Module 9.4

Safety Valve Sizing

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A safety valve must always be sized and able to vent any source of steam so that the pressure within the protected apparatus cannot exceed the maximum allowable accumulated pressure (MAAP). This not only means that the valve has to be positioned correctly, but that it is also correctly set. The safety valve must then also be sized correctly, enabling it to pass the required amount of steam at the required pressure under all possible fault conditions.

Once the type of safety valve has been established, along with its set pressure and its position in the system, it is necessary to calculate the required discharge capacity of the valve. Once this is known, the required orifice area and nominal size can be determined using the manufacturer's specifications.

In order to establish the maximum capacity required, the potential flow through all the relevant branches, upstream of the valve, need to be considered.

In applications where there is more than one possible flow path, the sizing of the safety valve becomes more complicated, as there may be a number of alternative methods of determining its size. Where more than one potential flow path exists, the following alternatives should be considered:

- The safety valve can be sized on the maximum flow experienced in the flow path with the greatest amount of flow.
- The safety valve can be sized to discharge the flow from the combined flow paths.

This choice is determined by the risk of two or more devices failing simultaneously. If there is the slightest chance that this may occur, the valve must be sized to allow the combined flows of the failed devices to be discharged. However, where the risk is negligible, cost advantages may dictate that the valve should only be sized on the highest fault flow. The choice of method ultimately lies with the company responsible for insuring the plant.

For example, consider the pressure vessel and automatic pump-trap (APT) system as shown in Figure 9.4.1. The unlikely situation is that both the APT and pressure reducing valve (PRV 'A') could fail simultaneously. The discharge capacity of safety valve 'A' would either be the fault load of the largest PRV, or alternatively, the combined fault load of both the APT and PRV 'A'.

This document recommends that where multiple flow paths exist, any relevant safety valve should, at all times, be sized on the possibility that relevant upstream pressure control valves may fail simultaneously.

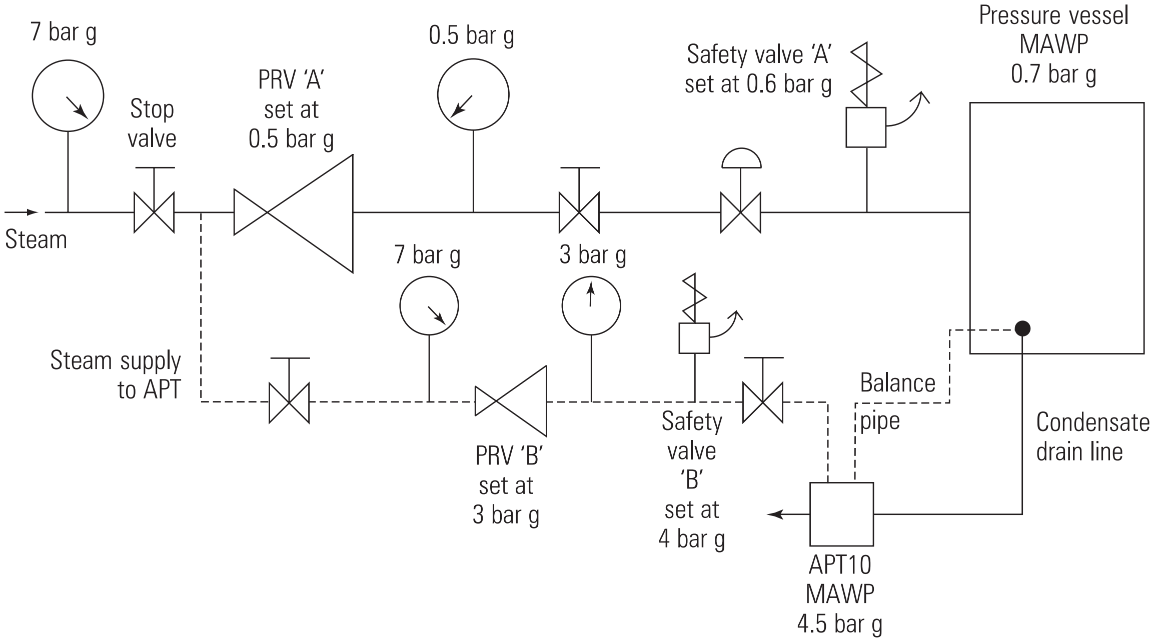


Fig. 9.4.1 An automatic pump trap and pressure vessel system

Finding the fault flow

In order to determine the fault flow through a PRV or indeed any valve or orifice, the following need to be considered:

- The potential fault pressure - this should be taken as the set pressure of the appropriate upstream safety valve
- The relieving pressure of the safety valve being sized
- The full open capacity (K_{vs}) of the upstream control valve, see Equation 9.4.1

Example 9.4.1

Consider the PRV arrangement in Figure 9.4.2.

Where:

NWP = Normal working pressure

MAWP = Maximum allowable working pressure

P_S = Safety valve set pressure

P_o = Safety valve overpressure

P_R = Safety valve relieving pressure

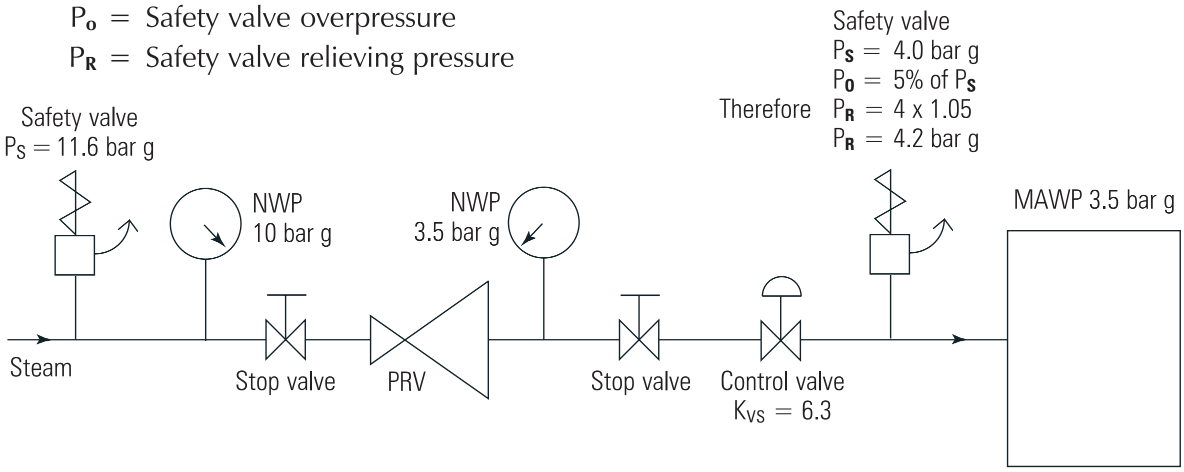


Fig. 9.4.2 Sizing a safety valve for a typical pressure reducing application

The supply pressure of this system (Figure 9.4.2) is limited by an upstream safety valve with a set pressure of 11.6 bar g. The fault flow through the PRV can be determined using the steam mass flow equation (Equation 9.4.1):

$$\dot{m} = 12\,K_{VS}\,P_1\,\sqrt{1 - 5.67\,(0.42 - \chi)^2} \qquad \textbf{Equation 9.4.1}$$

Where:

$\dot{m}$ = Fault load (kg/h)

K_{VS} = PRV full open capacity index (K_{VS} = 6.3)

χ = Pressure drop ratio = $\dfrac{P_1 - P_2}{P_2}$

P_1 = Fault pressure (taken as the set pressure of the upstream safety valve) (bar a)

P_2 = Relieving pressure of the apparatus safety valve (bar a)

Equation 9.4.1 is used when the pressure drop ratio is less than 0.42.

