## 7.4 Sizing according to ASME Code Sect. VIII and API RP 520 and API 521

The information contained in this section is based on following editions of codes and standards: ASME Section VIII (2008), API RP 520 (2000), API 521 (2007), API 526 (2002), API Standard 2000 (1998), API Standard 2510 (2001), ISO 23251(2007), prEN 14015-1 (2000)

### 7.4.1 Premise on ASME Section VIII and API RP 520

The ASME Code is a pressure vessel code that covers the certification of safety valves for the flows of saturated steam, water, air and natural gas (Section VIII UG-131).

API RP 520 is a recommended practice to standardize the pre-selection of safety valves for gases, vapors, liquids and two-phase flow service already in the design phase of the plant. API RP 520 uses the same basic formulas as the ASME Code but extends them with correction factors, e.g. for back pressure and viscosity, to make them applicable to many practical applications.

Both the ASME Code and API RP 520 apply for relieving pressures above 15 psig.

In API RP 520 the pre-selection of a safety valve requires the determination of an *effective relief area* and an *effective coefficient of discharge*, which are nominal values and therefore independent from the selection of either the design or the manufacturer. The effective relief areas are those listed in API 526 in increasing order from letter D to T.

Once the safety valve orifice is selected it must be proven that the certified capacity meets or exceeds that of the preliminary sizing. For this calculation the engineer must use the *actual discharge coefficient* and the *actual discharge area* from the manufacturer's catalog. In many practical cases it is enough to verify that the product of the actual area and the actual discharge coefficient exceeds that of the effective area and the effective discharge coefficient, as shown in Eq. *7.4.1-1* Actual orifice areas and discharge coefficient of LESER safety valves are documented in the *ASME NB-18* (*Red Book)*[3].

$$K_{actual} \cdot A_{actual} \geq K_{d-effective} \cdot A_{effective} \quad \textit{(Eq. 7.4.1-1)}$$

LESER facilitates the selection of the safety valves by introducing LEO (LESER Effective Orifice). By using LEO the engineer can select the final size of the safety valve after the preliminary sizing by choosing a valve with a LEO larger than the effective orifice.

$$LEO = A_{actual} \cdot K_{actual} / K_{d-effective} \quad \textit{(Eq. 7.4.1-2)}$$

[3] ASME National Board Pressure Relief Device Certifications NB-18, Edition: Feb. 2009
http://www.nationalboard.org/SiteDocuments/NB18/PDFs/NB18ToC.pdf

The actual discharge coefficients must be certified by ASME. The application of API RP 520 formulas with the ASME certified actual discharge coefficient and the actual relief areas from the manufacturers' catalog is commonly called "*Sizing acc. to ASME Section VIII*".

ASME VIII and API RP 520 are interconnected with each other and it is therefore common practice to present them together as a unique sizing procedure. All formulas are cited here in US units.

In VALVESTAR® a similar structure is present:

- The option "Sizing acc. to ASME VIII" is a one-step sizing procedure considering the sizing formulas in API RP 520 with their correction factors and using the actual discharge areas and actual discharge coefficients.
- The option "Sizing acc. to API RP 520" considers the two-step sizing procedure discussed before.

In both cases the same safety valve will be selected.

Table *7.4.1-1* lists the effective and the actual discharge coefficients as well as the effective and actual discharge areas for LESER API Series Type 526.

| Medium | API RP 520 | ASME Code Sect. VIII<br>LESER API Series 526 |
|---|---|---|
| | $K_{d-effective}$ [-] | $K_{actual}$ [-] |
| Gas, vapors, steam | 0.975 | 0.455 (Orifice D)<br>0.801 (Orifice E-T) |
| Liquid | 0.65 | 0.343 (Orifice D)<br>0.579 (Orifice E-T) |
| Two-phase flows | 0.85 | No certification procedure |

| Orifice letter | API RP 520<br>Effective discharge area | | ASME VIII<br>Actual discharge area<br>LESER API Series 526 | |
|---|---|---|---|---|
| | [in$^2$] | [mm$^2$] | [in$^2$] | [mm$^2$] |
| D | 0.110 | 71 | 0.239 | 154 |
| E | 0.196 | 126 | 0.239 | 154 |
| F | 0.307 | 198 | 0.394 | 254 |
| G | 0.503 | 325 | 0.616 | 398 |
| H | 0.785 | 506 | 0.975 | 625 |
| J | 1.287 | 830 | 1.58 | 1018 |
| K | 1.838 | 1186 | 2.25 | 1452 |
| L | 2.853 | 1841 | 3.48 | 2248 |
| M | 3.600 | 2322 | 4.43 | 2846 |
| N | 4.340 | 2800 | 5.30 | 3421 |
| P | 6.380 | 4116 | 7.79 | 5026 |
| Q | 11.050 | 7129 | 13.55 | 8742 |
| R | 16.000 | 10322 | 19.48 | 12668 |
| T | 26.000 | 16774 | 31.75 | 20485 |

*Table 7.4.1-1: Effective and actual discharge coefficients and discharge areas for LESER API Series Type 526*

## 7.4.2 List of Symbols/Nomenclature According to API RP 520

| Symbol | Description | Units [US] |
|---|---|---|
| $A$ | Required discharge area of the safety valve | in$^2$ |
| $C$ | Coefficient determined from an expression of the ratio of specific heats of the gas or vapor at relieving conditions | $\frac{\sqrt{lb \cdot lb_{mol} \cdot °R}}{lb_f \cdot hr}$ |
| $F_2$ | Coefficient of subcritical flow | -- |
| $G$ | Specific gravity of the gas at standard conditions referred to air at standard conditions or<br>Specific gravity of the liquid at flowing temperature referred to water at standard conditions | -- |
| $k$ | Ratio of the specific heats | -- |
| $K_b$ | Capacity correction factor due to back pressure (gas, vapors, steam).<br>Applies to balanced bellows valves only | -- |
| $K_c$ | Combination correction factor for safety valves installed with a rupture disk upstream of the valve | -- |
| $K_d$ | Discharge coefficient | -- |
| $K_N$ | Correction factor for Napier equation | -- |
| $K_{SH}$ | Superheat steam correction factor | -- |
| $K_v$ | Correction factor due to viscosity | -- |
| $K_w$ | Correction factor due to the back pressure (liquids).<br>Applies to balanced bellows valves only | -- |
| $M$ | Molecular weight of the gas or vapor at inlet relieving conditions | $lb/lb_{mol}$ |
| $P_1$ | Relieving pressure | psi |
| $P_2$ | Back pressure | psi |
| $Q$ | Flow rate | gpm |
| $T$ | Relieving temperature | °R |
| $U$ | Viscosity of the liquid at the flowing temperature | SSU |
| $V$ | Required flow through the device | scfm at 14.7 psia and 60°F |
| $W$ | Required flow | lb/hr |
| $Z$ | Compressibility factor for the deviation of the actual gas from a perfect gas, evaluated at relieving conditions | -- |
| $\mu$ | Absolute viscosity of the liquid at the flowing temperature | cP |

*Table 7.4.2-1: List of symbols*

The relieving pressure $P_1$ is defined in Eq. 7.4.2-1 as the sum of the set pressure, the overpressure and the atmospheric value.

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} \quad \text{(Eq. 7.4.2-1)}$$

The correction factor for the back pressure, $K_b$, is obtainable from LESER's catalog. Pilot and conventional valves in critical flows do not necessitate such a correction. The combination correction factor $K_c$ in the preliminary sizing must be taken equal to 0.9 if a rupture disk is inserted upstream of the valve. Otherwise $K_c = 1.0$.

### 7.4.3 Gases and Vapors - Critical Flow

$$A = \frac{W}{C\ K_b K_c K_d P_1}\sqrt{\frac{T\ Z}{M}} \quad \text{(Eq. 7.4.3-1)}$$

$$A = \frac{1}{6.32}\frac{V\sqrt{TZM}}{CK_b K_c K_d P_1} \quad \text{(Eq. 7.4.3-2)}$$

$$A = \frac{1}{1.175}\frac{V\sqrt{TZG}}{CK_b K_c K_d P_1} \quad \text{(Eq. 7.4.3-3)}$$

The correction factor due to the back pressure $K_b$ for the preliminary sizing is given in Fig. 7.4.3-1

