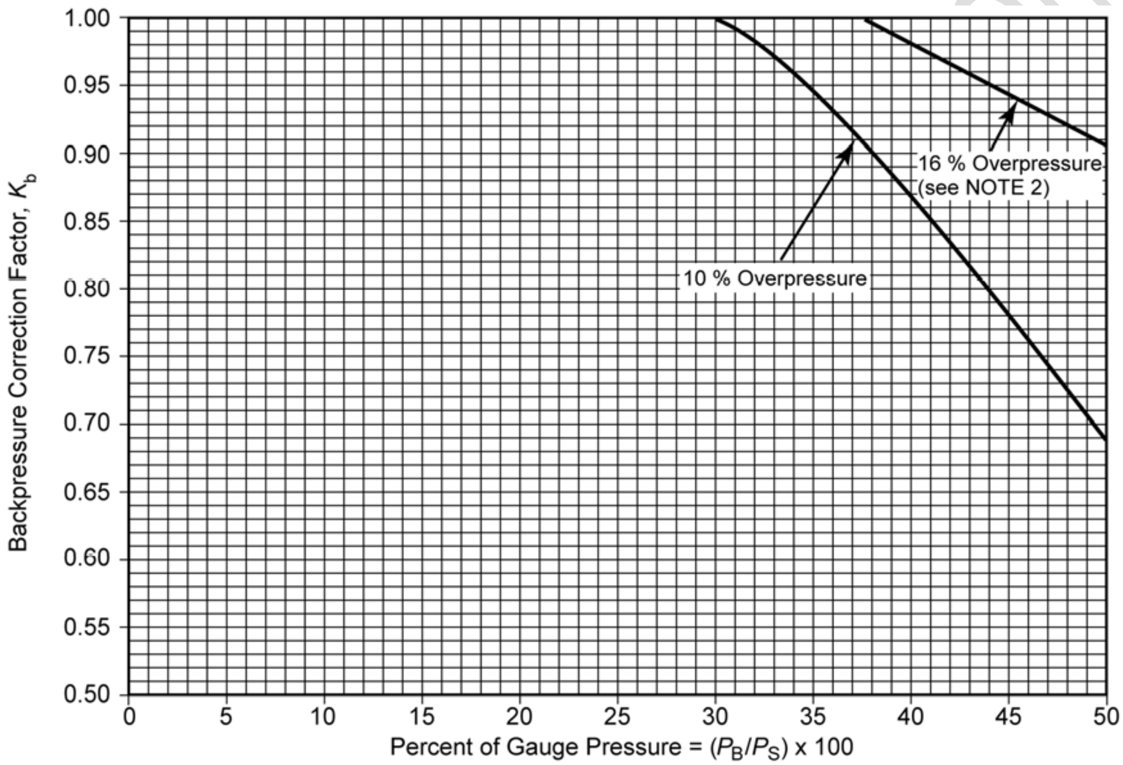
NOTE The built-up backpressure limitations discussed above do not necessarily apply to valves with open bonnet design due to the nature of their design. Consult the manufacturer for guidance.

5.3.3.2 Balanced Pressure-relief Valves

5.3.3.2.1 A balanced PRV can 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 can provide 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 The backpressure correction factors from Figure 31 and Figure 32 are suitable for the preliminary sizing procedures found in this document. If more accurate calculations are required, they should be completed using the manufacturers' actual charts along with the certified coefficient of discharge and actual orifice area (see 5.2.6).

In some applications, set pressure may be significantly less than MAWP allowing for overpressures in excess of those specified above. In such cases, the manufacturer should be consulted for guidance.



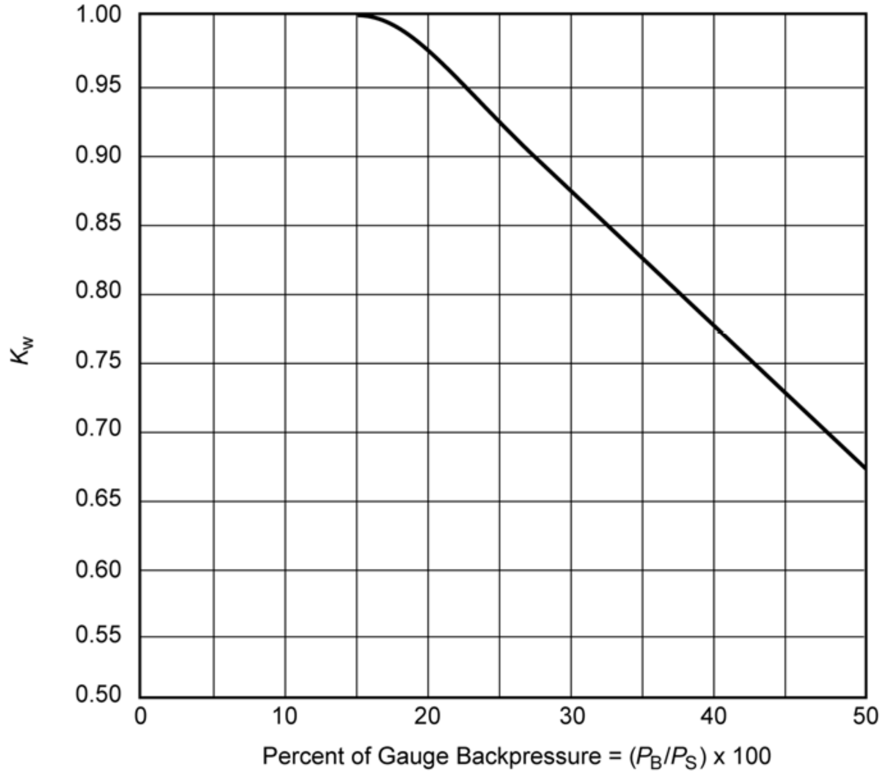
P_B = backpressure, in psig
P_S = set pessure, in psig

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 %.

Figure 31—Backpressure Correction Factor, K_b, for Balanced Spring-loaded Pressure-relief Valves (Vapors and Gases)



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 K_b curves (both those in Figure 31 and Manufacturer provided curves) are intended to be used with the critical flow formulas found in 5.6.3, even if the flow is subcritical. The curves in Figures 31 and 32 cannot be extrapolated and therefore the PRV manufacturer shall 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.~~

5.3.3.3.1 A pilot-operated PRV should be considered where total backpressure (superimposed plus built-up) is beyond the limits for conventional and balanced PRVs.

5.3.3.3.2 For pilot-operated PRVs on compressible fluids, subcritical and critical flow conditions are determined by the pressure just downstream of the actual orifice area/ actual discharge area. The specific PRV manufacturer should be consulted for backpressure correction factors or any special limitations on valve operation. Depending on the amount of backpressure, the size of the PRV, and other valve design attributes, there could be a reduction in flow capacity. Capacity correction factors, called backpressure correction factors, are provided by pilot-operated PRV manufacturers to account for this reduction in flow. Typical backpressure correction factors may be found for compressible fluid service in Figure 33.