If the pressure drop ratio is 0.42 or greater, the mass flow is calculated using Equation 9.4.2

$$\dot{m} = 12\,K_{VS}\,P_1 \qquad \textbf{Equation 9.4.2}$$

In this example:

$$P_1 = 11.6 \text{ bar g } = 12.6 \text{ bar a}$$

$$P_2 = 4.2 \text{ bar g } = 5.2 \text{ bar a}$$

$$\text{Therefore: } \chi = \frac{12.6 - 5.2}{12.6} = 0.59$$

Since χ is greater than 0.42, critical pressure drop occurs across the control valve, and the fault flow is calculated as follows using the formula in Equation 9.4.2:

$$\dot{m} = 12 \, K_{vs} \, P_1$$

$$\dot{m} = 12 \times 6.3 \times 12.6$$

Therefore: $\boldsymbol{\dot{m} = 953 \textbf{ kg/h}}$

Consquently, the safety valve would be sized to pass at least 953 kg/h when set at 4 bar g.

Once the fault load has been determined, it is usually sufficient to size the safety valve using the manufacturer's capacity charts. A typical example of a capacity chart is shown in Figure 9.4.3. By knowing the required set pressure and discharge capacity, it is possible to select a suitable nominal size. In this example, the set pressure is 4 bar g and the fault flow is 953 kg/h. A DN32/50 safety valve is required with a capacity of 1 284 kg/h.

SV615 flow capacity for saturated steam in kilogrammes per hour (kg/h)

(calculated in accordance with BS 6759 at 5% overpressure)

Derated coefficient of discharge (K_{dr}) = 0.71

Valve size DN	**15/20**	**20/32**	**25/40**	**32/50**	**40/65**	**50/80**
Area (mm²)	**113**	**314**	**452**	**661**	**1 075**	**1 662**
Set pressure (bar g)	**Flow capacity for saturated steam kg/h**					
0.5	65	180	259	379	616	953
1.0	87	241	348	508	827	1 278
1.5	109	303	436	638	1 037	1 603
2.0	131	364	524	767	1 247	1 929
2.5	153	426	613	896	1 458	2 254
3.0	175	487	701	1 026	1 668	2 579
3.5	197	549	790	1 155	1 879	2 904
4.0	220	610	878	1 284	2 089	3 230
4.5	242	672	967	1 414	2 299	3 555
5.0	264	733	1 055	1 543	2 510	3 880
5.5	286	794	1 144	1 672	2 720	4 205
6.0	308	856	1 232	1 802	2 930	4 530
6.5	330	917	1 321	1 931	3 141	4 856
7.0	352	979	1 409	2 061	3 351	5 181
7.5	374	1 040	1 497	2 190	3 561	5 506
8.0	396	1 102	1 586	2 319	3 772	5 831

Fig. 9.4.3 A typical safety valve capacity chart

Where sizing charts are not available or do not cater for particular fluids or conditions, such as backpressure, high viscosity or two-phase flow, it may be necessary to calculate the minimum required orifice area. Methods for doing this are outlined in the appropriate governing standards, such as:

- AD-Merkblatt A2, DIN 3320, TRD 421
- ASME/API RP 520
- BS 6759 for steam, air/gases and liquids

The methods outlined in these standards are based on the coefficient of discharge, which is the ratio of the measured capacity to the theoretical capacity of a nozzle with an equivalent flow area.

$$K_d = \frac{\text{Actual flowing capacity}}{\text{Theoretical flowing capacity}}$$

Equation 9.4.3

Where:

K_d = Coefficient of discharge

Coefficient of discharge

Coefficients of discharge are specific to any particular safety valve range and will be approved by the manufacturer. If the valve is independently approved, it is given a 'certified coefficient of discharge'.

This figure is often derated by further multiplying it by a safety factor 0.9, to give a derated coefficient of discharge. Derated coefficient of discharge is termed $K_{dr} = K_d \times 0.9$

When using standard methods of calculating the required orifice area, the following points may need to be considered:

- **Critical and sub-critical flow -** the flow of gas or vapour through an orifice, such as the flow area of a safety valve, increases as the downstream pressure is decreased. This holds true until the critical pressure is reached, and critical flow is achieved. At this point, any further decrease in the downstream pressure will not result in any further increase in flow. A relationship (called the critical pressure ratio) exists between the critical pressure and the upstream pressure, and, for gases, is shown by Equation 9.4.4.

  $$\frac{P_B}{P_1} = \left(\frac{2}{k+1}\right)^{\left(\frac{k}{k-1}\right)}$$

  Equation 9.4.4

  Where:

  P_B = Backpressure (bar a)
  P_1 = Actual relieving pressure (bar a)
  k = Isentropic coefficient of the gas or vapour upstream of the safety valve

  For gases, with similar properties to an ideal gas, 'k' is the ratio of specific heat of constant pressue (c_p) to constant volume (c_v), i.e. $c_p : c_v$. 'k' is always greater than unity, and typically between 1 and 1.7 (see Table 9.4.6).

  For steam, although 'k' is an isentropic coefficient, it is not actually the ratio of $c_p : c_v$. For saturated steam, 'k' is taken to be 1.135 and for superheated steam, 'k' is taken to be 1.3. As a guide, for saturated steam, critical pressure is taken as 58% of accumulated inlet pressure in absolute terms.

- **Overpressure -** Before sizing, the design overpressure of the valve must be established. It is not permitted to calculate the capacity of the valve at a lower overpressure than that at which the coefficient of discharge was established. It is however, permitted to use a higher overpressure (see Table 9.2.1, Module 9.2, for typical overpressure values). For DIN type full lift (Vollhub) valves, the design lift must be achieved at 5% overpressure, but for sizing purposes, an overpressure value of 10% may be used.

  For liquid applications, the overpressure is 10% according to AD-Merkblatt A2, DIN 3320, TRD 421 and ASME, but for non-certified ASME valves, it is quite common for a figure of 25% to be used.

- **Backpressure -** The sizing calculations in the AD-Merkblatt A2, DIN 3320 and TRD 421 standards account for backpressure in the outflow function,(Ψ), which includes a backpressure correction. The ASME/API RP 520 and BS 6759 standards, however, require an additional backpressure correction factor to be determined and then incorporated in the relevant equation.
- **Two-phase flow -** When sizing safety valves for boiling liquids (e.g. hot water) consideration must be given to vaporisation (flashing) during discharge. It is assumed that the medium is in liquid state when the safety valve is closed and that, when the safety valve opens, part of the liquid vaporises due to the drop in pressure through the safety valve. The resulting flow is referred to as two-phase flow.

  The required flow area has to be calculated for the liquid and vapour components of the discharged fluid. The sum of these two areas is then used to select the appropriate orifice size from the chosen valve range. (see Example 9.4.3)

  Many standards do not actually specify sizing formula for two-phase flow and recommend that the manufacturer be contacted directly for advice in these instances.