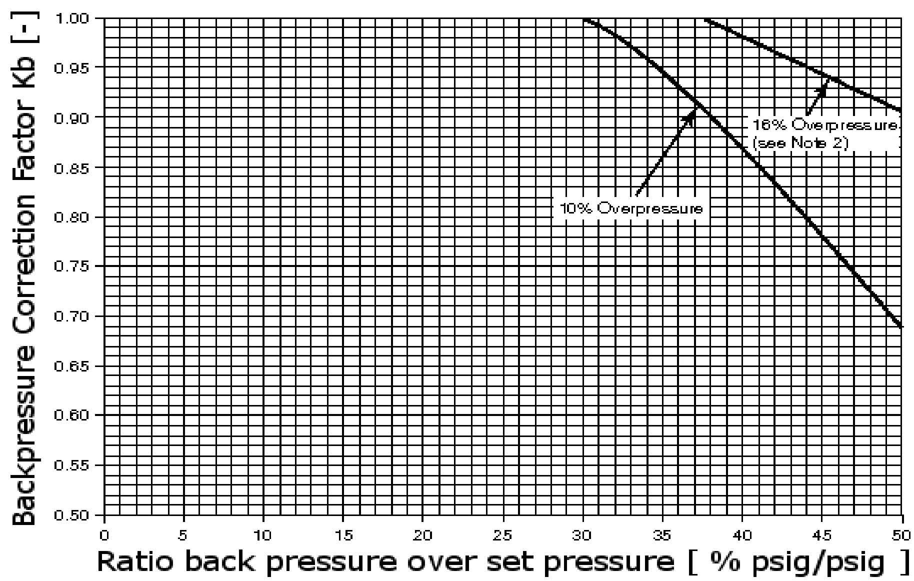


*Figure 7.4.3-1: Back pressure correction factor for gases and vapors $K_b$ from API RP 520, Page 37*

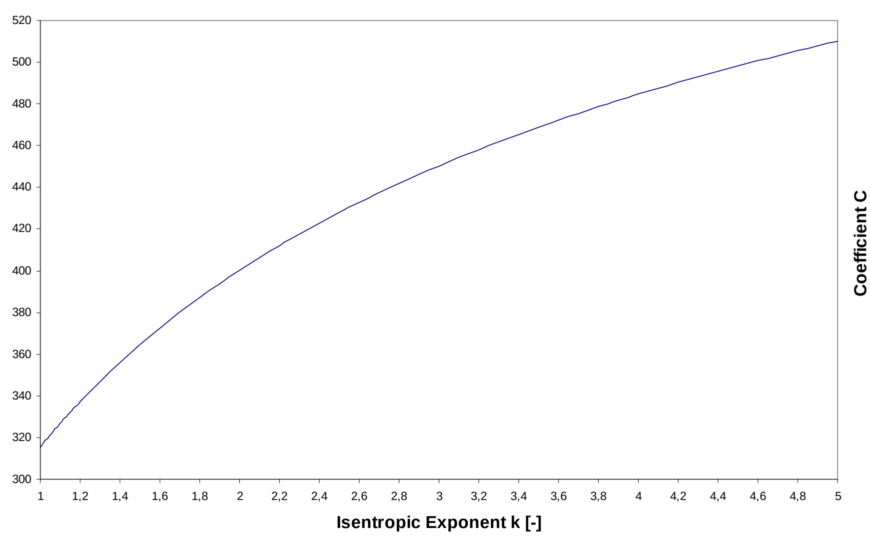


*Figure 7.4.3-2: Coefficient $C$ in function of the specific heat ratio from API RP 520, Page 44.*

In alternative to Fig. *7.4.3-1* the coefficient C can be calculated from Eq. 7.4.3-4

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \quad \text{Unit: } \frac{\sqrt{lb_m lb_{mol} \,{}^\circ R}}{lb_f hr} \quad \textit{(Eq. 7.4.3-4)}$$

### 7.4.4 Gases and Vapors - Subcritical Flow

$$A = \frac{1}{735} \frac{W}{F_2 K_c K_d} \sqrt{\frac{T\,Z}{M\;P_1} \frac{1}{P_1 - P_2}} \quad \text{(Eq. 7.4.4-1)}$$

$$A = \frac{1}{4645} \frac{V}{F_2 K_c K_d} \sqrt{\frac{ZTM}{P_1 (P_1 - P_2)}} \quad \text{(Eq. 7.4.4-2)}$$

$$A = \frac{1}{864} \frac{V}{F_2 K_c K_d} \sqrt{\frac{ZTG}{P_1 (P_1 - P_2)}} \quad \text{(Eq. 7.4.4-3)}$$

or equivalently

$$A = \frac{1}{735} \frac{W}{F_2 K_c K_d P_1} \sqrt{\frac{T\,Z}{M} \frac{1}{1 - r}} \quad \text{with} \quad r = \frac{P_1}{P_2} \quad \text{(Eq. 7.4.4-4)}$$

where $F_2$ is calculated from Eq. *7.4.4-5* or obtained from Fig. *7.4.4-1*

$$F_2 = \sqrt{\frac{k}{k-1} \cdot r^{\frac{2}{k}} \cdot \frac{1 - r^{\frac{k-1}{k}}}{1 - r}} \quad \text{(Eq. 7.4.4-5)}$$

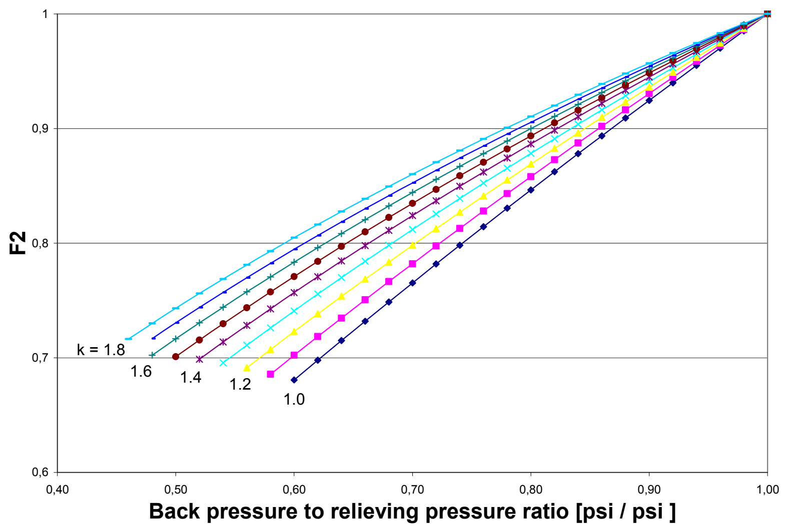


*Figure 7.4.4-1: Coefficient $F_2$ in function of the ratio of absolute back pressure on absolute relieving pressure for various specific heat ratios.*

## 7.4.5 Steam

$$A = \frac{1}{51.5} \cdot \frac{W}{P_1 K_b K_c K_d K_N K_{SH}} \qquad \textit{(Eq. 7.4.5-1)}$$

The correction factor for Napier equation $K_N$ is expressed by Eq. *7.4.5-2* and *7.4.5-3*

$$K_N = \frac{0.1906 \cdot P_1 - 1000}{0.2292 \cdot P_1 - 1061} \quad \text{if} \quad P_1 > 1500 \ \ psia \qquad \textit{(Eq. 7.4.5-2)}$$

$$K_N = 1 \quad \text{if} \quad P_1 \leq 1500 \ \ psia \qquad \textit{(Eq. 7.4.5-3)}$$

The Superheat steam correction factor $K_{SH}$ can be taken from Table 7.4.5-1, which is extracted from Table 9 on Page 51 of API RP 520.

| Set pressure [psig] | Temperature [°F] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 |
| 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 | 1.00 | 0.95 | 0.90 | 0.85 | 0.81 | 0.78 | 0.75 | 0.72 | 0.70 |
| 260 | 1.00 | 1.00 | 0.95 | 0.90 | 0.85 | 0.81 | 0.78 | 0.75 | 0.72 | 0.70 |
| 280 | 1.00 | 1.00 | 0.96 | 0.90 | 0.85 | 0.81 | 0.78 | 0.75 | 0.72 | 0.70 |
| 300 | 1.00 | 1.00 | 0.96 | 0.90 | 0.85 | 0.82 | 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 |
| 1000 | | | 1.00 | 0.96 | 0.89 | 0.84 | 0.78 | 0.76 | 0.73 | 0.71 |
| 1250 | | | 1.00 | 0.97 | 0.91 | 0.85 | 0.80 | 0.77 | 0.74 | 0.71 |
| 1500 | | | | 1.00 | 0.93 | 0.86 | 0.81 | 0.77 | 0.74 | 0.71 |
| 1750 | | | | 1.00 | 0.94 | 0.86 | 0.81 | 0.77 | 0.73 | 0.70 |
| 2000 | | | | 1.00 | 0.95 | 0.86 | 0.80 | 0.76 | 0.72 | 0.69 |
| 2500 | | | | 1.00 | 0.95 | 0.85 | 0.78 | 0.73 | 0.69 | 0.66 |
| 3000 | | | | | 1.00 | 0.82 | 0.74 | 0.69 | 0.65 | 0.62 |

*Table 7.4.5-1: Correction factors $K_{SH}$ for superheat steam acc. to API RP 520*

## 7.4.6 Liquids

$$A = \frac{1}{38} \cdot \frac{Q}{K_c K_d K_v K_w} \sqrt{\frac{G}{P_1 - P_2}} \quad \text{(Eq. 7.4.6-1)}$$