5.3.3.3.3 For liquids, for all overpressures, a back pressure correction factor of 1.0 should be used.

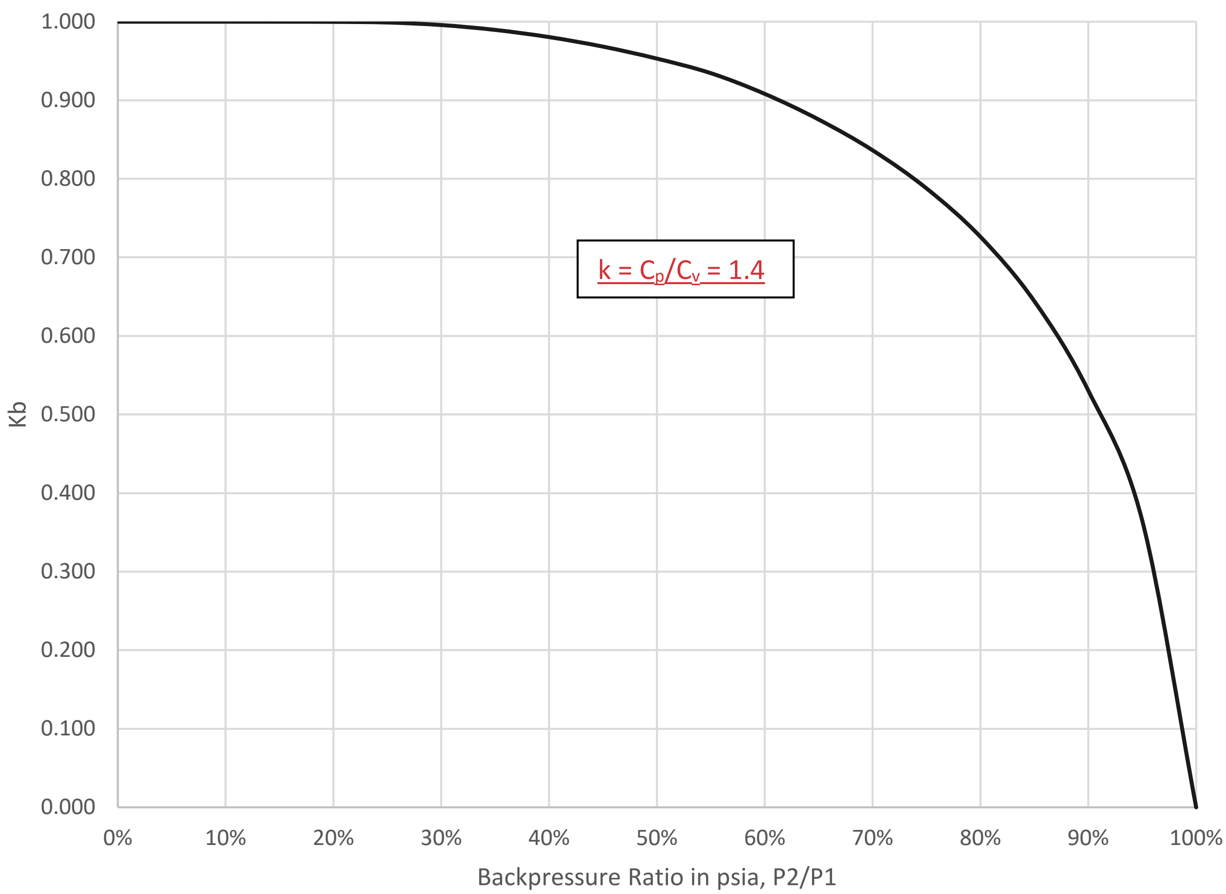


Figure 33 – Backpressure Correction Factor, Kb, for Pilot-Operated Pressure-relief Valves (Vapors and Gases)

NOTE 1 P2/P1 = absolute pressure at outlet flange/absolute pressure at inlet flange. These correction factors are suitable for the preliminary sizing procedures found in this document. The curve above represents an average 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 and if more accurate calculations are required, they should be completed using the manufacturers' actual curves along with the certified coefficient of discharge and actual orifice area (see 5.2.6).

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 or a pilot-operated 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.~~

~~**5.3.4.4**~~**5.3.4.3** Outlet pipe sizing and flare header sizing are discussed in more detail in API 520, Part II and API 521.

5.4 Relieving Pressure

5.4.1 General

5.4.1.1 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 nonreclosing 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 drop does not exceed 3 % of set pressure.

5.4.1.2 The allowable overpressure is established from the accumulation permitted by the applicable code. The allowable overpressure may vary for different applications depending on the relationship of the set pressure to the MAWP of the vessel or system that is protected.

5.4.1.3 The discussion in this section generally cites the ASME *Code* as the applicable code. Unless stated otherwise, citations refer only to Section VIII of the ASME *Code*. The designer should be aware of revisions to the ASME *Code*. If pertinent revisions occur, the discussion in this section should be adjusted accordingly by the designer. Adjustments may also be required by the designer if other (non-ASME) codes apply.

5.4.1.4 Sections 5.4.2 through 5.4.3 discuss methods of determining the relieving pressure for PRDs. In applications where these paragraphs do not apply, alternate accumulations are sometimes specified, as required by other codes or the equipment manufacturer.

5.4.1.5 Table 4 summarizes the maximum accumulation and set pressure for PRDs specified in accordance with the ASME *Code*.

5.4.2 Operating Contingencies

5.4.2.1 Single Device Installation

5.4.2.1.1 In accordance with the requirements of the ASME *Code*, accumulated pressure shall be limited to 110 % of the MAWP in vessels that are protected by a single PRD sized for operating (nonfire) contingencies. The set pressure of the device shall not exceed the MAWP.

Table 4—Set Pressure and Accumulation Limits for Pressure-relief Devices

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.				

5.4.2.1.2 The allowable accumulation is 3 psi (21 kPa) when the MAWP is between 15 psig and 30 psig (103 kPag and 207 kPag) in accordance with the ASME *Code*.

5.4.2.1.3 Table 5 shows an example determination of relieving pressure for a single device whose set pressure is less than or equal to the vessel's MAWP.

Table 5—Example Determination of Relieving Pressure for Operating Contingencies for a Single Relief Device Installation

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.	

5.4.2.2 Multiple Device Installation

5.4.2.2.1 A multiple device installation requires the combined capacity of two or more PRDs to alleviate a given overpressure contingency.

5.4.2.2.2 In accordance with the requirements of the ASME *Code*, accumulated pressure shall be limited to 116 % of the MAWP in vessels that are protected by multiple PRDs sized for operating (nonfire) contingencies. The set pressure of the first device shall not exceed the MAWP. The set pressure of the additional device or devices shall not exceed 105 % of the MAWP.

5.4.2.2.3 The allowable accumulation is 4 psi (28 kPa) when the MAWP is between 15 psig and 30 psig (103 kPag and 207 kPag).

5.4.2.2.4 Table 6 shows an example determination of the relieving pressure for a multiple device installation in which the set pressure of the first device is equal to the MAWP of the vessel, and the set pressure of the additional device is 105 % of the vessel's MAWP.

Table 6—Example Determination of Relieving Pressure for Operating Contingencies for a Multiple Relief Device Installation

Characteristic	Value
First Relief Device (Set Pressure Equal to MAWP)	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	116.0 (800)
Relief device set pressure, psig (kPag)	100.0 (689)
Allowable overpressure, psi (kPa)	16.0 (110)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	130.7 (901)
Additional Relief Device (Set Pressure Equal to 105 % of MAWP)	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	116.0 (800)
Relief device set pressure, psig (kPag)	105.0 (724)
Allowable overpressure, psi (kPa)	11.0 (76)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	130.7 (901)

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.

5.4.3 Fire Contingencies

5.4.3.1 General

5.4.3.1.1 In accordance with the requirements of the ASME *Code*, accumulated pressure shall be limited to 121 % of the MAWP in vessels that are protected by PRDs sized for fire contingencies. This applies to single, multiple, and supplemental device installations.

5.4.3.1.2 Single or multiple devices sized for fire may also be utilized for relieving requirements attributed to operating (nonfire) contingencies, provided that the constraint of 110 % and 116 % (of the MAWP) accumulated pressure for the nonfire contingencies is observed.

5.4.3.2 Single Device Installation

5.4.3.2.1 Where a vessel is protected by a single device sized for fire, the set pressure shall not exceed the MAWP.

5.4.3.2.2 Table 7 shows an example determination of relieving pressure for a single device whose set pressure is less than or equal to the vessel's MAWP.

Table 7—Example Determination of Relieving Pressure for Fire Contingencies for a Single Relief Device Installation

Characteristic	Value
Relief Device Set Pressure Equal to MAWP	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	121.0 (834)
Relief device set pressure, psig (kPag)	100.0 (689)
Allowable overpressure, psi (kPa)	21.0 (145)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	135.7 (936)
Relief Device Set Pressure Less Than MAWP	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	121.0 (834)
Relief device set pressure, psig (kPag)	90.0 (621)
Allowable overpressure, psi (kPa)	31.0 (214)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	135.7 (936)
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.	