Sizing equations for safety valves designed to the following standards

The following methods are used to calculate the minimum required orifice area for a safety valve, as mentioned in the most commonly used national standards.

AD-Merkblatt A2, DIN 3320, TRD 421

Use Equation 9.4.5 to calculate the minimum required orifice area for a safety valve used on **steam applications:**

$$A_O = \frac{\chi \, \dot{m}}{\alpha_w \, P_R} \qquad \textbf{Equation 9.4.5}$$

Use Equation 9.4.6 to calculate the minimum required orifice area for a safety valve used on **air and gas applications:**

$$A_O = \frac{0.1791 \, \dot{m}}{\Psi \, \alpha_w \, P_R} \sqrt{\frac{T \, Z}{M}} \qquad \textbf{Equation 9.4.6}$$

Use Equation 9.4.7 to calculate the minimum required orifice area for a safety valve used on **liquid applications:**

$$A_O = \frac{0.6211 \, \dot{m}}{\alpha_w \sqrt{\rho \, \Delta P}} \qquad \textbf{Equation 9.4.7}$$

Where:

A_O = Minimum cross sectional flow area (mm²)

$\dot{m}$ = Mass flow to be discharged (kg/h)

P_R = Absolute relieving pressure (bar a)

$\Delta P = P_R - P_B$

P_B = Absolute backpressure (bar a)

T = Inlet temperature (K)

ρ = Density (kg/h) (see Appendix A at the back of this module)

M = Molar mass (kg/kmol) (see Appendix A at the back of this module)

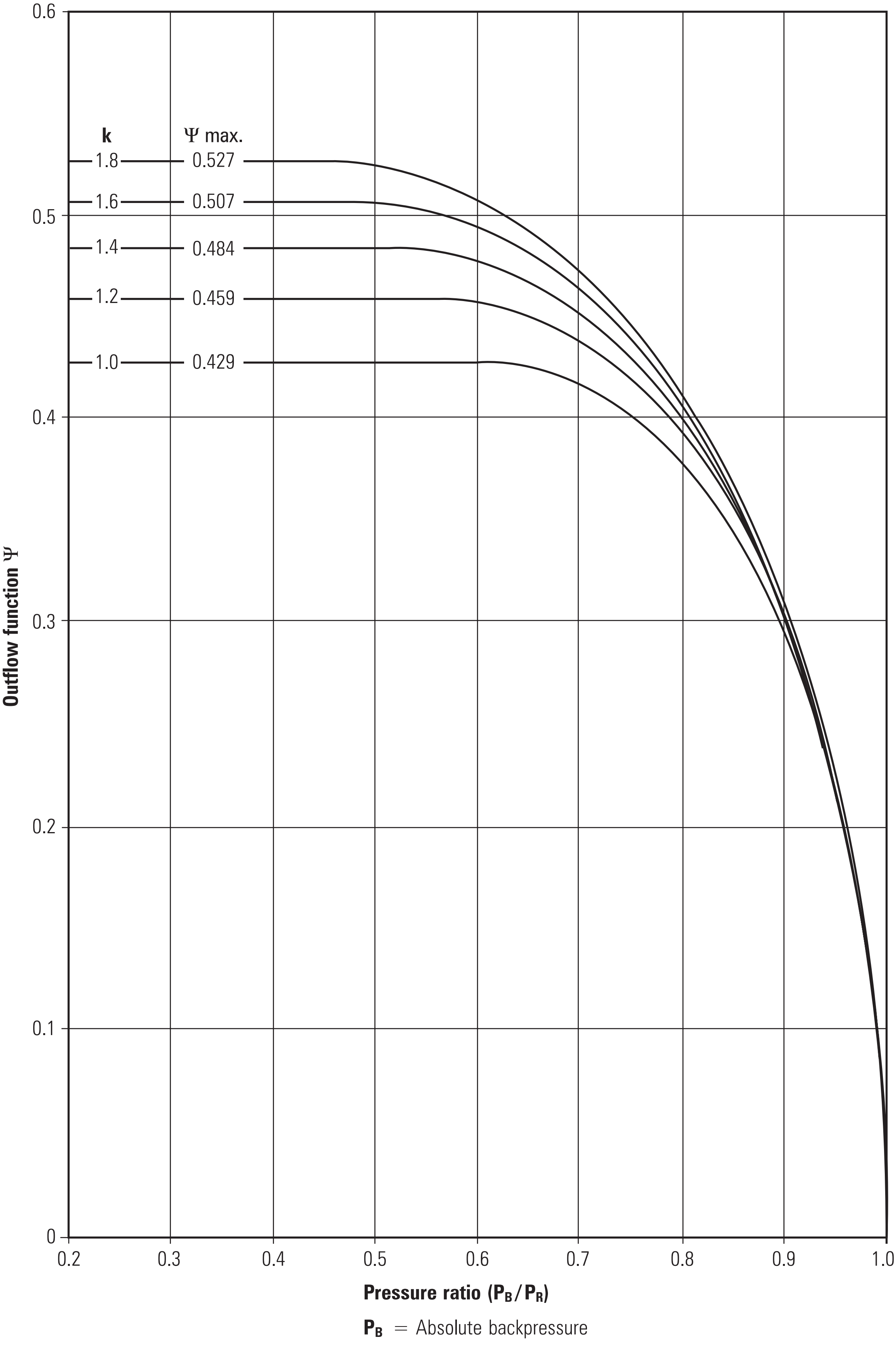
Z = Compressibility factor (see Equation 9.4.8)

α_w = Outflow coefficient (specified by the manufacturer)

Ψ = Outflow function (see Figure 9.4.4)

χ = Pressure medium coefficient (see Figure 9.4.5)

The outflow function (Ψ) for AD-Merkblatt A2, DIN 3320 and TRD 421



P_B = Absolute backpressure

P_R = Absolute relieving pressure

Fig. 9.4.4 The outflow function (Ψ) as used in AD-Merkblatt A2, DIN 3320 and TRD 421