The correction factor due to the back pressure $K_w$ for the preliminary sizing can be read from Fig. *7.4.6-1*. The correction factor due to viscosity $K_v$ can be either calculated from Eq. *7.4.6-2.*

$$K_v = \left(0.9935 + \frac{2.878}{\mathrm{Re}^{0.5}} + \frac{342.75}{\mathrm{Re}^{1.5}}\right)^{-1} \ldots \text{(Eq. 7.4.6-2)}$$

by using the definition of the Reynolds number in Eq. *7.4.6-3*

$$\mathrm{Re} = 2800 \frac{Q\,G}{\mu\,\sqrt{A}} \quad \text{or} \quad \mathrm{Re} = 12700 \frac{Q}{U\,\sqrt{A}} \quad \text{(Eq. 7.4.6-3)}$$

or graphically estimated from Fig. 7.2.4-2. When a safety valve is to be sized for viscous liquids, it should first be sized as the fluid were in viscid ($K_v = 1$) to obtain a preliminary minimum discharge area using Eq. *7.4.6-1*. The next larger effective orifice area is then selected from Table 7.4.1-1 to calculate the Reynolds number in Eq. 7.4.6-3, which is used to determine the viscosity correction factor in Eq. 7.4.6-2. This correction factor $K_v$ is introduced back into Eq. *7.4.6-1* to correct the preliminary discharge area. If the corrected area exceeds the chosen standard orifice, this procedure should be repeated using the next larger standard orifice area from Table 7.4.1-1.

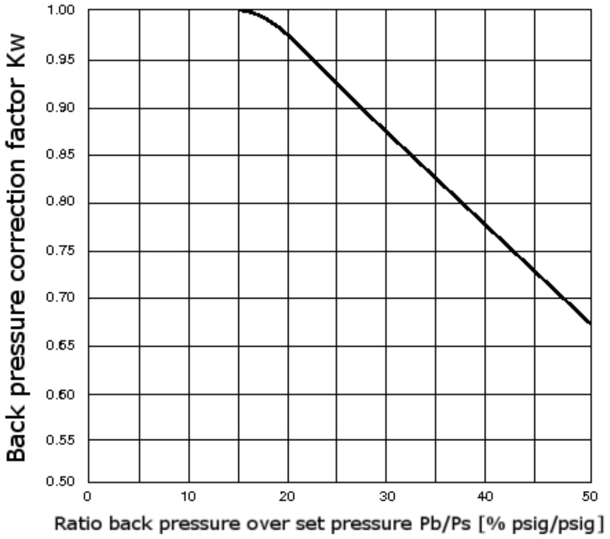


*Figure 7.4.6-1: Back pressure correction factor for liquids $K_w$ from API RP 520, Page 38*

### 7.4.7 Two-Phase Flows according to API RP 520, 7th Edition, 2000, Appendix D

In API RP 520 on page 69 there is a short preface intended for people approaching two-phase flow calculation routines. The reader is invited to read it carefully before using this sizing procedure.

The most relevant points are that

1. This sizing procedure is just one of the several techniques currently in use.
2. This sizing procedure has not been yet validated by tests.
3. There is no recognized procedure for the certification of safety valves in two-phase flows.

Two-phase flows occur in a variety of scenarios, where either

- a liquid vaporizes within the safety valve, or
- a two-phase mixture enters the safety valve or
- a vapor condenses in the safety valve
- a supercritical fluid enters the safety valve and condenses

In all cases a two-phase mixture is likely to be discharged from the safety valve.

The complete list of the two-phase flow scenarios for safety valves is presented in Table 7.4.7-1.

| | |
|---|---|
| Saturated liquid and saturated vapor enter the valve and the liquid flashes. No non-condensable gas is present (*flashing flow*). | See section 7.4.7.1 |
| Supercritical fluid condensing in the safety valve. | |
| Highly subcooled liquid and either non-condensable gas, condensable vapors or both enter the valve but the liquid does not flash (*frozen flow*). | See section 7.4.7.2 |
| Subcooled liquid enters the valve and flashes. No vapor or gas is present at the inlet. | See section 7.4.7.3 |
| Generic two-phase flow with a subcooled or saturated liquid and non-condensable gas with or without condensable vapor. | (not present in this chapter) |

*Table 7.4.7-1: Two-phase flow scenarios*

The sizing procedure of API RP 520 Appendix D is based on the Omega method of Leung[4]. This sizing method uses the so-called Omega-parameter, which is a measure of the compressibility of the two-phase mixture.

The required steps of this method are:

- Calculation of the Omega-Parameter
- Determination if the flow is critical or subcritical
- Calculation of the mass flux, which is the mass flow per unit area
- Calculation of the required orifice area of the safety valve among those in API RP 526

[4] Leung, J.C. *On the application of the method of Landau and Lifshitz to sonic velocities in homogeneous two-phase mixtures*, **J. Fluids Engineering**, 1996, 118, 1,186–188.

Some additional nomenclature, which is necessary for two-phase flows, is given in Table 7.4.7-2.

| Symbol | Description | Units [US] |
|---|---|---|
| $C_p$ | Specific heat at constant pressure of the liquid at the safety valve inlet | Btu/(lb °R) |
| $G$ | Mass flux | lb/(s ft²) |
| $h_{vl0}$ | Latent heat of vaporization at the safety valve inlet. For multicomponent systems, it represents the difference between the vapor and the liquid specific enthalpies at the safety valve inlet | Btu/lb |
| $h_{vls}$ | Latent heat of vaporization at $P_s$. For multi-component systems it is the difference between the vapor and liquid specific enthalpies at $P_s$ | Btu/lb |
| $P_1$ | Pressure at safety valve inlet | psi |
| $P_a$ | Downstream back pressure | psi |
| $P_c$ | Critical pressure | psi |
| $P_r$ | Relative pressure | [--] |
| $P_s$ | Saturation pressure (single-component flows) or bubble point pressure (multi-component flows) at the relieving temperature $T_0$ | psi |
| $Q$ | Volumetric flow rate | gal/min |
| $T_0$ | Temperature at safety valve inlet | °R |
| $T_r$ | Relative temperature | [--] |
| $v_{v0}$ | Specific volume of the vapor at safety valve inlet | ft³/lb |
| $v_0$ | Specific volume of the two-phase mixture at safety valve inlet | ft³/lb |
| $v_{vg0}$ | Specific volume of the vapor, gas or combined vapor and gas at the safety valve inlet | ft³/lb |
| $v_{vl0}$ | Difference between the vapor and the liquid specific volumes at the safety valve inlet | ft³/lb |
| $v_{vls}$ | Difference between the vapor and the liquid specific volumes at $P_s$ | ft³/lb |
| $v_9$ | Specific volume evaluated at 90% of the safety valve inlet pressure (= relieving pressure), assuming isentropic flashing | ft³/lb |
| $x_0$ | Vapor (or gas or combined vapor and gas) mass fraction (quality) at safety valve inlet | [--] |
| $\eta_a$ | Ratio between ambient pressure and relieving pressure | [--] |
| $\eta_c$ | Ratio between critical pressure and relieving pressure | [--] |
| $\eta_s$ | Ratio between saturation pressure at relieving temperature and relieving pressure | [--] |
| $\rho_{l0}$ | Density of the liquid at the inlet of the safety valve | lb/ft³ |
| $\rho_9$ | Density evaluated at 90% of the saturation pressure (single-component flows) or bubble point pressure (multi-component flows) $P_s$ at $T_0$. The flash calculation should be carried out isentropically. | lb/ft³ |
| $\omega$ | Omega Parameter | [--] |
| $\omega_s$ | Omega Parameter for subcooled liquid flows at safety valve inlet | [--] |

*Table 7.4.7-2: List of symbols for two-phase flows*

### 7.4.7.1 Saturated Liquid and Saturated Vapor, Liquid Flashes

The definitions of the Omega-Parameter in Eq. *7.4.7.1-1*, *7.4.7.1-2* and *7.4.7.1-3* can be employed for multi-component systems, whose nominal boiling range, that is the difference in the atmospheric boiling points of the heaviest and the lightest components, is less than 150°F. For single-component systems with relative temperature $T_r \leq 0.9$ (see Eq. 7.2.2-4) and pressure (see Eq. 7.2.2-5) $p_r \leq 0.5$, either Eq. 7.4.7.1-1 or Eq. 7.4.7.1-2 can be used.

$$\omega = \frac{x_0 v_{v0}}{v_0} \cdot \left(1 - 0.37 \frac{P_1 \cdot v_{vl0}}{h_{vl0}}\right) + 0.185 \frac{C_p T_0 P_1}{v_0} \left(\frac{v_{vl0}}{h_{vl0}}\right)^2 \quad \text{(Eq. 7.4.7.1-1)}$$

$$\omega = \frac{x_0 v_{v0}}{v_0 k} + 0.185 \frac{C_p T_0 P_1}{v_0} \left(\frac{v_{vl0}}{h_{vl0}}\right)^2 \quad \text{(Eq. 7.4.7.1-2)}$$