5.4.3.3 Multiple Device Installation

5.4.3.3.1 A multiple device installation requires the combined capacity of two or more devices to alleviate overpressure. The set pressure of the first device to open shall not exceed the MAWP. The set pressure of the last device to open shall not exceed 105 % of the MAWP.

5.4.3.3.2 Table 8 shows an example determination of relieving pressure for a multiple device installation in which the set pressure of the first device is equal to the vessel's MAWP, and the set pressure of the additional device is 105 % of the vessel's MAWP.

5.4.3.4 Supplemental Device Installation

5.4.3.4.1 A supplemental device installation provides relieving capacity for an additional hazard created by exposure to fire or other unexpected sources of external heat. The set pressure of a supplemental device for fire shall not exceed 110 % of the MAWP.

Table 8—Example Determination of Relieving Pressure for Fire Contingencies for a Multiple Relief Device Installation

Characteristic	Value
First Relief Device (Set Pressure Equal to MAWP)	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	121.0 (834)
Relief device set pressure, psig (kPag)	100.0 (689)
Allowable overpressure, psi (kPa)	21.0 (145)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	135.7 (936)
Additional Relief Device (Set Pressure Equal to 105 % of MAWP)	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	121.0 (834)
Relief device set pressure, psig (kPag)	105.0 (724)
Allowable overpressure, psi (kPa)	16.0 (110)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	135.7 (936)
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.	

5.4.3.4.2 Supplemental devices are used only in addition to devices sized for operating (nonfire) contingencies.

5.4.3.4.3 Table 9 shows an example determination of relieving pressure for a supplemental device installation in which the set pressure of the first (nonfire) device does not exceed the vessel's MAWP (see 5.4.1 for determination of relieving pressure), and the set pressure of the supplemental device is 110 % of the vessel's MAWP.

5.5 Development of Sizing Equations

5.5.1 The assumption of isentropic nozzle flow for a homogeneous fluid provides a standard theoretical framework for PRV sizing equations. See Annex B for more information regarding the assumptions and/or simplifications that are made to the isentropic nozzle flow equation, which have resulted in the analytical equations presented in 5.6 through 5.11.

5.5.2 Annex C provides additional information on the development of the sizing equations for two-phase flow.

Table 9—Example Determination of Relieving Pressure for Fire Contingencies for a Supplemental Valve Installation

Characteristic	Value
First Relief Device (Set Pressure Equal to MAWP)	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	121.0 (834)
Relief device set pressure, psig (kPag)	100.0 (689)
Allowable overpressure, psi (kPa)	21.0 (145)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	135.7 (936)
Supplemental Relief Device (Set Pressure Equal to 110 % of MAWP)	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	121.0 (834)
Relief device set pressure, psig (kPag)	110.0 (758)
Allowable overpressure, psi (kPa)	11.0 (76)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	135.7 (936)
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.	

5.6 Sizing for Gas or Vapor Relief

5.6.1 Applicability

5.6.1.1 The sizing equations for PRDs in vapor or gas service provided in this section assume that the pressure-specific volume relationship along an isentropic path is well described by the expansion relation:

$$Pv^k = \text{constant} \tag{2}$$

where

P is the pressure, psia (Pa);

v is the specific volume at P, ft^3/lb (m^3/kg);

k is the ideal gas specific heat ratio at the relieving temperature (see B.3.2.2).

5.6.1.2 Years of experience with this basis indicates that this approach has provided satisfactory results over a wide range of conditions. Commonly, for real gas behavior, the nonideality of the fluid has been taken into consideration through the use of the compressibility factor Z and the use of the isentropic expansion exponent n in place of the ideal gas k (see B.3.1). However, the validity of the use of the ideal gas k may diminish as the vapor or gas approaches the thermodynamic critical locus, such as at very high pressures or as the vapor, gas, or supercritical fluid exhibits more liquid-like behavior. One indicator of this behavior is when the reduced volume (v_R) of the fluid is less than two (2.0) at the inlet pressure [17]. The reduced volume is expressed as:

$$v_R = \frac{v}{v_c} \qquad (3)$$

where

v is the specific volume of the relief fluid at the inlet to the device, ft^3/lb (m^3/kg);

v_R is the reduced volume, dimensionless;

v_c is the critical specific volume of the relief fluid, ft^3/lb (m^3/kg).

5.6.1.3 Although many simulation tools can provide the critical specific volume, in some cases it may be necessary to calculate it from other critical fluid properties. In these cases, the determination of the critical volume should include the critical compressibility factor to ensure that the nonideality of the fluid at this point is considered, as in the following equation:

$$v_c = Z_c R_u \frac{T_c}{MP_c} \qquad (4)$$

where

Z_c is the critical compressibility factor;

T_c is the critical temperature, °R (K);

P_c is the critical pressure, psia (Pa);

M is the molecular weight, lb/lb-mole (kg/kg-mole);

R_u is the universal gas constant = 10.73 psia·ft^3/lb-mole·°R (8.314 Pa·m^3/kg-mole·K).

NOTE The determination of the critical properties of a mixture is complex, and the user should use appropriate thermodynamic techniques. The use of a mole fraction average approximation is not appropriate.

5.6.1.4 Another indicator that the vapor or gas may be in one of these regions is a compressibility factor, Z, less than approximately 0.8 [16], or greater than approximately 1.1. It is important to note that the replacement of the ideal gas specific heat ratio, k, with the calculated isentropic expansion coefficient, n, in the gas sizing equation (see B.3.1) may not be sufficient to correct for the deviation from ideal gas behavior the further this deviation progresses.

5.6.1.5 There are two expressions used to derive the analytical gas sizing equation: the isentropic expansion relationship as given in Equation (2), and the critical flow pressure ratio as given in Equation (5). The assumptions used in both expressions contribute to poor prediction of the maximum mass flux and relief area in the gas sizing equations when the conditions do not reflect an ideal gas.

5.6.1.6 In such cases, use of the direct integration method (see Annex B) using an appropriate thermodynamic model is recommended to provide more accurate results [16]. To ensure the most appropriate sizing results, users should establish the limits of applicability for their own systems.

5.6.2 Critical Flow Behavior

5.6.2.1 If a compressible gas is expanded across a nozzle, an orifice, or the end of a pipe, its velocity and specific volume increase with decreasing downstream pressure. For a given set of upstream conditions (using the example of a nozzle), the mass rate of flow through the nozzle will increase until a limiting velocity is reached in the nozzle. It can be shown that the limiting velocity is the velocity of sound in the flowing fluid at that location. The flow rate that corresponds to the limiting velocity is known as the critical flow rate.

5.6.2.2 The absolute pressure ratio of the pressure at the nozzle exit at sonic velocity (P_{cf}) to the inlet pressure (P_1) is called the critical pressure ratio. P_{cf} is known as the critical flow pressure.

5.6.2.3 Under critical flow conditions, the actual pressure at the nozzle exit of the PRD cannot fall below the critical flow pressure even if a much lower pressure exists downstream. At critical flow, the expansion from nozzle pressure to downstream pressure takes place irreversibly with the energy dissipated in turbulence into the surrounding fluid.

5.6.2.4 The critical flow pressure ratio in absolute units may be estimated using the ideal gas relationship in Equation (5), provided the expansion law, Pv^k = constant, is a good approximation of the pressure/specific volume relationship [18]:

$$\frac{P_{cf}}{P_1} = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}} \tag{5}$$

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.

The ideal gas specific heat ratio is independent of pressure. Most process simulators will provide real gas specific heats that should not be used in the above equation because the real gas specific heat ratio does not provide a good representation of the isentropic expansion coefficient (see Annex B).