Pressure medium coefficient (χ) for AD-Merkblatt A2, DIN 3320 and TRD 421

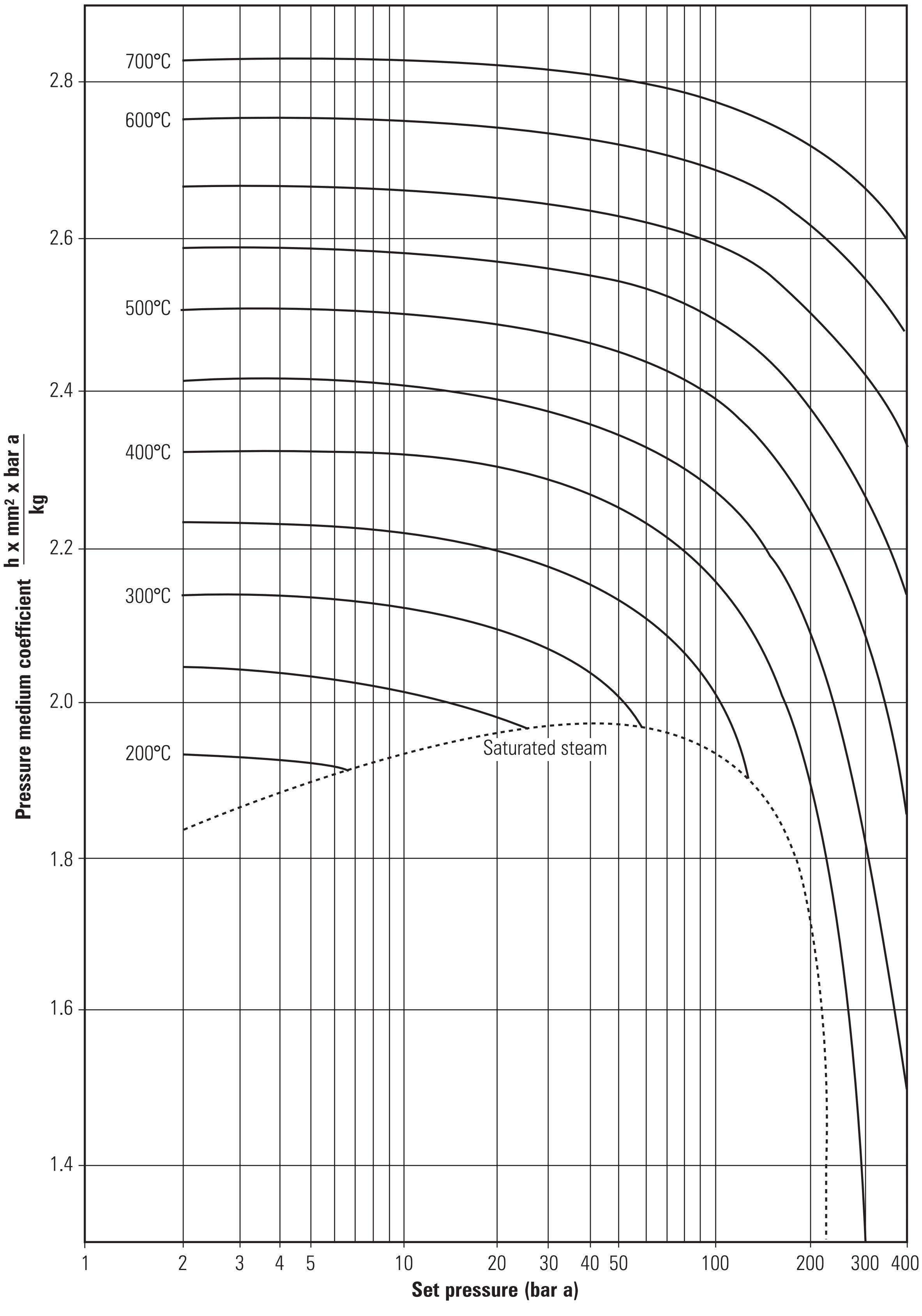


Fig. 9.4.5 Pressure medium coefficient (χ) for steam as used in AD-Merkblatt A2, DIN 3320, TRD 421

Compressibility factor (Z)

For gases, the compressibility factor, Z, also needs to be determined. This factor accounts for the deviation of the actual gas from the characteristics of an ideal gas. It is often recommended that Z = 1 is used where insufficient data is available. Z can be calculated by using the formula in Equation 9.4.8:

$$Z = \frac{10^5\, P_R\, M\, \nu}{R_u\, T}$$ **Equation 9.4.8**

Where:

Z = Compressibility factor

P_R = Safety valve relieving pressure (bar a)

ν = Specific volume of the gas at the actual relieving pressure and temperature (m^3/kg) (see Appendix A at the back of this module). Note: The specific volume of a gas will change with temperature and pressure, and therefore it must be determined for the operating conditions.

M = Molar mass (kg/kmol) (see Appendix A at the back of this module)

R_u = Universal gas constant (8 314 Nm/kmol K)

T = Actual relieving temperature (K)

Example 9.4.2

Determine the minimum required safety valve orifice area under the following conditions:

Medium:	Saturated steam
Discharge quantity ($\dot{m}$):	2 500 kg/h
Set pressure (P_s):	4 bar a
Backpressure:	Atmospheric pressure 1 bar a
Stated outflow coefficient (α_w):	0.7

It is first necessary to determine the pressure medium coefficient using Figure 9.4.5.

Pressure medium coefficient (χ): 1.88

Using Equation 9.4.5: $$A_O = \frac{\chi \times \dot{m}}{\alpha_w \times P_s}$$

Therefore : $$\mathbf{A_O} = \frac{1.88 \times 2500}{0.7 \times 4} = \mathbf{1\,678\ mm}$$

Consequently, the chosen safety valve would need an orifice area of at least 1 678 mm^2.

Two-phase flow

In order to determine the minimum orifice area for a two-phase flow system (e.g. hot water), it is first necessary to establish what proportion of the discharge will be vapour (n). This is done using the Equation 9.4.9:

$$n = \frac{h_{f1} - h_{f2}}{h_{fg2}} \qquad \textbf{Equation 9.4.9}$$

Where:

n = The proportion of discharge fluid which is vapour

h_{f1} = Enthalpy of liquid before the valve (kJ / kg)

h_{f2} = Enthalpy of liquid after the valve (kJ / kg)

h_{fg2} = Enthalpy of evaporation after the valve (kJ / kg)

For hot water, the enthalpy values can be obtained from steam tables.

In order to determine the proportion of flow, which is vapour, the discharge capacity is multiplied by n. The remainder of the flow will therefore be in the liquid state.

The area sizing calculation from Equations 9.4.5, 9.4.6 and 9.4.7 can then be used to calculate the required area to discharge the vapour portion and then the liquid portion. The sum of these areas is then used to establish the minimum required orifice area.

Example 9.4.3

Consider hot water under the following conditions:

Temperature:	160°C
Discharge quantity ($\dot{m}$):	3 900 kg/h
Set pressure (P_S):	10 bar g = 11 bar a
Backpressure (P_B):	Atmospheric
Density of water at 160°C (ρ):	908 kg/m³
$\Delta P = P_S - P_B$:	10 bar
Stated outflow coefficient (α_w):	0.7

Using steam tables, the proportion of vapour is first calculated:

h_{f1} = 675 kJ / kg (at 160°C)

h_{f2} = 417 kJ / kg (at 1 bar a, atmospheric pressure)

h_{fg2} = 2 258 kJ / kg (at 1 bar a, atmospheric pressure)

$$\text{Using Equation 9.4.9: } n = \frac{h_{f1} - h_{f2}}{h_{fg2}}$$

$$\text{Therefore : } n = \frac{675 - 417}{2\,258} = 0.114\,3$$

Capacity discharge as vapour (steam) = 0.114 3 x 3 900 kg/h = 446 kg/h

Capacity discharge as liquid (water) = 3 900 kg/h - 446 kg/h = 3 454 kg/h

Calculated area for vapour portion:

$$\text{Using Equation 9.4.5: } A_O = \frac{\chi\,\dot{m}}{\alpha_w\,P_S}$$

(where χ = Pressure medium coefficient at the set pressure)

$$\text{Therefore : } A_{O\,Steam} = \frac{1.92 \times 446}{0.7 \times 11} = 111\,\text{mm}^2$$

Calculated area for liquid portion:

Using Equation 9.4.7: $$A_O = \frac{0.6211 \text{ x } \dot{m}}{\alpha_w \sqrt{\rho \; \Delta P}}$$

$$\text{Therefore: } A_{O\,\text{liquid}} = \frac{0.6211 \text{ x } 3\,454}{0.7\sqrt{908 \text{ x } 10}} = 33\,\text{mm}^2$$

Total required discharge area = $111 + 33$ = 144 mm²

Therefore, a valve must be selected with a discharge area greater than 144 mm².