For multi-component systems, whose nominal boiling range is greater than 150°F or for single-component systems close to the thermodynamic critical point or supercritical fluids in condensing two-phase flows Eq. 7.4.7.1-3 must be used.

$$\omega = 9\left(\frac{v_9}{v_0} - 1\right) \quad \text{(Eq. 7.4.7.1-3)}$$

The two-phase flow is critical if the critical pressure is larger than the back pressure

$P_c > P_b \Rightarrow$ the two-phase flow is *critical*

$P_c < P_b \Rightarrow$ the two-phase flow is *subcritical*

The critical pressure ratio, $\eta_c = P_c / P_1$, is the iterative solution of Eq. 7.4.7.1-4

$$\eta_c^2 + \left(\omega^2 - 2\omega\right)\left(1 - \eta_c\right)^2 + 2\omega^2 \ln\left(\eta_c\right) + 2\omega^2\left(1 - \eta_c\right) = 0 \quad \text{(Eq. 7.4.7.1-4)}$$

The mass flux is defined in Eq. 7.4.7.1-5 for critical flow and in Eq. 7.4.7.1-6 for subcritical flow

| | | |
|---|---|---|
| $G = 68.09 \cdot \eta_c \cdot \sqrt{\frac{1}{\omega} \frac{P_1}{v_0}}$ | critical flow | *(Eq. 7.4.7.1-5)* |
| $G = 68.09 \sqrt{\frac{P_1}{v_0}} \frac{\sqrt{-2 \cdot \left[\omega \ln\left(P_a / P_1\right) + \left(\omega - 1\right)\left(1 - P_a / P_1\right)\right]}}{\omega\left(P_1 / P_a - 1\right) + 1}$ | subcritical flow | *(Eq. 7.4.7.1-6)* |

Finally, the required area of the safety valve can be computed from Eq. 7.4.7.1-7

$$A = 0.04 \cdot \frac{1}{K_b K_c K_d} \cdot \frac{W}{G} \quad \text{(Eq.7.4.7.1-7)}$$

For a preliminary sizing to calculate the effective orifice area the discharge coefficient $K_d$ can be assumed equal to 0.85 and the correction factor for back pressure is that in Fig 7.4.3-1.

7.4.7.2 Highly Subcooled Liquid, Non-Condensable Gas/Condensable Vapors, Non-Flashing Liquid (Frozen Flow).

Same sizing procedure as in Section 7.4.7.1 but with the Omega Parameter in Eq. 7.4.7.2-1

$$\omega = \frac{x_0 v_{vg0}}{v_0 k} \quad \textit{(Eq. 7.4.7.2.-1)}$$

7.4.7.3 Subcooled Liquid enters the Valve and Flashes, No Vapor or Gas at the Inlet

For subcooled liquid flows the Omega-Parameter is generally referred with $\omega_s$. For multi-component systems with nominal boiling range less than 150°F $\omega_s$ can be calculated either from Eq. 7.4.7.3-1 or from Eq. 7.4.7.3-2. For single component systems with a relative temperature and pressure within the limits $T_r \leq 0.9$ and $p_r \leq 0.5$ $\omega_s$ is given by Eq. 7.4.7.3-1.

$$\omega_s = 0.185 \rho_{l0} C_p T_0 P_s \left( \frac{v_{vls}}{h_{vls}} \right)^2 \quad \textit{(Eq. 7.4.7.3-1)}$$

For multi-component systems, whose nominal boiling range is greater than 150°F or for single-component systems close to the thermodynamic critical point $\omega_s$ is given by Eq. 7.4.7.3-2.

$$\omega_s = 9\left( \frac{\rho_{l0}}{\rho_9} - 1 \right) \quad \textit{(Eq. 7.4.7.3-2)}$$

When a liquid enters the safety valve in a subcooled state, it is necessary to determine where indicatively it saturates and the extension of the subcooling region on the base of the following table:

| | |
|---|---|
| $P_s > P_0 \dfrac{2 \cdot \omega_s}{1 + 2 \cdot \omega_s}$ | *low subcooling region*<br>(flashing occurs before the valve throat) |
| $P_s < P_0 \dfrac{2 \cdot \omega_s}{1 + 2 \cdot \omega_s}$ | *high subcooling region*<br>(flashing occurs at the valve throat) |

The condition for the existence of critical and subcritical flow are:

| | Critical flow | Subcritical flow |
|---|---|---|
| in the low subcooling region | $P_c > P_a$ | $P_c < P_a$ |
| in the high subcooling region | $P_s > P_a$ | $P_s < P_a$ |

The mass flux in case of low and high subcooling is:

| | | | | |
|---|---|---|---|---|
| *Low subcooling region* | $G = 68.09 \dfrac{\left\{ 2(1-\eta_s) + 2\left[\omega_s \eta_s \ln\left( \eta_s / \eta \right) - (\omega_s - 1)(\eta_s - \eta)\right] \right\}^{0.5}}{\omega_s\left(\eta_s / \eta - 1\right) + 1} \sqrt{P_1 \rho_{l0}}$ | *with* | $\eta = \eta_c$ | Crit. flow |
| | | | $\eta = \eta_a$ | Subcrit. flow |
| *High subcooling region* | $G = 96.3\left[\rho_{l0} \cdot (P_1 - P)\right]^{0.5}$ | *with* | $P = P_s$ | Crit. Flow |
| | | | $P = P_a$ | Subcrit. flow |

The required area of the pressure relief valve is calculated from Eq. 7.4.7.3-3

$$A = 0.3208 \frac{1}{K_b K_c K_d} \frac{Q \cdot \rho_{l0}}{G} \quad \text{(Eq.7.4.7.3-3)}$$

The correction factor for back pressure for balanced bellow valves is $K_w$ in Fig. 7.4.6-1. The discharge coefficient $K_d$ for a preliminary sizing is equal to 0.65 for subcooled liquids at the safety valve inlet or 0.85 for saturated liquids.

### 7.4.8 Fire Case and Hydraulic (Thermal) Expansion acc. to API 521 and ISO 23251

This standard deals with the planning of safety requirements for pressure-relieving and depressurizing systems. It analyses the major causes for overpressure and gives some indicative values for the determination of the individual relieving rates in a variety of practical cases. It is fully introduced in the new standard[5] ISO 23251. Formulas in both standards are identical, except for the units. For the application of API 521 formulas the user must use the US units, which are reported on the third column of Table 7.4.8.1-1, while for the formulas in ISO 23251 the SI units, defined of the fourth column of the same table.

This section of ENGINEERING shows the equations for the sizing in case of

- ✓ Hydraulic Expansion (API 521 Par. 5.14, ISO 23251 Par. 5.14)
- ✓ External Fire Case (API 521 Par. 5.15, ISO 23251 Par 5.15)

Hydraulic expansion or Thermal expansion is the increase in the liquid volume due to an increment in temperature. Typically it occurs for liquids, which are trapped in vessels, pipes, heat exchangers and exposed to heat, for instance from electrical coils, ambient heat, fire, etc.

In the external fire case sizing API 521 distinguishes between *wetted* and *unwetted vessels* according to the following definitions and presents for each of them a sizing procedure.

A wetted vessel contains a liquid in equilibrium with its vapor or a gas. Wetted vessels contain temperated systems. In consequence of the heat transfer from the external fire a partial evaporation of the liquid occurs. In the calculation of the portion of vessel exposed to fire only that portion in contact with the liquid within a distance of 25 feet (in ISO 23251 7.6 m) above the fire source must be considered for sizing, see Table 7.4.8.3-1. If the exposure to fire leads to vapor generation from thermal cracking, alternate sizing methods may be appropriate.

An unwetted vessel is a vessel, which is either thermally insulated on the internal walls or filled with gases, vapors or a supercritical fluid. Unwetted vessels contain gassy systems. Vessels with separated liquid and vapor under normal conditions which become single-phase at relieving conditions belong here as well. However, vessels, whose walls become thermally insulated due to the deposition of coke or material from the contained fluids, are still considered wetted for fire sizing case however additional protection is required. In comparison to wetted vessels the thermal flow from the walls to the interior is low in unwetted vessels due to the large thermal resistance. In case of prolonged exposure of the outside surface to the fire source the temperature within the walls may be so high to cause thermal rupture of the vessel.