5.6.2.5 The sizing equations for PRDs in vapor or gas service fall into two general categories depending on whether the flow is critical or subcritical. If the pressure downstream of the nozzle is less than, or equal to, the critical flow pressure, P_{cf}, then critical flow will occur, and the procedures in 5.6.3 should be applied. If the downstream pressure exceeds the critical flow pressure, P_{cf}, then subcritical flow will occur, and the procedures in 5.6.4 or 5.6.5 should be applied. See Table 10 for typical critical flow pressure ratio values.

Table 10—Properties of Gases

Gas	Molecular Weight	Ideal Gas Specific Heat Ratio ($k = C_p/C_v$) at 60 °F and One Atmosphere	Ideal Gas Critical Flow Pressure Ratio at 60 °F and One Atmosphere	Ideal Gas Specific Gravity at 60 °F and One Atmosphere	Critical Constants		Condensation Temperature One Atmosphere
					Pressure psia (kPa)	Temperature °F (°C)	°F (°C)
Methane [a]	16.04	1.31	0.54	0.554	673 (4640)	–116 (–82)	–259 (–162)
Ethane [a]	30.07	1.19	0.57	1.058	718 (4950)	90 (32)	–128 (–89)
Ethylene [a]	28.03	1.24	0.57	0.969	742 (5116)	50 (10)	–155 (–104)
Propane [a]	44.09	1.13	0.58	1.522	617 (4254)	206 (97)	–44 (–42)
Propylene	42.08	1.15	0.58	1.453	667 (4599)	197 (92)	–54 (–48)
Isobutane [a]	58.12	1.10	0.59	2.007	529 (3647)	273 (134)	11 (–12)
n-Butane [a]	58.12	1.09	0.59	2.007	551 (3799)	304 (151)	31 (–1)
1-Butene	56.10	1.11	0.59	1.937	586 (4040)	296 (147)	21 (–6)
Isopentane [a]	72.15	1.08	0.59	2.491	483 (3330)	369 (187)	82 (28)
n-Pentane [a]	72.15	1.08	0.59	2.491	490 (3378)	386 (197)	97 (36)
1-Pentene [a]	70.13	1.08	0.59	2.421	510 (3930)	377 (192)	86 (30)
n-Hexane [a]	86.18	1.06	0.59	2.973	437 (3013)	454 (234)	156 (69)
Benzene	78.11	1.12	0.58	2.697	714 (4923)	552 (289)	176 (80)
n-Heptane [a]	100.20	1.05	0.60	3.459	397 (2737)	513 (267)	209 (98)
Toluene	92.13	1.09	0.59	3.181	590 (4068)	604 (318)	231 (111)
n-Octane [a]	114.22	1.05	0.60	3.944	362 (2496)	564 (296)	258 (126)
n-Nonane	128.23	1.04	0.60	4.428	332 (2289)	610 (321)	303 (151)
n-Decane	142.28	1.03	0.60	4.912	304 (2096)	632 (333)	345 (174)
Air	28.96	1.40	0.53	1.000	547 (3771)	–221 (–141)	–313 (–192)
Ammonia	17.03	1.30	0.53	0.588	1636 (11,280)	270 (132)	–28 (–33)
Carbon dioxide	44.01	1.29	0.55	1.519	1071 (7384)	88 (31)	–109 (–78)
Hydrogen	2.02	1.41	0.52	0.0696	188 (1296)	–400 (–240)	–423 (–253)
Hydrogen sulfide	34.08	1.32	0.53	1.176	1306 (9005)	213 (101)	–77 (–61)
Sulfur dioxide	64.04	1.27	0.55	2.212	1143 (7881)	316 (158)	14 (–10)
Steam	18.01	1.33	0.54	0.622	3206 (22,104)	706 (374)	212 (100)

[a] Estimated.

5.6.3 Sizing for Critical Flow

5.6.3.1 General

5.6.3.1.1 PRDs in gas or vapor service that operate at critical flow conditions (see 5.6.2) may be sized using Equation (6) through Equation (11). Each of the equations may be used to calculate the required discharge area, A, to achieve a required flow rate through a PRD. A PRV that has a discharge area equal to or greater than the calculated value of A is then chosen for the application. Note that the equations presented here can be used for preliminary sizing when effective values for area and coefficient of discharge are used and for final sizing when actual areas and certified coefficients of discharge are used.

In USC units:

$$A = \frac{W}{CK_\mathrm{d}P_1K_\mathrm{b}K_\mathrm{c}}\sqrt{\frac{TZ}{M}} \tag{6}$$

$$A = \frac{V\sqrt{TZM}}{6.32CK_\mathrm{d}P_1K_\mathrm{b}K_\mathrm{c}} \tag{7}$$

$$A = \frac{V\sqrt{TZG_\mathrm{v}}}{1.175CK_\mathrm{d}P_1K_\mathrm{b}K_\mathrm{c}} \tag{8}$$

In SI units:

$$A = \frac{W}{CK_\mathrm{d}P_1K_\mathrm{b}K_\mathrm{c}}\sqrt{\frac{TZ}{M}} \tag{9}$$

$$A = \frac{2.676 \times V\sqrt{TZM}}{CK_\mathrm{d}P_1K_\mathrm{b}K_\mathrm{c}} \tag{10}$$

$$A = \frac{14.41 \times V\sqrt{TZG_\mathrm{v}}}{CK_\mathrm{d}P_1K_\mathrm{b}K_\mathrm{c}} \tag{11}$$

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 ($k = C_\mathrm{p}/C_\mathrm{v}$) 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]:

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

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

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

The ideal gas specific heat ratio is independent of pressure. Most process simulators will provide real gas specific heats that should not be used in the above equation; otherwise, the PRD may be undersized. The value of C can be obtained from Figure 3~~4~~3, Figure 3~~5~~4, or Table11. For ideal gases, where k cannot be established, it is suggested that a conservative value of C equal to 315 (0.0239) be used. The units for C are as follows.

In USC units:

$$\frac{\sqrt{\mathrm{lb_m} \times \mathrm{lb-mole} \times {}^\circ\mathrm{R}}}{\mathrm{lb_f} \times \mathrm{hr}}$$

In SI units:

$$\frac{\sqrt{\mathrm{kg} \times \mathrm{kg-mole} \times K}}{\mathrm{mm}^2 \times \mathrm{hr} \times \mathrm{kPa}}$$

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 for balanced bellows valves and Figure 33 for pilot-operated valves. ~~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);

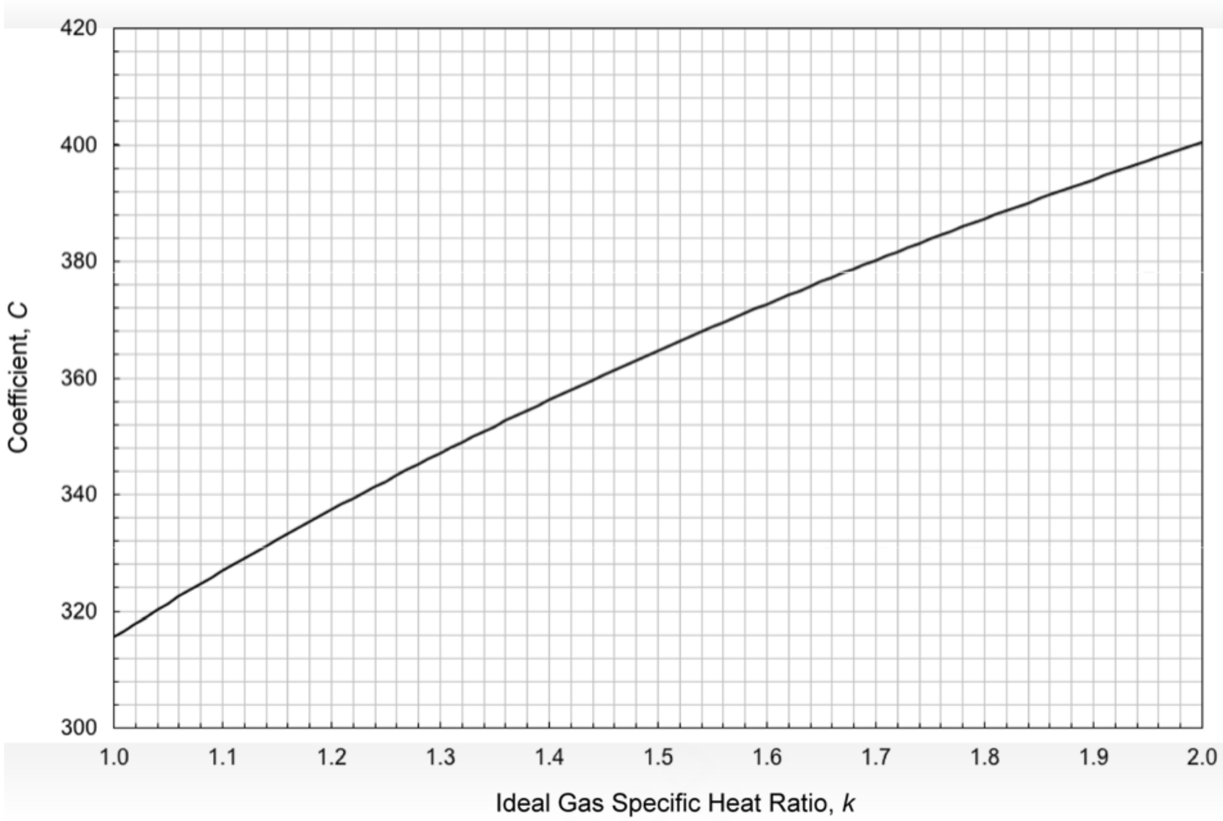
G_v is the specific gravity of gas at standard conditions referred to air at standard conditions (normal conditions); in other words, G_v = 1.00 for air at 14.7 psia and 60 °F (101.325 kPa and 0 °C).