ASME / API RP 520

The following formulae are used for calculating the minimum required orifice area for a safety valve according to ASME standards and the API RP 520 guidelines.

Use Equation 9.4.10 to calculate the minimum required orifice area for a safety valve used on **steam applications:**

$$A_O = \frac{\dot{m}}{51.5\, P_R\, K_d\, K_{SH}} \qquad \textbf{Equation 9.4.10}$$

Use Equation 9.4.11 to calculate the minimum required orifice area for a safety valve used on **air and gas applications:**

$$A_O = \frac{\dot{V}\sqrt{T\,Z\,G}}{1.175\, C_g\, K_d\, P_R\, K_B} \qquad \textbf{Equation 9.4.11}$$

Use Equation 9.4.12 to calculate the minimum required orifice area for a safety valve used on **liquid applications:**

$$A_O = \frac{\dot{V}^1}{38\, K_d\, K_\mu\, K_w}\sqrt{\frac{G}{P_R - P_S}} \qquad \textbf{Equation 9.4.12}$$

Where:

A_O = Required effective discharge area (in²)
$\dot{m}$ = Required mass flow through the valve (lb / h)
$\dot{V}$ = Required volume flow through the valve (ft³ / min)
V^1 = Required volume flow through the valve (U.S. gal / min)
P_R = Upstream relieving pressure (psi a)
P_B = Absolute backpressure (psi a)
C_g = Nozzle gas constant (see Table 9.4.1)
T = Relieving temperature (°R ≡ °F + 460)
G = Specific gravity (ratio of molar mass of the fluid to the molar mass of air (28.96 kg / kmol)) (see Appendix A at the back of this module)
Z = Compressibility factor (see Equation 9.4.8)
K_d = Effective coefficient of discharge (specified by the manufacturer)
K_{SH} = Superheat correction factor (see Table 9.4.2)
K_B = Backpressure correction factor for gas and vapour (see Figures 9.4.6 and 9.4.7)
K_W = Backpressure correction factor for liquids (bellows balanced valves only) (see Figure 9.4.8)
K_μ = Viscosity factor (see Figure 9.4.9)

Nozzle gas constant for ASME / API RP 520

Table 9.4.1 Nozzle gas constant (C_g) relative to isentropic constant (k) as used in ASME / API RP 520

k	C_g	k	C_g	k	C_g	k	C_g
1.01	317	1.26	343	1.51	365	1.76	384
1.02	318	1.27	344	1.52	366	1.77	385
1.03	319	1.28	345	1.53	367	1.78	386
1.04	320	1.29	346	1.54	368	1.79	386
1.05	321	1.30	347	1.55	369	1.80	387
1.06	322	1.31	348	1.56	369	1.81	388
1.07	323	1.32	349	1.57	370	1.82	389
1.08	325	1.33	350	1.58	371	1.83	389
1.09	326	1.34	351	1.59	372	1.84	390
1.10	327	1.35	352	1.60	373	1.85	391
1.11	328	1.36	353	1.61	373	1.86	391
1.12	329	1.37	353	1.62	374	1.87	392
1.13	330	1.38	354	1.63	375	1.88	393
1.14	331	1.39	355	1.64	376	1.89	393
1.15	332	1.40	356	1.65	376	1.90	394
1.16	333	1.41	357	1.66	377	1.91	395
1.17	334	1.42	358	1.67	378	1.92	395
1.18	335	1.43	359	1.68	379	1.93	396
1.19	336	1.44	360	1.69	379	1.94	397
1.20	337	1.45	360	1.70	380	1.95	397
1.21	338	1.46	361	1.71	381	1.96	398
1.22	339	1.47	362	1.72	382	1.97	398
1.23	340	1.48	363	1.73	383	1.98	399
1.24	341	1.49	364	1.74	383	1.99	400
1.25	342	1.50	365	1.75	384	2.00	400

The nozzle gas constant C_g is calculated using Equation 9.4.13

For dry saturated steam use: $C_g = 330$
For superheated steam use: $C_g = 347$

$$C_g = 520\sqrt{k\left(\frac{2}{k+1}\right)\left(\frac{k+1}{k-1}\right)} \text{ for } k > 1$$

$$C_g = 315 \text{ for } k = 1$$

Equation 9.4.13

Superheat correction factors for ASME / API RP 520

Table 9.4.2 Superheat correction factors (K_{SH}) as used in ASME / API RP 520 (Imperial units)

Set pressure (psi g)	**Temperature (°F)**									
	300	**400**	**500**	**600**	**700**	**800**	**900**	**1 000**	**1 100**	**1 200**
15	1.00	0.98	0.93	0.88	0.84	0.80	0.77	0.74	0.72	0.70
20	1.00	0.98	0.93	0.88	0.84	0.80	0.77	0.74	0.72	0.70
40	1.00	0.99	0.93	0.88	0.84	0.81	0.77	0.74	0.72	0.70
60	1.00	0.99	0.93	0.88	0.84	0.81	0.77	0.75	0.72	0.70
80	1.00	0.99	0.93	0.88	0.84	0.81	0.77	0.75	0.72	0.70
100	1.00	0.99	0.94	0.89	0.84	0.81	0.77	0.75	0.72	0.70
120	1.00	0.99	0.94	0.89	0.84	0.81	0.78	0.75	0.72	0.70
140	1.00	0.99	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.70
160	1.00	0.99	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.70
180	1.00	0.99	0.94	0.89	0.85	0.81	0.78	0.75	0.72	0.70
200	1.00	0.99	0.95	0.89	0.85	0.81	0.78	0.75	0.72	0.70
220	1.00	0.99	0.95	0.89	0.85	0.81	0.78	0.75	0.72	0.70
240		1.00	0.95	0.90	0.85	0.81	0.78	0.75	0.72	0.70
260		1.00	0.95	0.90	0.85	0.81	0.78	0.75	0.72	0.70
280		1.00	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.70
300		1.00	0.96	0.90	0.85	0.81	0.78	0.75	0.72	0.70
350		1.00	0.96	0.90	0.86	0.82	0.78	0.75	0.72	0.70
400		1.00	0.96	0.91	0.86	0.82	0.78	0.75	0.72	0.70
500		1.00	0.96	0.92	0.86	0.82	0.78	0.75	0.73	0.70
600		1.00	0.97	0.92	0.87	0.82	0.79	0.75	0.73	0.70
800			1.00	0.95	0.88	0.83	0.79	0.76	0.73	0.70
1 000			1.00	0.96	0.89	0.84	0.78	0.76	0.73	0.71
1 250			1.00	0.97	0.91	0.85	0.80	0.77	0.74	0.71
1 500			1.00	1.00	0.93	0.86	0.81	0.77	0.74	0.71

Gas and vapour constant backpressure correction factor for ASME / API 520

▫ Balanced bellows valves

The backpressure correction factor (Equation 9.4.14) is the ratio of the capacity with backpressure, C_1, to the capacity with zero backpressure, C_2.