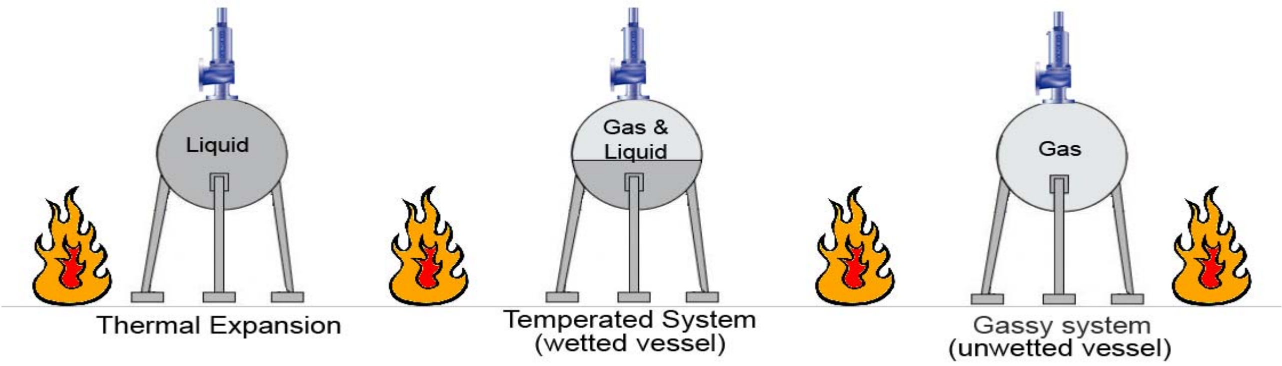


*Figure: 7.4.8-1: Hydraulic (thermal) expansion and fire case*

[5] ISO 23251 Petroleum and natural gas industries – Pressure relieving and depressuring systems, 2007

7.4.8.1 List of Symbols/Nomenclature

| Symbol | Description | Units [US] | Units [SI] |
|---|---|---|---|
| $A$ | Effective discharge area of the valve | [in²] | * |
| $A'$ | Exposed surface area of the vessel | [ft²] | * |
| $A_{ws}$ | Total wetted surface | [ft²] | [m²] |
| $\alpha_v$ | Cubical expansion coefficient of the liquid at the expected temperature | [1/°F] | [1/°C] |
| $c$ | Specific heat capacity of the trapped liquid | [Btu/(lb °F)] | [J/(kg K)] |
| $F$ | Environment factor | -- | -- |
| $d$ | Relative density referred to water at 60°F (15.6°C) | -- | -- |
| $h_{vl0}$ | Latent heat of vaporization | [Btu/lb] | [J/kg] |
| $K_D$ | Coefficient of discharge | -- | -- |
| $\phi$ | Total heat transfer rate | [Btu/hr] | [W] |
| $M$ | Molecular mass of the gas | [$lb/lb_{mol}$] | [$kg/k_{mol}$] |
| $P_1$ | Upstream relieving absolute pressure | [psi] | * |
| $Q$ | Total absorbed (input) heat to the wetted surface | [Btu/hr] | [W] |
| $q$ | Volume flow rate at the flowing temperature | [gpm] | [m³/s] |
| $q_m$ | Relief load / mass flow rate | [lb/hr] | * |
| $T_1$ | Gas temperature at upstream relieving pressure | [°R] | * |
| $T_w$ | Recommended max. vessel wall temperature | [°R] | * |

*Table 7.4.8.1-1 List of symbols for sizing acc. to API 521*

* The sizing formulas in ISO 23251 are identical to those in API 521, which are expressed in US Units. Conversion factors to specified SI units have been not yet provided. The application of the formula using US units is therefore recommended.

### 7.4.8.2 Hydraulic Expansion (Thermal Expansion)

The mass flow rate for the sizing of the safety valve for a liquid vessel exposed to a heat source can be approximated by Eq. 7.4.8.2-1 (Eq. 7.4.8.2-2) for the case that the trapped liquid does not evaporate. However, the mass flow rates are usually so small that a safety valve sized NPS ¾ x NPS 1 (DN 20 x DN 25) should be sufficient acc. to API 521 Par. 5.14.2.

$$q = \frac{1}{500}\frac{\alpha_v \cdot \phi}{d \cdot c} \quad \text{(API 521)} \qquad \textit{(Eq. 7.4.8.2-1)}$$

$$q = \frac{1}{1000}\frac{\alpha_v \cdot \phi}{d \cdot c} \quad \text{(ISO 23251)} \qquad \textit{(Eq. 7.4.8.2-2)}$$

The cubical expansion coefficient of the liquid should be obtained from the process data; however, for water and hydrocarbon liquids at 60°F (15.6°C) some reference values are given in Table 7.4.8.2-1. However, more precise values should be obtained from process design data.

| Gravity of liquid (°API) | $\alpha_v$ [1/°F] | $\alpha_v$ [1/°C] |
|---|---|---|
| 3 – 34.9 | 0.0004 | 0.00072 |
| 35 – 50.9 | 0.0005 | 0.0009 |
| 51 – 63.9 | 0.0006 | 0.00108 |
| 64 – 78.9 | 0.0007 | 0.00126 |
| 79 – 88.9 | 0.0008 | 0.00144 |
| 89 – 93.9 | 0.00085 | 0.00153 |
| 94 – 100 and lighter | 0.0009 | 0.00162 |
| Water | 0.0001 | 0.00018 |

*Table 7.4.8.2-1 Value of cubical expansion coefficient for hydrocarbon liquids at 60°F in API 521*

If the liquid is supposed to flash or form solids during the flow in the safety valve, the sizing procedure for two-phase flows in API RP 520 is recommended.

### 7.4.8.3 External Fire - Wetted Vessels

| Class of vessels | Portion of liquid inventory | Remarks |
|---|---|---|
| Liquid-full, e.g. treaters | All up to the height of 25 ft (7.6 m) | |
| Surge or knockout drums, process vessels | Normal operating level up to the height of 25 ft (7.6 m) | |
| Fractionating columns | Normal level in bottom plus liquid hold-up from all trays dumped to the normal level in the column bottom; total wetted surface up to the height of 25 ft (7.6 m) | Level in reboiler is to be included if the reboiler is an integral part of the column |
| Working storage | Max. inventory level up to 25 ft (7.6 m), normally excluding the portions of the wetted area in contact with the foundations or the ground | For storage and process tanks, see API Standard 2000[6] or prEN 14015-1[7] |
| Spheres and spheroids | Up to the height of 25 ft or up to the max. horizontal diameter, whichever is greater | |

*Table 7.4.8.3-1 Portions of wetted surfaces to be considered*

The amount of heat absorbed from a non-insulated vessel filled with a liquid depends at least on

- The type of fuel feeding the fire
- The degree of envelopment of the vessel with fire, which is a function of its size and shape
- The immediateness of firefighting measures and the possibility of drainage of flammable materials from the vessel

The total heat absorption Q for the wetted surface can be estimated by Eq. 7.4.8.3-1 in case of adequate drainage and prompt firefighting measures and by Eq. 7.4.8.3-2 in case of absent adequate drainage and/or firefighting measures.

| | US units | SI units | |
|---|---|---|---|
| Drainage and firefighting measures | $Q=21000\ FA_{ws}^{0.82}$ | $Q=43200\ FA_{ws}^{0.82}$ | (Eq. 7.4.8.3-1) |
| Absent drainage and/or firefighting measures | $Q=34500\ FA_{ws}^{0.82}$ | $Q=70900\ FA_{ws}^{0.82}$ | (Eq. 7.4.8.3-2) |

Adequate drainage of flammable fuels might be implemented with a strategic use of sewers and trenches as well as of the natural slope of the land. The values of the environment factor F for some types of installations are collected in Table 7.4.8.3-2. In case the conditions for Eq. 7.4.8.3-1 and 7.4.8.3-2 are not present, either higher values of the environment factor are assigned on the base of engineering judgment or some protection measures against fire exposure must be introduced to the plant. For water application facilities on bare vessels and depressurizing or emptying facilities insulation should withstand dislodgement by fire hose streams. Some example drainage criteria are given in API Standard 2510[8]

[6] API Standard 2000 Venting atmospheric and low pressure storage tanks : nonrefrigerated and refrigerated, 1998.

[7] prEN 14015-1: Specification for the design and manufacture of site built, vertical, cylindrical, flat-bottomed, above ground, welded, metallic tanks for the storage of liquids at ambient temperature and above – Part 1: Steel tanks, 2000.