Table 11—Values of Coefficient C

k	C		k	C		k	C		k	C	
	USC	SI		USC	SI		USC	SI		USC	SI
1.00	315	0.0239	1.26	343	0.0261	1.51	365	0.0277	1.76	384	0.0292
1.01	317	0.0240	1.27	344	0.0261	1.52	366	0.0278	1.77	385	0.0292
1.02	318	0.0241	1.28	345	0.0262	1.53	367	0.0279	1.78	386	0.0293
1.03	319	0.0242	1.29	346	0.0263	1.54	368	0.0279	1.79	386	0.0293
1.04	320	0.0243	1.30	347	0.0263	1.55	369	0.0280	1.80	387	0.0294
1.05	321	0.0244	1.31	348	0.0264	1.56	369	0.0280	1.81	388	0.0294
1.06	322	0.0245	1.32	349	0.0265	1.57	370	0.0281	1.82	389	0.0295
1.07	323	0.0246	1.33	350	0.0266	1.58	371	0.0282	1.83	389	0.0296
1.08	325	0.0246	1.34	351	0.0266	1.59	372	0.0282	1.84	390	0.0296
1.09	326	0.0247	1.35	352	0.0267	1.60	373	0.0283	1.85	391	0.0297
1.10	327	0.0248	1.36	353	0.0268	1.61	373	0.0283	1.86	391	0.0297
1.11	328	0.0249	1.37	353	0.0268	1.62	374	0.0284	1.87	392	0.0298
1.12	329	0.0250	1.38	354	0.0269	1.63	375	0.0285	1.88	393	0.0298
1.13	330	0.0251	1.39	355	0.0270	1.64	376	0.0285	1.89	393	0.0299
1.14	331	0.0251	1.40	356	0.0270	1.65	376	0.0286	1.90	394	0.0299
1.15	332	0.0252	1.41	357	0.0271	1.66	377	0.0286	1.91	395	0.0300
1.16	333	0.0253	1.42	358	0.0272	1.67	378	0.0287	1.92	395	0.0300
1.17	334	0.0254	1.43	359	0.0272	1.68	379	0.0287	1.93	396	0.0301
1.18	335	0.0254	1.44	360	0.0273	1.69	379	0.0288	1.94	397	0.0301
1.19	336	0.0255	1.45	360	0.0274	1.70	380	0.0289	1.95	397	0.0302
1.20	337	0.0256	1.46	361	0.0274	1.71	381	0.0289	1.96	398	0.0302
1.21	338	0.0257	1.47	362	0.0275	1.72	382	0.0290	1.97	398	0.0302
1.22	339	0.0258	1.48	363	0.0276	1.73	382	0.0290	1.98	399	0.0303
1.23	340	0.0258	1.49	364	0.0276	1.74	383	0.0291	1.99	400	0.0303
1.24	341	0.0259	1.50	365	0.0277	1.75	384	0.0291	2.00	400	0.0304
1.25	342	0.0260	—	—	—	—	—	—	—	—	—

NOTE 1 Values of C in USC units apply to Equation (6), Equation (7), and Equation (8) only.

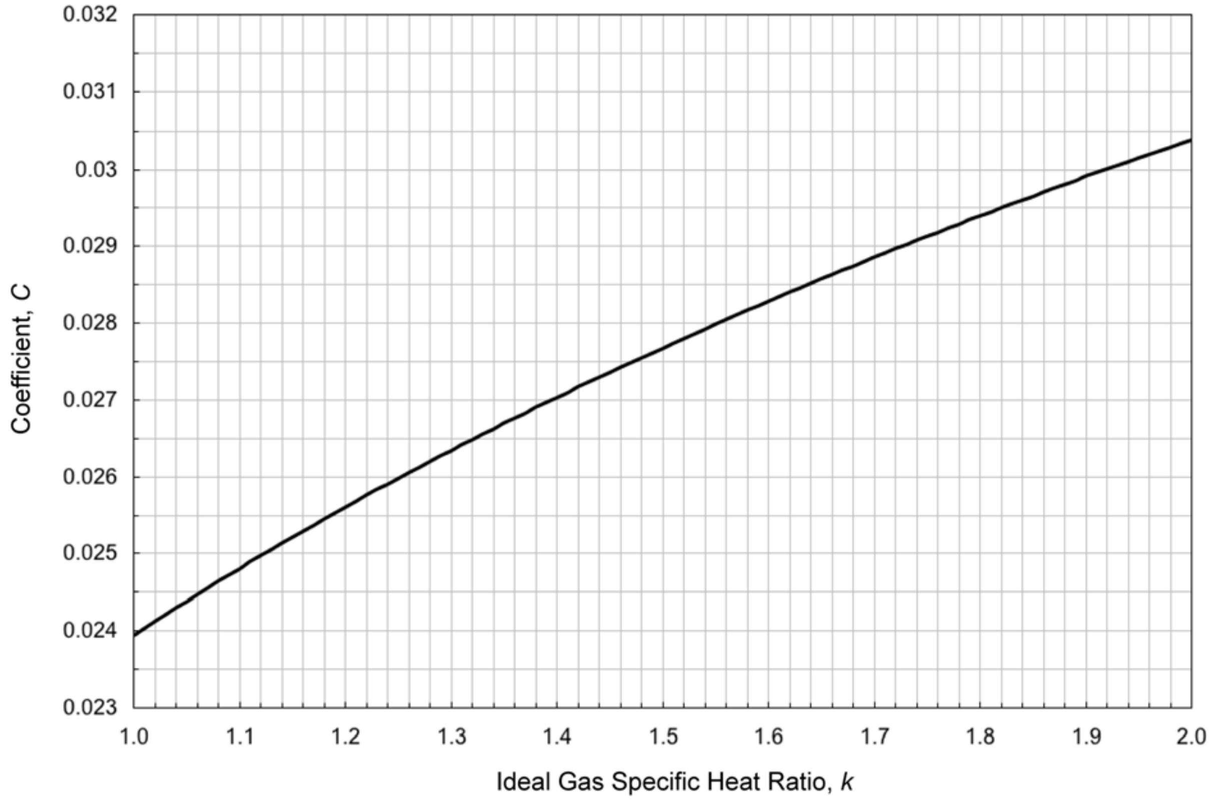
NOTE 2 Values of C in SI units apply to Equation (9), Equation (10), and Equation (11) only.