$$K_B = \frac{C_1}{C_2} \qquad \textbf{Equation 9.4.14}$$

The curves shown in Figure 9.4.6 to Figure 9.4.8 are applicable to set pressures of 50 psi g (3.4 bar g) and above. For a given set pressure, these values are limited to a backpressure less than the critical pressure. For sub-critical flow and backpressures below 50 psi g, the manufacturer should be consulted for values of K_B.

$$\text{\% of gauge backpressure} = \frac{P_B}{P_S} \text{ x } \frac{100}{1} \qquad \textbf{Equation 9.4.15}$$

Where:

P_B = Backpressure (psi g)

P_S = Set pressure (psi g)

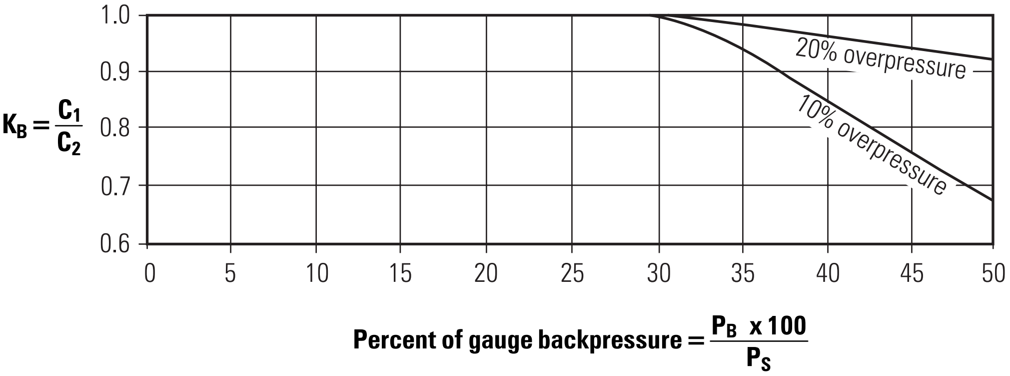


Fig. 9.4.6 Constant backpressure correction factor (K_B) for gas and vapour as used in ASME / API RP 520 for balanced bellows valves

▫ Conventional valves

$$\text{\% of gauge backpressure} = \frac{P_B}{P_R} \text{ x } \frac{100}{1} \qquad \textbf{Equation 9.4.16}$$

Where:

P_B = Backpressure (psi g)

P_R = Relieving pressure (psi g)

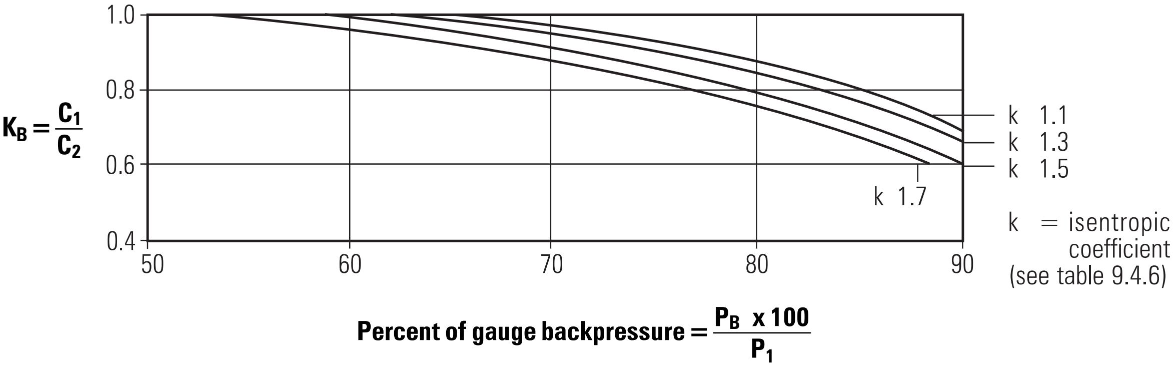


Fig. 9.4.7 Constant backpressure correction factor (K_B) for gas and vapour as used in ASME / API RP 520 for conventional valves

Liquid constant backpressure correction factor for ASME/API RP 520

☐ Balanced bellows valves

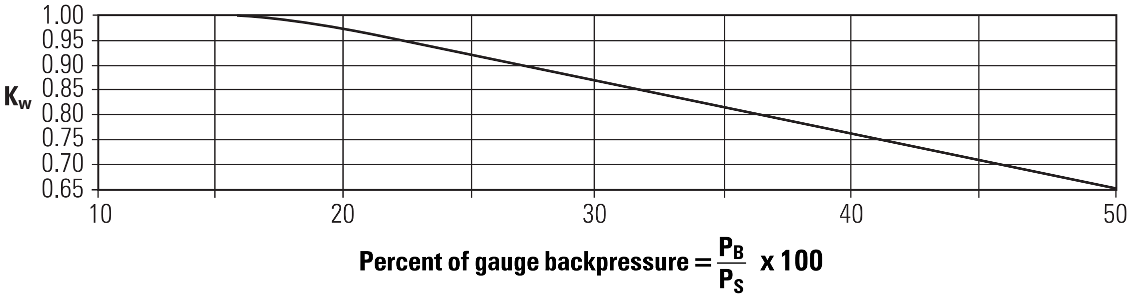


Fig. 9.4.8 Constant backpressure correction factor (K_w) for liquids as used in ASME/API RP 520 for balanced bellows valves

Viscosity correction factor for ASME/API RP 520 and BS 6759

This is used to make allowances for high viscosity fluids. In order to account for this, the valve size must first be established, assuming the fluid is non-viscous. Once the size has been selected, the Reynolds number for the valve is calculated and used to establish the correction factor from Figure 9.4.9.

The valve size should then be checked to ensure that the original size chosen would accommodate the flow after the viscous correction factor has been applied. If not this process should be repeated with the next largest valve size.

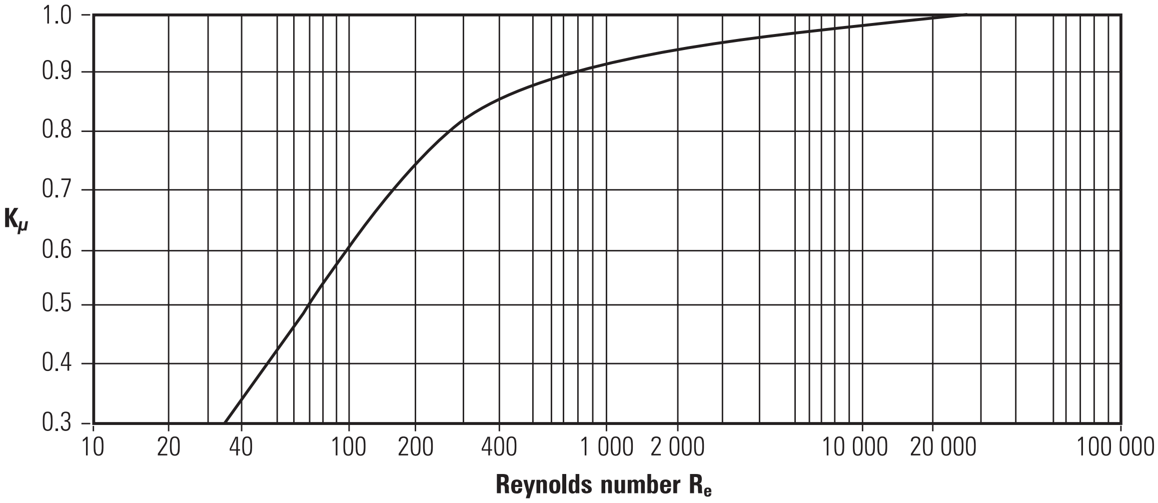


Fig. 9.4.9 Viscosity correction factor ($K\mu$) as used in ASME/API RP 520 and BS 6759