[8] API Standard 2510 Design and construction of liquefied petroleum gas installations (LPG), 2001

| Type of Equipment | | F |
|---|---|---|
| Bare vessel | | 1.0 |
| Insulated vessel , with insulation conductance values for fire exposure conditions | | |
| 4 [Btu/(hr ft² °F)] | 22.71 [W/ (m² K)] | 0.3 |
| 2 | 11.36 | 0.15 |
| 1 | 5.68 | 0.075 |
| 0.67 | 3.80 | 0.05 |
| 0.5 | 2.84 | 0.0376 |
| 0.4 | 2.27 | 0.03 |
| 0.33 | 1.87 | 0.026 |
| Water-application facilities, on bare vessel | | 1.0 |
| Depressurizing and emptying facilities | | 1.0 |
| Earth-covered storage | | 0.03 |
| Below-grade storage | | 0.00 |

*Table 7.4.8.3-2 Values of the environment factor F for various types of installations*

Heat absorption equations in Eq. 7.4.8.3-1 and 7.4.8.3-2 are for process vessels and pressurized storage of liquefied gases. For other storage, whether on pressure vessels or vessels and tanks with a design pressure of 15 psig or less the recommended heat absorption rates in case of external fire exposure can be extracted from API Standard 2000. The wetted areas for pressurized vessels of different forms in respect of Table 7.4.8.3-1 are collected in Table 7.4.8.3-3. Some examples are described also graphically in Fig. 7.4.3.3-1. The symbols are conform to those in VALVESTAR®.

| Class of vessels | Portion of liquid inventory and remarks |
|---|---|
| Sphere | $A_{wet} = \pi \cdot D \cdot F_{eff}$ |
| Horizontal cylindrical vessel with flat ends | $A_{wet} = \beta \cdot D \cdot \left[ L + \frac{D}{2} \right] - D \cdot \sin\beta \cdot \left[ \frac{D}{2} - F_{eff} \right]$ |
| Horizontal cylindrical vessel with spherical ends | $A_{wet} = \pi \cdot D \cdot \left[ (L - D)\frac{\beta}{\pi} + F_{eff} \right]$ |
| Vertical cylinder with flat ends<br>✓ Partially filled ( $F < L$ ) | $A_{wet} = \pi \cdot D \cdot \left[ \frac{D}{4} + F_{eff} \right]$ |
| ✓ Totally filled ( $F = L$ ) | $A_{wet} = \pi \cdot D \cdot \left[ \frac{D}{2} + F_{eff} \right]$ |
| Vertical cylinder with spherical ends | $A_{wet} = \pi \cdot D \cdot F_{eff}$ |

*Table 7.4.8.3-3 Calculation of the total wetted surface for some vessels.*

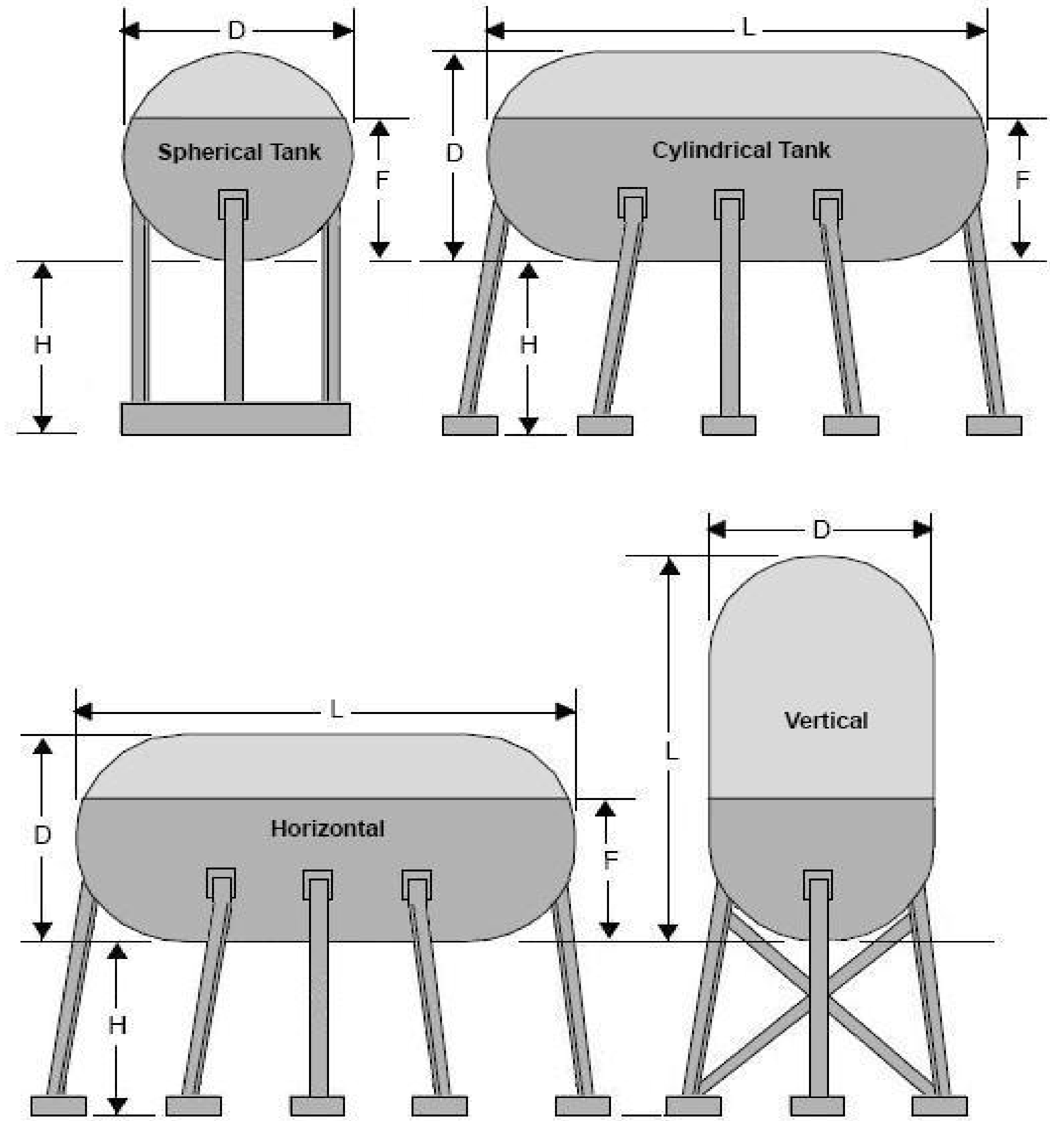


*Figure 7.4.8.3-1 : Possible positions of wetted vessels, partially filled with liquids*

The angle $\beta$ in Table 7.4.8.3-3 is defined in Eq. 7.4.8.3-3

$$\beta = \cos^{-1}(1 - 2F/D) \quad \textit{(Eq. 7.4.8.3-3)}$$

and the height $F_{eff}$ is the effective liquid level up to a max. distance of 25 feet away from the flame source, Eq. 7.4.8.3-4 (Eq. 7.4.8.3-5)

$$F_{eff} = \min(25 \ \ ft; F) - H \quad \text{(API 521)} \quad \textit{(Eq. 7.4.8.3-4)}$$

$$F_{eff} = \min(7.6 \ \ m; F) - H \quad \text{(ISO 23521)} \quad \textit{(Eq. 7.4.8.3-5)}$$

The mass flow rate to the safety valve is determined by Eq. 7.4.8.3-6, considering that all absorbed heat vaporizes the liquid

$$W = Q / h_{vl0} \quad \textit{(Eq. 7.4.8.3-6)}$$

### 7.4.8.4 External Fire - unwetted vessels

If the vessel is filled with a gas, a vapor or a supercritical medium, Eq. 7.4.8.4-1 may be used to find the safety valve discharge area

$$A = \frac{F'A'}{\sqrt{P_1}} \quad \text{(Eq. 7.4.8.4-1)}$$

F' may be determined from Eq. 7.4.8.4-2 if the calculated value is less than 0.01, then a recommended minimum value equal to 0.01 must be taken. When the available information is not enough to use Eq. 7.4.8.3-8, then the environment factor can be assumed equal to 0.045. The recommended maximum vessel wall temperature $T_w$ for the usual carbon steel plate materials is 1100°F (593°C). For plates made of alloys the wall temperature must be changed to a more adequate recommended max. value.

The constant C is given from Eq. 7.4.3-3.

$$F' = \frac{0.1406}{C \cdot K_d}\left[\frac{(T_w - T_1)^{1.25}}{T_1^{0.6506}}\right] \quad \text{(Eq. 7.4.8.4-2)}$$

The relieving temperature $T_1$ is determined from Eq. 7.4.8.4-3 in function of the normal operating temperature and pressure, respectively $T_n$ and $p_{n,}$ and of the relieving pressure

$$T_1 = T_n \frac{P_1}{P_n} \quad \text{(Eq. 7.4.8.4-3)}$$

For plates made of alloys the gas mass flow rate can be calculated from Eq. 7.4.8.4-4

$$W = 0.1406\sqrt{M\ P_1}\left(A'\frac{(T_w - T_1)^{1.25}}{T_1^{1.1506}}\right) \quad \text{(Eq. 7.4.8.4-4)}$$

The derivation of the formulas for unwetted vessels is based on the physical properties of air and ideal gas laws. Furthermore, they assume that the vessel is non-insulated and without its own mass, that the vessel wall temperature will not reach rupture under stress and that the fluid temperature does not change. All these assumptions should be checked if they are appropriate for the particular situation.

### 7.4.8.5 Consideration of Accumulated Pressure in Fire and Non-Fire Contingencies

The requirements on the accumulated pressure in API RP 520, sec. 3.5.2, page 39-40 propose different treatments for the cases of fire and non-fire contingencies.

In non-fire contingencies the accumulated pressure shall be limited to 110% of the maximum allowable working pressure (MAWP) in vessels that are protected by only one safety valve. If the MAWP lies between 15 and 30 psig, the allowable accumulation is fixed to 3 psi.
In vessels which are protected by more valves in non-fire contingencies, the accumulated pressure shall be limited to 116% of the maximum allowable working pressure (MAWP) or to 4 psi, if the MAWP lies between 15 and 30 psig. Typically the first safety valve is set at 100% of the MAWP and it is smaller than all other ones so to minimize the product loss. The additional valve is larger and it is sized in order to ensure the protection against the maximum required mass flow.