NOTE 1 The equation for this curve is $C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$

NOTE 2 The units for the coefficient C are $\frac{\sqrt{lb_m \times lb - mole \times {}^\circ R}}{lb_f \times hr}$

Figure 3~~3~~4—Curve for Evaluating Coefficient C in the Flow Equation from the Specific Heat Ratio, Assuming Ideal Gas Behavior (USC Units)



NOTE 1 The equation for this curve is $C = 0.03948\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$

NOTE 2 The units for the coefficient C are $\frac{\sqrt{kg \times kg - mole \times K}}{mm^2 \times hr \times kPa}$

Figure 3~~4~~5—Curve for Evaluating Coefficient C in the Flow Equation from the Specific Heat Ratio, Assuming Ideal Gas Behavior (SI Units)

5.6.3.1.2 Whereas ideal gas law behavior (with compressibility factor, Z, included) is generally acceptable for the majority of refinery applications, Annex B should be referred to for unusual situations in which deviation from ideal behavior is significant.

5.6.3.2 Example 1

5.6.3.2.1 In this example, the following relief requirements are given.

a) Required hydrocarbon vapor flow, W, caused by an operational upset, of 53,500 lb/h (24,270 kg/h).

b) The hydrocarbon vapor is a 50/50 (by mole) mixture of n-butane (C_4) and propane (C_3). The molecular weight of the vapor, M, is 51.

c) Relieving temperature, T, of 627 °R (167 °F) (348 K).

d) PRV set at 75 psig (517 kPag), which is the design pressure of the equipment.

e) Backpressure of 14.7 psia (0 psig) [101.325 kPa (0 kPag)].

f) Overpressure of 10 %.

5.6.3.2.2 In this example, the following data are derived.

a) Relieving pressure, P_1, of 75 × 1.1 + 14.7 = 97.2 psia (670 kPa).

b) Calculated compressibility, Z, of 0.90 (if a calculated compressibility is not available, a Z value of 1.0 should be used).

c) Critical flow pressure (from Table 10) of 97.2 × 0.585 = 56.9 psia (42.2 psig) (392 kPa).

NOTE Since the backpressure [0 psig (0 kPag)] is less than the critical flow pressure [42.2 psig (291 kPag)], the PRV sizing is based on the critical flow equation [see Equation (6) and 5.6.1 and 5.6.2].

d) $C_p/C_v = k$ (from Table 10) of 1.11. From Table 11, C = 328 (0.0249).

NOTE For this example problem, k was obtained from Table 10 at standard conditions, which could result in a conservative answer. If the k value is known at the relieving temperature, use this value instead. In this case, the ideal gas specific heat ratio is a good approximation of the isentropic exponent for the purposes of this calculation. See Annex B for further discussion.

e) Capacity correction due to backpressure, K_b, of 1.0.

f) Capacity correction for rupture disk, K_c = 1.0.

5.6.3.2.3 For preliminary sizing, the effective coefficient of discharge, K_d, of 0.975 can be used. The size of a single PRV is calculated using Equation (6) or Equation (9) as follows.

In USC units:

$$A = \frac{53{,}500}{328 \times 0.975 \times 97.2 \times 1.0 \times 1.0} \sqrt{\frac{627 \times 0.90}{51}} = 5.73 \text{ in.}^2 \qquad (14)$$

In SI units:

$$A = \frac{24{,}270}{0.0249 \times 0.975 \times 670 \times 1.0 \times 1.0 \sqrt{\frac{348 \times 0.90}{51}}} = 3698 \text{ mm}^2 \qquad (15)$$

5.6.3.2.4 See API 526 for selection of the proper orifice size. API 526 provides standard effective orifice areas in terms of letter designations. For this example, a "P" size orifice was selected since it has an effective orifice area of 6.38 in.^{2} (4116 mm^2).

5.6.3.2.5 A completed PRV specification sheet for this example is provided in Figure 35 (a blank specification sheet is provided in Annex D).

SPRING-LOADED PRESSURE-RELIEF VALVE SPECIFICATION SHEET	Sheet Number Page of
	Requisition Number
	Job Number
	Date
	Revision Number
	By

	GENERAL		
1.	Item Number: ***Example 1***	3.	Service, Line, or Equip. Number:
2.	Tag Number:	4.	Number of Valves Required:
	BASIS OF SELECTION		
5.	Code: ASME VIII [**X**] Stamp Required: Yes [**X**] No [ ] Other [ ] Specify:	7.	Fire [ ] Other [**X**] Specify:
		8.	Rupture Disk: Yes [ ] No [**X**]
6.	Comply with API 526: Yes [**X**] No [ ]		
	VALVE DESIGN		
9.	Design Type: ***XXXX*** Conventional [**X**] Bellows [ ] Balanced Piston [ ]	13.	Bonnet Type: Open [ ] Closed [**X**]
		14.	Seat Type: Metal-to-Metal [**X**] Resilient [ ]
10.	Trim Type: Liquid [ ] Vapor [**X**] Dual [ ]	15.	Seat Tightness: API 527 [**X**] Other [ ] Specify:
11.	Restricted Lift: Yes [ ] No [**X**]		
12.	Nozzle Type: Full [**X**] Semi [ ] Other [ ] Specify:		
	CONNECTIONS		
16.	Inlet Size: ***4*** Rating: ***150*** Facing: ***RP***	18.	Other [ ] Specify:
17.	Outlet Size: ***6*** Rating: ***150*** Facing: ***RF***		
	MATERIALS		
19.	Body:	25.	Spring: Washer:
20.	Bonnet:	26.	Bellows: ***N / A***
21.	Seat (Nozzle): Disk:	27.	Balanced Piston: ***N / A***
22.	Resilient Seal:	28.	Comply with NACE: Yes [ ] No [**X**]
23.	Guide:	29.	Internal Gasket Materials:
24.	Adjusting Ring(s):	30.	Other [ ] Specify:
	ACCESSORIES		
31.	Cap: Screwed [ ] Bolted [**X**]	34.	Bug Screen: Yes [ ] No [**X**]
32.	Lifting Lever: Plain [ ] Packed [ ] None [**X**]	35.	Other [ ] Specify:
33.	Test Gag: Yes [ ] No [**X**]		
	SERVICE CONDITIONS		
36.	Fluid and State: ***Hydrocarbon Vapor***	45.	Operating Temperature and Units: ***100 °F***
37.	Required Capacity per Valve and Units: ***53,500 lb/hr***	46.	Relieving Temperature and Units: ***167 °F***
38.	Mass Flux and Basis:	47.	Built-up Backpressure and Units:
39.	Molecular Weight or Specific Gravity: ***51***	48.	Superimposed Backpressure and Units: 0 psig
40.	Viscosity at Flowing Temperature and Units: **--**	49.	Cold Differential Test Pressure and Units:
41.	Operating Pressure and Units: ***50 psig***	50.	Allowable Overpressure in Percent or Units: ***10***
42.	Set Pressure and Units: ***75 psig***	51.	Compressibility Factor, Z: ***0.90***
43.	Blowdown: Standard [**X**] Other [ ]	52.	Ratio of Specific Heats: ***1.11***
44.	Latent Heat of Vaporization and Units:		
	SIZING AND SELECTION		
53.	Calculated Orifice Area (in square inches): ***5.73***	56.	Manufacturer: *****
54.	Selected Effective Orifice Area (in square inches): ***6.38***	57.	Model Number: *****
55.	Orifice Designation (letter): ***P***	58.	Vendor Calculations Required: Yes [**X**] No [ ]
	GENERAL NOTES		
59.			

NOTE The user should indicate items to be completed by the manufacturer with an asterisk (*).