The Reynolds number can be calculated using Equations 9.4.17 and 9.4.18:

Metric units

$$R_e = 0.341\,4\ \frac{\dot{m}}{\mu\sqrt{A_O}}$$

Equation 9.4.17

Imperial units

$$R_e = \frac{2\,800\ G\ \dot{V}}{\mu\sqrt{A_O}}$$

Equation 9.4.18

Where:

R_e = Reynolds number

$\dot{V}$ = Volume flow to be discharged (U.S. gal/min)

$\dot{m}$ = Mass flow to be discharged (kg/h)

μ = Dynamic viscosity (Imperial – cP, Metric – Pa s)

A_O = Discharge area (Imperial – in², Metric – mm²)

Safety valves designed to British Standard BS 6759

Use Equation 9.4.19 to calculate the minimum required orifice area for a safety valve used on **steam applications:**

$$A_O = \frac{\dot{m}}{0.525\ P_R\ K_{dr}\ K_{SH}} \qquad \textbf{Equation 9.4.19}$$

Use Equation 9.4.20 to calculate the minimum required orifice area for a safety valve used on **air applications:**

$$A_O = \frac{\dot{V}}{0.193\ P_R\ K_{dr}} \sqrt{\frac{T}{288}} \qquad \textbf{Equation 9.4.20}$$

Use Equation 9.4.21 to calculate the minimum required orifice area for a safety valve used on **gas applications:**

$$A_O = \frac{\dot{m}}{P_R\ C_g\ K_{dr}} \sqrt{\frac{Z\ T}{M}} \qquad \textbf{Equation 9.4.21}$$

Use Equation 9.4.22 to calculate the minimum required orifice area for a safety valve used on **liquid applications:**

$$A_O = \frac{\dot{m}}{1.61\ K_{dr}\ K_{\mu} \sqrt{\rho\ \Delta P}} \qquad \textbf{Equation 9.4.22}$$

Use Equation 9.4.23 to calculate the minimum required orifice area for a safety valve used on **hot air applications:**

$$A_O = \frac{\dot{Q}}{0.329\ P_R\ K_{dr}} \qquad \textbf{Equation 9.4.23}$$

Where:

A_O = Flow area (mm²)
$\dot{m}$ = Mass flow to be discharged (kg/h)
$\dot{V}$ = Volumetric flow to be discharged (l/s)
$\dot{Q}$ = Hot water capacity (kW)
C_g = Nozzle gas constant (see Table 9.4.3)
ΔP = P_R - P_B
P_R = Absolute relieving pressure (bar a)
P_B = Absolute backpressure (bar a)
T = Inlet temperature (K)
ρ = Density (kg/m³) (see Appendix A at the back of this module)
M = Molecular mass (kg/kmol) (see Appendix A at the back of this module)
Z = Compressibility factor (see Equation 9.4.8)
K_{dr} = Derated coefficient of discharge (specified by the manufacturer)
K_{SH} = Superheat correction factor (see Table 9.4.4)
K_{μ} = Viscosity correction factor (see Figure 9.4.9)

Nozzle gas constant for BS 6759

Table 9.4.3 Nozzle gas constant (C_g) relative to isentropic coefficient (k) as used in BS 6759

k	C_g
0.40	1.65
0.45	1.73
0.50	1.81
0.55	1.89
0.60	1.96
0.65	2.02
0.70	2.08
0.75	2.14
0.80	2.20
0.82	2.22
0.84	2.24
0.86	2.26
0.88	2.28
0.90	2.30
0.92	2.32
0.94	2.34
0.96	2.36
0.98	2.38
0.99	2.39
1.001	2.40
1.02	2.41
1.04	2.43
1.06	2.45
1.08	2.46
1.10	2.48
1.12	2.50
1.14	2.51
1.16	2.53
1.18	2.55
1.20	2.56
1.22	2.58
1.24	2.59
1.26	2.61
1.28	2.62
1.30	2.63
1.32	2.65
1.34	2.66
1.36	2.68
1.38	2.69
1.40	2.70
1.42	2.72
1.44	2.73
1.46	2.74
1.48	2.76
1.50	2.77
1.52	2.78
1.54	2.79
1.56	2.80
1.58	2.82
1.60	2.83
1.62	2.84
1.64	2.85
1.66	2.86
1.68	2.87
1.70	2.89
1.80	2.94
1.90	2.99
2.00	3.04
2.10	3.09
2.20	3.13

The nozzle gas constant C_g is calculated using Equation 9.4.24

For dry saturated steam use: $C_g = 2.5$
For superheated steam use: $C_g = 2.63$

$$C_g = 3.948\sqrt{k\left(\frac{2}{k+1}\right)\left(\frac{k+1}{k-1}\right)}$$

Equation 9.4.24

Superheat correction factor (K_{SH}) for BS 6759

Table 9.4.4 Superheat correction factors (K_{SH}) as used in BS 6759 (Metric units)

Set pressure (bar g)	Temperature (°C)									
	150	200	250	300	350	400	450	500	550	600
2	1.00	0.99	0.94	0.89	0.86	0.82	0.79	0.76	0.74	0.72
3	1.00	0.99	0.94	0.89	0.86	0.82	0.79	0.76	0.74	0.72
4	1.00	0.99	0.94	0.90	0.86	0.82	0.79	0.76	0.74	0.72
5	1.00	0.99	0.94	0.90	0.86	0.82	0.79	0.76	0.74	0.72
6		0.99	0.94	0.90	0.86	0.82	0.79	0.76	0.74	0.72
7		0.99	0.95	0.90	0.86	0.82	0.79	0.77	0.74	0.72
8		1.00	0.95	0.90	0.86	0.82	0.79	0.77	0.74	0.72
9		1.00	0.95	0.90	0.86	0.83	0.79	0.77	0.74	0.72
10		1.00	0.95	0.90	0.86	0.83	0.79	0.77	0.74	0.72
11		1.00	0.95	0.90	0.86	0.83	0.79	0.77	0.74	0.72
12		1.00	0.95	0.90	0.86	0.83	0.79	0.77	0.74	0.72
13		1.00	0.96	0.91	0.86	0.83	0.80	0.77	0.74	0.72
14		1.00	0.96	0.91	0.86	0.83	0.80	0.77	0.74	0.72
16		1.00	0.96	0.91	0.87	0.83	0.80	0.77	0.74	0.72
18			0.96	0.91	0.87	0.83	0.80	0.77	0.74	0.72
20			0.97	0.91	0.87	0.83	0.80	0.77	0.74	0.72
24			0.98	0.92	0.87	0.84	0.80	0.77	0.74	0.72
28			0.99	0.92	0.87	0.84	0.80	0.77	0.75	0.72
34			0.99	0.93	0.88	0.84	0.80	0.77	0.75	0.72
40			1.00	0.94	0.89	0.84	0.81	0.78	0.75	0.72
56				0.96	0.90	0.86	0.81	0.78	0.75	0.73
70				0.98	0.92	0.86	0.82	0.79	0.76	0.73
85				1.00	0.93	0.87	0.83	0.79	0.76	0.73
100				1.00	0.93	0.88	0.84	0.80	0.76	0.74

Appendix A - Properties of industrial liquids

Table 9.4.5 Properties of some common industrial liquids

For specific gravity (G) used in ASME liquid sizing calculations, divide density by 998 (density of water).