In fire contingencies the accumulated pressure shall be below 121% (= 10% above 110%) of the maximum allowable working pressure (MAWP), independently if the vessels are protected by one or more safety valves. Safety valves sized for the fire case may be also used in non-fire situations, provided that they satisfy the constrain on the accumulated pressure of 110% (one valve) and 116% (= 10% above 105%) (more valves) respectively.

Following the strategy of Table 7.4.8.5-1, which is extracted from the table on Page 39 in API RP 520, a safe sizing with a minimum product loss is possible. The supplemental valves are installed in case of an additional hazard, like fire case or other sources of external heat. Supplemental valves are in addition to devices for non-fire contingency.

| | Single valve installation | | Multiple valve installation | |
|---|---|---|---|---|
| Contingency | Max. set pressure [%] | Max. accumulated pressure [%] | Max. set pressure [%] | Max. accumulated pressure [%] |
| **Non-fire contingency** | | | | |
| First valve | 100 | 110 | 100 | 116 |
| Additional valves | - | - | 105 | 116 |
| **Fire contingency** | | | | |
| First valve | 100 | 121 | 100 | 121 |
| Additional valves | - | - | 105 | 121 |
| Supplemental valve | - | - | 110 | 121 |

*Table 7.4.8.5-1 Set pressure and accumulated pressure limits for safety valves*

## 7.4.10 Examples

### 7.4.10.1 Gases and Vapors - Critical Flow (1)

**Example 7.4.10.1**. It is required to size a conventional valve without rupture disc for a vessel filled with ethylene ($C_2H_4$) at the relieving temperature of 55°C (590.7 °R) and a set pressure of 55 bar g (797.7 psig). The mass flow rate and the back pressure are respectively 4200 kg/h (9259 $lb_m$/hr) and 10 bar g (145 psig). The safety valve shall be from the LESER API Series 526.

*Solution*. The relieving pressure is calculated from Eq. 7.4.2-1 and it values

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 797.7 \ psig + 79.8 \ psig + 14.7 \ psi = 892.2 \ psi$$

From the Example 7.2.6.1 the calculated compressibility factor $Z$ is 0.712. The isentropic exponent $k$ and the molecular weight $M$ are given from the customer as 1.19 and 28.03 lb/$lb_{mol}$ respectively. The back pressure coefficient can be calculated from Fig. 7.4.3-1, by expressing the set pressure and the back pressure in psig

$$\frac{p_b}{p_s} = \frac{10 \ bar \ g}{55 \ bar \ g} = \frac{145 \ psig}{797.7 \ psig} = 0.182$$

and it results that no correction for the back pressure is necessary ( $K_b = 1.0$ ).

The value of the coefficient C is obtained from Eq. 7.4.3-3

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} = 520\sqrt{1.19\left(\frac{2}{1.19+1}\right)^{\frac{1.19+1}{1.19-1}}} = 336.22\frac{\sqrt{lb \cdot lb_{mol} \cdot {}^\circ R}}{lb_f \cdot hr}$$

The critical pressure ratio can be calculated from Eq. 7.2.3-2

$$\left.\frac{p}{P_1}\right]_{critical-flow} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = \left(\frac{2}{1.19+1}\right)^{\frac{1.19}{1.19-1}} = 0.5664$$

The absolute pressure ratio for this sizing problem is

$$\frac{p_b}{P_1} = \frac{145\,psig + 14.7\,psi}{892.2\,psi} = 0.178$$

which is much lower than the critical pressure ratio and therefore the flow is critical. The minimum required effective discharge area can be calculated from Eq. 7.4.4-1 with $K_d = 0.975$

$$A = \frac{W}{C\,K_b K_c K_d P_1}\sqrt{\frac{T\,Z}{M}} = \frac{9259}{336.22 \cdot 1 \cdot 1 \cdot \underline{0.975} \cdot 892.2}\sqrt{\frac{590.7 \cdot 0.712}{28.03}} in^2 = 0.122 \ in^2$$

From Table 7.2.1-2 the discharge area of the effective orifice E ( $A = 0.196 \ in^2 > 0.122 \ in^2$ ) exceeds the minimum requirement. It must be now proven that the actual discharge area of the E orifice ( $K_d = 0.801$ ; $A = 0.239 \ in^2$ ) meets or exceeds the minimum required actual relief area.

$$A = \frac{W}{C\,K_b K_c K_d P_1}\sqrt{\frac{T\,Z}{M}} = \frac{9259}{336.22 \cdot 1 \cdot 1 \cdot 0.801 \cdot 892.2}\sqrt{\frac{590.7 \cdot 0.712}{28.03}} in^2 = 0.149 \ in^2$$

The discharge area of the actual Orifice E is larger than that the required minimum relief area and therefore it suffices the sizing. From the Selection Chart on Page 01/20 of the Catalog LESER Series API the required flange ratings are 600 for the inlet and 150 for the outlet. The safety valve size would be then **LESER Type 526 1E2 (5262.0172)**.

7.4.10.2 Gases and Vapors - Critical Flow (2)

**Example 7.4.10.2**. A safety valve is required for a vessel containing natural gas (= methane, $M = 16.04 \ lb/lb_{mol}$) venting to the ambience. The required mass flow is 22600 lb/hr. The relieving temperature is 650°R and the design pressure (= set pressure) of the vessel is 80 psig.

*Solution*. The relieving pressure for an overpressure of 10 % values

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 80 \ psig + 8 \ psig + 14.7 \ psi = 102.7 \ psi$$

The critical temperature and pressure of methane are extracted from Table 7 on Page 43 of API RP 520. They are 673 psi and -116°F ( = 343°R). The relative temperature and pressure are therefore

$$T_R = \frac{T}{T_c} = \frac{650°R}{343°R} = 1.895 \qquad p_R = \frac{P_1}{p_c} = \frac{102.7 \ psi}{673 \ psi} = 0.152$$

The compressibility factor $Z$ from Fig. 7.9.1-1 for the calculated relative temperature and pressure is about 0.98 (NIST WebBook : 0.993). The isentropic exponent $k$ from the NIST Chemistry WebBook is almost 1.286.
The back pressure coefficient can be extracted from Fig. 7.4.3-1 in terms of ratio between the set pressure and the back pressure, both in psig

$$\frac{p_b}{p_s} = \frac{14.7 \ psig}{80 \ psig} = 0.1837$$

and here as well no correction for the back pressure is necessary ($K_b = 1.0$).
The value of the coefficient C is obtained from Eq. 7.4.3-3

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} = 520\sqrt{1.286\left(\frac{2}{1.286+1}\right)^{\frac{1.286+1}{1.286-1}}} = 345.65 \ \frac{\sqrt{lb \cdot lb_{mol} \cdot °R}}{lb_f \cdot hr}$$

The critical pressure ratio can be calculated from Eq. 7.3.2-2

$$\left.\frac{p}{P_1}\right]_{critical-flow} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = \left(\frac{2}{1.286+1}\right)^{\frac{1.286}{1.286-1}} = 0.548$$

The absolute pressure ratio is much lower than the critical pressure ratio and therefore the flow is critical. The minimum required <u>effective discharge area</u> from Eq. 7.4.4-1 is

$$A = \frac{W}{C\ K_b K_c K_d P_1}\sqrt{\frac{T\,Z}{M}} = \frac{22600}{345.65 \cdot 1 \cdot 1 \cdot \underline{0.975} \cdot 102.7}\sqrt{\frac{650 \cdot 0.993}{16.04}} in^2 = 4.14 \ in^2$$

From Table 7.4.1-2 the effective discharge area of the orifice N exceeds the minimum requirement. It remains to prove that the <u>actual discharge area</u> of the N orifice ( $K_d = 0.801 \ ; \ A = 5.30 \ in^2$ ) exceeds the minimum requirement.

$$A = \frac{W}{C\ K_b K_c K_d P_1}\sqrt{\frac{T\,Z}{M}} = \frac{22600}{345.65 \cdot 1 \cdot 1 \cdot \underline{0.801} \cdot 102.7}\sqrt{\frac{650 \cdot 0.993}{16.04}} in^2 = 5.06 \ in^2 \rightarrow \text{OK}$$

and therefore the actual orifice N will be selected. From the Selection Chart on Page 01/20 of the LESER Catalog API Series the required flange levels are 150 for both the inlet and the outlet and therefore the safety valve **<u>LESER Type 526 4N6 (5262.5902)</u>** suits the requirements**.**

7.4.10.3 Gases and Vapors - Subcritical Flow

**Example 7.4.10.3**. Same case as Example 7.4.10.2. but with a set pressure of 20 psig (20+3+14.7 =37.7 psi), back pressure 10 psig (24.7 psi) and $Z = 1$.