Figure 3~~5~~6—Sample of Completed Pressure-relief Valve Specification Sheet

5.6.4 Sizing for Subcritical Flow: Gas or Vapor

5.6.4.1 Conventional PRVs ~~and Pilot-operated Pressure-relief Valves~~

When the ratio of backpressure to inlet pressure exceeds the critical pressure ratio P_{cf}/P_1, the flow through the PRD is subcritical (see 5.6.2). Equation (16) through Equation (21) may be used to calculate the required discharge area for a conventional PRV that has its spring setting adjusted to compensate for superimposed backpressure. ~~Equation (16) through Equation (21) may also be used for sizing a pilot-operated PRV.~~ Note that the equations presented here can be used for preliminary sizing when effective values for area and coefficient of discharge are used and for final sizing when actual areas and certified coefficients of discharge are used.

In USC units:

$$A = \frac{W}{735 \times F_2 K_d K_c} \sqrt{\frac{TZ}{M \times P_1 (P_1 - P_2)}} \quad (16)$$

$$A = \frac{V}{4645 \times F_2 K_d K_c} \sqrt{\frac{TZM}{P_1 (P_1 - P_2)}} \quad (17)$$

$$A = \frac{V}{864 \times F_2 K_d K_c} \sqrt{\frac{TZG_v}{P_1 (P_1 - P_2)}} \quad (18)$$

In SI units:

$$A = \frac{17.9W}{F_2 F_d K_c} \sqrt{\frac{TZ}{MP_1 (P_1 - P_2)}} \quad (19)$$

$$A = \frac{47.95V}{F_2 F_d K_c} \sqrt{\frac{TZM}{P_1 (P_1 - P_2)}} \quad (20)$$

$$A = \frac{258V}{F_2 K_d K_c} \sqrt{\frac{TZG_V}{P_1 (P_1 - P_2)}} \quad (21)$$

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 37~~6~~ for values, or use Equation (22).

$$F_2 = \sqrt{\left(\frac{k}{k-1}\right) r^{\left(\frac{2}{k}\right)} \left[\frac{1 - r^{\left(\frac{k-1}{k}\right)}}{1 - r}\right]} \quad (22)$$

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 may 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).

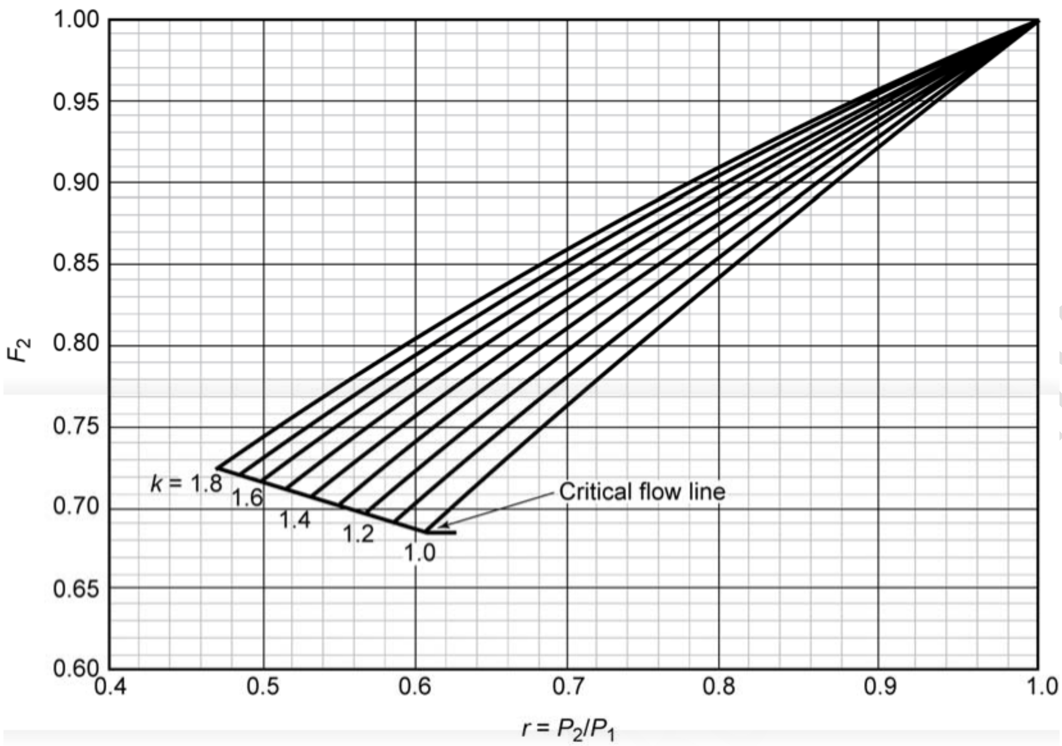


Figure 37~~6~~—Values for F_2 for Subcritical Flow

5.6.4.2 Example 2

5.6.4.2.1 In this example, the following relief requirements are given.

a) Required hydrocarbon vapor flow, W, caused by an operational upset, of 53,500 lb/h (24,270 kg/h).

b) The hydrocarbon vapor is a 50/50 (by mole) mixture of n-butane (C_4) and propane (C_3). The molecular weight of the vapor, M, is 51.

c) Relieving temperature, T, of 627 °R (167 °F) (348 K).

d) PRV set at 75 psig (517 kPag), which is the design pressure of the equipment.

e) Constant backpressure of 55 psig (379 kPa).

f) For a conventional valve, the spring setting of the valve is adjusted according to the amount of constant superimposed backpressure obtained. In this example, the CDTP is 20 psig (138 kPa).

g) Overpressure of 10 %.

5.6.4.2.2 In this example, the following data are derived.

a) Relieving pressure, P_1, of 75 × 1.1 + 14.7 = 97.2 psia (670 kPa).

b) Calculated compressibility, Z, of 0.90 (if a calculated compressibility is not available, a value for Z of 1.0 should be used).

c) Critical backpressure (from Table 10) of 97.2 × 0.585 = 56.9 psia (42.2 psig) [392 kPa (291 kPag)].

d) Since the backpressure [55 psig (379 kPag)] is greater than the critical backpressure [42.2 psig (291 kPag)], the PRV sizing is based on the subcritical flow equation [see Equation (16)].

e) Permitted built-up backpressure of 0.10 × 75 = 7.5 psi (51.7 kPa).

f) The actual built-up backpressure was used.

g) Permitted total backpressure of 55 + 7.5 + 14.7 = 77.2 psia (532 kPa).

h) $C_p/C_v = k$ (from Table 10) of 1.11.

i) For this example problem, *k* was obtained from Table 10 at standard conditions.

j) P_2/P_1 = 77.2/97.2 = 0.794.

k) Coefficient of subcritical flow, F_2, of 0.86 (from Figure 37~~6~~).

l) Capacity correction for rupture disk, K_c = 1.0.

5.6.4.2.3 For preliminary sizing, the effective coefficient of discharge, K_d, of 0.975 can be used. The size of a single PRV is derived from Equation (16) as follows:

$$A = \frac{53{,}500}{735 \times 0.86 \times 0.975 \times 1.0}\sqrt{\frac{627 \times 0.90}{51 \times 97.2 \times (97.2 - 77.2)}} = 6.55\ in.^2\ \ (4{,}226\ mm^2) \qquad (23)$$

5.6.4.2.4 For selection of the proper orifice size, see API 526. For this example, a "Q" size orifice was selected since it has an effective orifice area of 11.05 in.^{2} (7129 mm^2).

5.6.4.3 Balanced ~~Pressure-relief Valves~~and Pilot-Operated PRVs

Balanced and pilot-operated PRVs should be sized using Equation (6) through Equation (11) in 5.6.3.1.1. The backpressure correction factor in this application accounts for flow velocities that are subcritical as well as the tendency for the disc to drop below full lift (the use of subcritical flow equations are appropriate only where full lift is maintained). The backpressure correction factor, K_b, for this application should be obtained from the manufacturer.