Liquid	Chemical formula	Boiling point (0°C) at 1.013 mbar	Density (kg/m³)
Acetone	$CH_2.CO.CH_3$	56.0	791
Ammonia	NH_3	- 33.4	609
Benzene	C_6H_6	80.0	879
Butalene	C_4H_8	- 6.3	600
Butane	C_4H_{10}	- 0.5	580
Carbon disulphide	CS_2	46.0	1 260
Carbon tetrachloride	CCl_4	76.7	1 594
20% caustic soda	NaOH		1 220
Crude oil			700 to 1 040
Diesel oil		175.0	880
Ethanol	C_2H_5OH	78.0	789
Freon 12	CF_2Cl_2	- 29.8	1 330
Glycol	$C_2H_4(OH)_2$	197.5	1 140
Light fuel oil		175.0	850
Heavy fuel oil		220.0 to 350.0	950
Kerosene		150.0 to 300.0	740
Methanol	C_3OH	65.0	792
Naphthalene	$C_{10}H_8$	218.0	1 145
Nitric acid	HNO_3	86.0	1 560
Propane	C_3H_8	- 42.0	500
Sulphurous acid	H_2SO_3	338.0	1 400
Toluene	$C_6H_5.CH_3$	111.0	867
Trichlorethylene	$CHCl.CCl_2$	87.0	1 464
Water	H_2O	100.0	998

Properties of industrial gases

Table 9.4.6 Properties of some common industrial gases

For specific gravity (G) used in ASME gas sizing calculations, divide molar mass by 28.96 (molar mass of air).

Gas	Chemical formula	Molar mass (M) kg/kmol	Isentropic coefficient (k) at 1.013 bar and 0°C	Specific volume (V) m^3/kg at 1.013 bar and 0°C
Acetylene	C_2H_2	26.02	1.26	0.853
Air		28.96	1.40	0.773
Ammonia	NH_3	17.03	1.31	1.297
Argon	Ar	39.91	1.66	0.561
Benzene	C_6H_6	78.00	1.10	
Butane - n	C_4H_{10}	58.08	1.11	0.370
Butylene	C_4H_8	56.10	1.20	
Carbon disulphide		76.00	1.21	
Carbon dioxide	CO_2	44.00	1.30	0.506
Carbon monoxide	CO	28.00	1.40	0.800
Chlorine	Cl_2	70.91	1.35	0.311
Cyclohexane		84.00	1.08	
Dipenyl	$C_{12}H_{10}$	154.00		
Ethane	C_2H_6	30.05	1.22	0.737
Ethylene	C_2H_4	28.03	1.25	0.794
Freon 12	Cf_2Cl_2	121.00	1.14	
Helium	He	4.00	1.66	
Hexane	C_6H_{14}	86.00	1.08	
Hydrogen	H_2	2.02	1.41	11.124
Hydrogen chloride	HCl	36.46	1.40	0.610
Hydrogen sulphide	H_2S	34.08	1.32	0.651
Isobutane	$CH(CH_3)_3$	58.05	1.11	0.375
Methane	CH_4	16.03	1.31	1.395
Methyl chloride	CH_3Cl	50.48	1.28	0.434
Natural gas		19.00	1.27	
Nitrogen	N_2	28.02	1.40	0.799
Nitrous oxide	N_2O	44.02	1.30	0.746
Oxygen	O_2	32.00	1.40	0.700
Pentane	C_5H_{12}	72.00	1.09	0.451
Propane	C_3H_8	44.06	1.13	0.498
Sulphur dioxide	SO_2	64.07	1.29	0.342
Dry saturated steam	H_2O	18.00	1.135	
Superheated steam	H_2O	18.01	1.30	

Questions

1. A process vessel is supplied with steam from a pressure reducing station through a temperature control valve. In order to protect the process vessel from overpressure, a safety valve is to be installed downstream of the control valve. Given the following conditions, determine the potential fault load.

Safety valve set pressure	**6.0 bar g**
Safety valve overpressure	**10%**
Control valve full open capacity (K_{VS})	**10.3**
Maximum possible upstream pressure	**12.5 bar g**
Vessel MAAP	**7.3 bar g**

a| 900 kg/h ☐
b| 1 020 kg/h ☐
c| 1 545 kg/h ☐
d| 1 670 kg/h ☐

2. Using the sizing formulae from ASME/API RP 520, calculate the minimum required orifice diameter for a safety valve discharging superheated steam under the following conditions:

Relieving temperature	**700°F**
Discharge quantity	**88 500 lb/h**
Safety valve coefficient of discharge	**0.995**
Safety valve set pressure	**240 psi g**
Safety valve overpressure	**10%**
Safety valve relieving pressure	**278.7 psi a**

a| 6.7 in² ☐
b| 7.3 in² ☐
c| 7.9 in² ☐
d| 8.5 in² ☐

3. Using the sizing formulae from BS 6759, calculate the minimum required orifice diameter for a safety valve discharging air under the following conditions:

Relieving temperature	**50°C**
Discharge quantity	**28 800 m³/h**
Safety valve coefficient of discharge	**0.995**
Safety valve set pressure	**12 bar g**
Safety valve overpressure	**5%**

a| 18 140 mm² ☐
b| 11 680 mm² ☐
c| 49 770 mm² ☐
d| 52 250 mm² ☐

4. A safety valve is used to provide overpressure protection on an ammonia system. Using the AD-Merkblatt A2 standard calculations, determine the minimum required orifice area required for the following system parameters:

Discharge quantity	**4 000 kg/h**
Relieving pressure	**8.5 bar a**
Backpressure	**2 bar a**
Relieving temperature	**293 K**
Specific volume (8.5 bar a, 293 K)	**0.149 4 m^3/kg**
Outflow coefficient	**0.7**

a| 2 555 mm^2 ☐

b| 2 000 mm^2 ☐

c| 3 000 mm^2 ☐

d| 4 000 mm^2 ☐

5. A safety valve (with a relieving pressure, P_R, of 6 bar a and coefficient of discharge K_{dr}, of 0.76) is used to provide overpressure protection in a hot water system. The safety valve discharges the 160°C water against a backpressure of 2 bar a in a manifold system. Using the BS 6759 standard calculations and the concept of two-phase flow, determine the minimum orifice area required to discharge 5 000 kg/h of the hot water.

a| 60 mm^2 ☐

b| 90 mm^2 ☐

c| 160 mm^2 ☐

d| 220 mm^2 ☐

6. Determine the minimum required orifice area for a safety valve to be used on heavy fuel oil (density, ρ = 980 kg/m^3 and viscosity, m = 1.05 Pa s), under the following conditions, using the BS 6759 standard method of calculation:

Discharge quantity	**10 000 kg/h**
Safety valve coefficient of discharge	**0.71**
Safety valve relieving pressure	**8 bar a**
Backpressure	**1 bar a (atmospheric)**

a| 90 mm^2 ☐

b| 110 mm^2 ☐

c| 130 mm^2 ☐

d| 150 mm^2 ☐

Answers

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