5.6.5 Alternate Sizing Procedure for Conventional ~~and Pilot-operated Valves~~ in Subcritical Flow

5.6.5.1 General

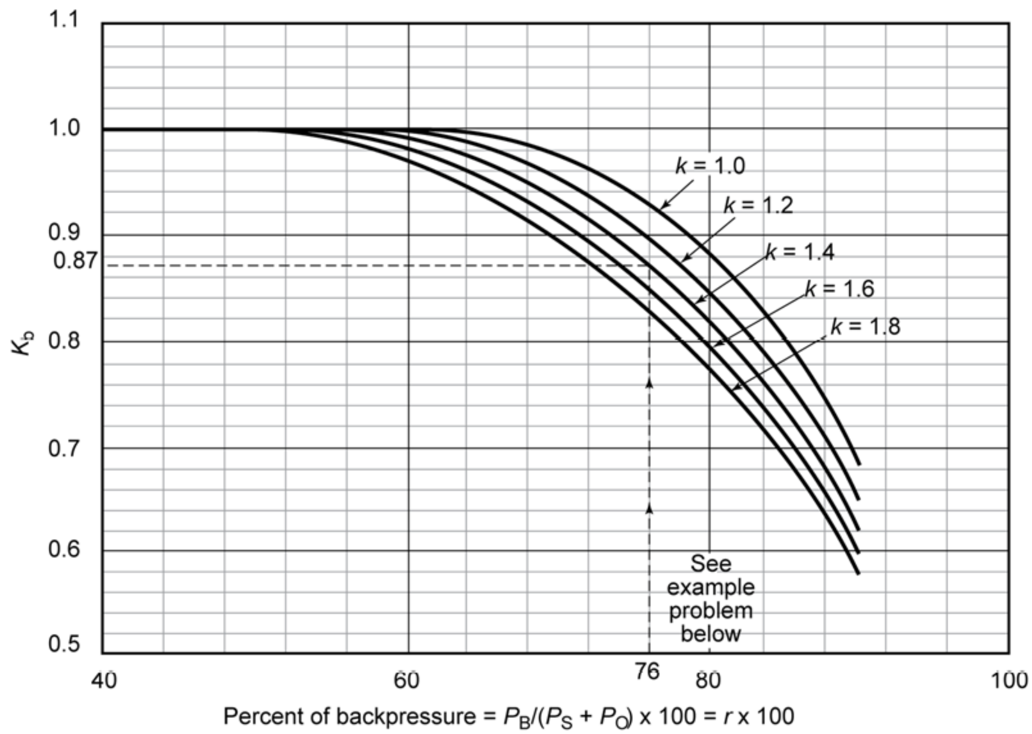
As an alternative to using the subcritical flow equations given in 5.6.4, the critical flow Equation (6) through Equation (11), presented in 5.6.3, may be used to calculate the required effective discharge area of a conventional ~~or pilot-operated~~ PRV used in subcritical service. The area obtained using this alternate sizing procedure is identical to the area obtained using the subcritical flow equations. In this alternate method, the capacity correction factor due to backpressure, K_b, is derived by setting the subcritical flow equation (see 5.6.4) equal to the critical flow equation (see 5.6.3) and algebraically solving for K_b. The resulting equation is provided as Equation (24). Note that this equation only applies to subcritical flow applications, see Equation (5). A graphical presentation of the capacity correction factor, K_b, is given in Figure 38~~7~~. This alternate sizing procedure allows the designer to use the critical flow equation to calculate the same area obtained with the subcritical flow equation provided K_b is obtained from Equation (24) or

Figure 38~~7~~ (instead of a K_b value of 1.0 when the critical flow equations of 5.6.3 are used).

$$K_b = \sqrt{\frac{\frac{2k}{k-1}\left[(r)^{\frac{2}{k}} - (r)^{\frac{k+1}{k}}\right]}{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}} \qquad (24)$$

where

- K_b is the capacity correction factor due to backpressure;
- k is the ratio of the ideal specific heats (C_p/C_V) of the gas or vapor at relieving temperature; the ideal gas specific heat ratio is independent of pressure;
- r is the ratio of backpressure to upstream relieving pressure, P_2/P_1;
- 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).



K_b = backpressure correction factor
P_B = backpressure, in psia
P_S = set pressure, in psia
P_O = ovepressure, in psi

Set pressure (MAWP)	= 100 psig
Overpressure	= 10 psi
Superimposed backpressure (constant)	= 70 psig
Spring set	= 30 psi
Built-up backpressure	= 10 psi
Percent absolute backpressure	$= \frac{(70 + 10 + 14.7)}{(100 + 10 + 14.7)} \times 100$
	= 76
K_b (follow dotted line for $C_p/C_v = k = 1.4$)	= 0.87 (from the curve)

NOTE This chart is typical and suitable for use only when the make of the valve or the actual critical flow pressure point for the vapor or gas is unknown; otherwise, the valve manufacturer should be consulted for specific data. This correction factor should be used only in the sizing of conventional (nonbalanced) PRVs that have their spring setting adjusted to compensate for the superimposed backpressure. It should not be used to size balanced type valves.

Figure 38~~7~~—Constant Backpressure Correction Factor, K_b, for Conventional ~~and Pilot-operated Pressure-relief Valves~~

Note that this method is used only for the sizing of ~~pilot-operated PRVs and~~ conventional (nonbalanced) PRVs that have their spring settings adjusted to compensate for the superimposed backpressure. This method should not be used to size balanced type valves or pilot-operated PRVs.

5.6.5.2 Example 3

5.6.5.2.1 In this example, the following relief requirements are given.

a) Required hydrocarbon vapor flow, W, caused by an operational upset, of 53,500 lb/h (24,270 kg/h).

b) The hydrocarbon vapor is a mixture of n-butane (C_4) and propane (C_3). The molecular weight of the mixture, M, is 51.

c) Relieving temperature, T, of 627 °R (167 °F) [348 K (75 °C)].

d) PRV set at 75 psig (517 kPag), which is the design pressure of the equipment.

e) Constant backpressure of 55 psig (379 kPag).

f) For a conventional valve, the spring setting of the valve is adjusted according to the amount of constant superimposed backpressure obtained. In this example, the CDTP is 20 psig (138 kPag).

5.6.5.2.2 In this example, the following data are derived.

a) Permitted accumulation of 10 %.

b) Relieving pressure, P_1, of 75 × 1.1 + 14.7 = 97.2 psia (670 kPa).

c) Calculated compressibility, Z, of 0.90 (if a calculated compressibility is not available, a value for Z of 1.0 should be used).

d) Critical backpressure (from Table 10) of 97.2 × 0.585 = 56.9 psia (42.2 psig) [392 kPa (291 kPag)].

NOTE Since the backpressure [55 psig (379 kPag)] is greater than the critical backpressure [42.2 psig (291 kPag)], the sizing of the PRV is based on subcritical flow. The backpressure correction factor, K_b, should be determined using Figure 38~~7~~ or Equation (24) when the critical flow formulas are used [see Equation (6) through Equation (11)].

e) Built-up backpressure of 0.10 × 75 = 7.5 psi (51.7 kPa).

f) Total backpressure of 55 + 7.5 + 14.7 = 77.2 psia (532 kPa).

g) $C_p/C_v = k$ of 1.11.

NOTE For this example problem, k was obtained from Table 10 at standard conditions.

h) P_2/P_1 = 77.2/97.2 = 0.794.

i) Backpressure correction factor, K_b, of 0.87 (using Figure 3~~7~~8 or Equation 24).

j) Coefficient determined from an expression of the ratio of the specific heats of the gas or vapor at inlet relieving conditions, C, of 328 (0.0249) (from Table 11).

k) Capacity correction for rupture disk, K_c = 1.0.

5.6.5.2.3 For preliminary sizing, the effective coefficient of discharge, K_d, of 0.975 can be used. The size of the PRV is derived from Equation (6) as follows:

$$A = \frac{53{,}500}{328 \times 0.975 \times 97.2 \times 0.88 \times 1.0} \sqrt{\frac{627 \times 0.90}{51}} = 6.51\ in.^2\ (4{,}197\ mm^2) \qquad (25)$$

NOTE This area requirement is roughly the same as that obtained using the subcritical flow Equation (16). See the example in 5.6.4.2.