*Solution*. The critical pressure ratio is again that of the Example 7.4.10.2.

$$\left.\frac{p}{P_1}\right]_{critical-flow} = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = \left(\frac{2}{1.286+1}\right)^{\frac{1.286}{1.286-1}} = 0.548$$

However, this time the ratio of the absolute back pressure on the relieving pressure, which is

$$r = \frac{P_2}{P_1} = \frac{24.7\ psi}{37.7\ psi} = 0.6552$$

is larger than the critical pressure ratio and therefore the flow is subcritical. The parameter $F_2$ from Eq. 7.4.4-3 is equal to

$$F_2 = \sqrt{\frac{k}{k-1} \cdot r^{2/k} \cdot \frac{1-r^{1-1/k}}{1-r}} = \sqrt{\frac{1.286}{1.286-1} \cdot 0.6552^{2/1.286} \cdot \frac{1-0.6552^{1-1/1.286}}{1-0.6552}} = 0.779$$

The minimum required effective discharge area from Eq. 7.4.4-2 is

$$A = \frac{1}{735}\frac{W}{F_2 K_c K_d P_1}\sqrt{\frac{TZ}{M}\frac{1}{1-r}} = \frac{1}{735}\frac{22600}{0.779 \cdot 1 \cdot 0.975 \cdot 37.7}\sqrt{\frac{650 \cdot 1}{16.04} \cdot \frac{1}{1-0.6552}} = 11.73\ in^2$$

The effective discharge area is then an R orifice. It must now be verified that the actual discharge area of a R orifice of LESER Type 526 ( $K_d = 0.801; A = 19.48\ in^2$ ) is large enough, which is when it exceeds the minimum actual required area of

$$A = \frac{1}{735}\frac{W}{F_2 K_c K_d P_1}\sqrt{\frac{TZ}{M}\frac{1}{1-r}} = \frac{1}{735}\frac{22600}{0.779 \cdot 1 \cdot 0.801 \cdot 37.7}\sqrt{\frac{650 \cdot 1}{16.04} \cdot \frac{1}{1-0.673}} = 14.28\ in^2 \rightarrow \text{OK}$$

The final choice of the safety valve is therefore **LESER Type 526 6R8 (5262.6652)**.

7.4.10.4 Steam

**Example 7.4.10.4**. A safety valve must be sized for a large vessel containing saturated steam ($K_{SH} = 1$) at a set pressure of 1600 psig (10% accumulation). The expected mass flow rate is of 154000 lb/hr.

*Solution*: A conventional safety valve ($K_b = 1$) without additional rupture disk ($K_c = 1$) is chosen.

The relieving pressure is

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 1600\ psig + 160\ psig + 14.7\ psi = 1774.7\ psi$$

The correction factor for Napier equation $K_N$ is calculated from Eq. 7.4.5-2

$$K_N = \frac{0.1906 \cdot P_1 - 1000}{0.2292 \cdot P_1 - 1061} = \frac{0.1906 \cdot 1774.7 - 1000}{0.2292 \cdot 1774.7 - 1061} = 1.0115$$

The minimum required effective discharge area is calculated from Eq. 7.4.5-1

$$A = \frac{1}{51.5} \cdot \frac{W}{P_1 K_b K_c K_d K_N K_{SH}} = \frac{1}{51.5} \cdot \frac{154000}{1774.4 \cdot 1 \cdot 1 \cdot 0.975 \cdot 1.0115 \cdot 1} = 1.709\ in^2$$

which is exceeded by selecting an orifice K.

The orifice K of LESER Type 526 ($K_d = 0.801$ ; $A = 2.25\ in^2$ ) is selected for the actual discharge area since it exceeds the minimum requirement of

$$A = \frac{1}{51.5} \cdot \frac{W}{P_1 K_b K_c K_d K_N K_{SH}} = \frac{1}{51.5} \cdot \frac{154000}{1774.4 \cdot 1 \cdot 1 \cdot 0.801 \cdot 1.0115 \cdot 1} = 2.08\ in^2$$

The required flanges are 900 (inlet) and 150 (outlet) according to Page 01/40 of LESER Catalog for the API Series and therefore the safety valve to be purchased is **LESER Type 526 3K6 (5262.2053).**

7.4.10.5 Liquids

**Example 7.4.10.5**. A safety valve must be sized for a flow rate of 5 l/s (79.25 gpm) of glycerin ($G = 1.26$; $\mu = 1410\ cP$). The set pressure is 10 bar-g (145 psig) with 10% accumulation and atmospheric backpressure.

*Solution* The relieving pressure is

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 145\ \ psig + 14.5\ \ psig + 14.7\ \ psi = 174.2\ \ psi$$

The procedure in API RP 520 foresees a preliminary relief area for inviscid service by using Eq. 7.4.6-1 assuming $K_v = 1$. The minimum preliminary effective discharge area is

$$A_{prel} = \frac{1}{38} \cdot \frac{Q}{K_c K_d K_w} \sqrt{\frac{G}{P_1 - P_2}} = \frac{1}{38} \cdot \frac{79.25}{1 \cdot 0.65 \cdot 1} \sqrt{\frac{1.26}{159.5}} = 0.285\ \ in^2$$

which would lead to an F orifice ($A = 0.307\ \ in^2$) as effective discharge area for the inviscid fluid.

Now the viscosity of the fluid has to be considered. The assumption of the API RP 520 is that the effective relief area for the inviscid flow may also suit the sizing of the viscous flow. Therefore the user must calculate the Reynolds number on the base of Eq. 7.4.6-3 on that orifice area.

$$\mathrm{Re} = 2800 \frac{Q\ G}{\mu\ \sqrt{A}} = 2800 \frac{79.25 \cdot 1.26}{1410\ \sqrt{0.307}} = 357.9$$

and on the base of this Reynolds number the viscosity correction factor from Eq. 7.4.6-2

$$K_v = \left( 0.9935 + \frac{2.878}{\mathrm{Re}^{0.5}} + \frac{342.75}{\mathrm{Re}^{1.5}} \right)^{-1} = \left( 0.9935 + \frac{2.878}{357.9^{0.5}} + \frac{342.75}{357.9^{1.5}} \right)^{-1} = 0.8359$$

The corrected (effective minimum) discharge area for the viscous liquid is then

$$A_{corr} = \frac{1}{38} \cdot \frac{Q}{K_c K_d K_v K_w} \sqrt{\frac{G}{P_1 - P_2}} = \frac{1}{38} \cdot \frac{79.25}{1 \cdot 0.65 \cdot 1 \cdot 0.8359} \sqrt{\frac{1.26}{159.5}} = 0.3413\ \ in^2$$

Since the effective minimum corrected discharge area exceeds the foreseen orifice, the above procedure for viscous flows must be repeated with the larger orifice G ($A = 0.503\ \ in^2$). For sake of brevity the Reynolds number, viscosity correction factor and corrected minimum discharge area are given here below

$$\mathrm{Re} = 279.6 \qquad K_v = 0.807 \qquad A_{corr} = 0.353\ \ in^2$$

Since the corrected minimum discharge area is smaller than the G orifice, the selected orifice size is sufficient. A quick verification that the actual G orifice of LESER Type 441 ($K_d = 0.579$; $A = 0.616\ \ in^2$) suffices is given as following.

$$A_{prel} = 0.320\ \ in^2 \qquad \mathrm{Re} = 252.65 \qquad K_v = 0.794 \qquad A_{corr} = 0.403\ \ in^2$$

The required valve, incl. the flanges, is **LESER Type 526 1½G3 (5262.0452)**.

7.4.10.6 Two-Phase Flow - Saturated Liquid and its Saturated Vapor

**Example 7.4.10.6**. A safety valve must be sized for a two-phase flow of saturated water at 10 bar g (145 psig). The mass flow rate to be delivered is 125 000 kg/h (275 600 lb/hr).

*Solution*. The relieving pressure is
$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 145\ \ psig + 14.5\ \ psig + 14.7\ \ psi = 174.2\ \ psi$

The saturation temperature ($T_{sat} = 830°R$) is the temperature at the inlet of the safety valve. At that temperature the physical properties for saturated water and steam are

| | Metric units | US units |
|---|---|---|
| $v_{v0}$ | 0.1632 m³/kg | 2.6142 ft³/lb |
| $v_{l0}$ | 0.0011386 m³/kg | 0.01824 ft³/lb |
| $h_{vl0}$ | 1984.3 kJ/kg | 853.667 Btu/lb |
| $C_p$ | 4.440 KJ/(kg K) | 1.06116 Btu/(lb°R) |

The Omega Parameter for the case of saturated liquid at inlet ($x_0 = 0$) is calculated from Eq. 7.4.7.1-1

$$\omega = \frac{x_0 v_{v0}}{v_0} \cdot \left(1 - 0.37 \frac{P_1 \cdot v_{vl0}}{h_{vl0}}\right) + 0.185 \frac{C_p T_0 P_1}{v_0}\left(\frac{v_{vl0}}{h_{vl0}}\right)^2 = 0 + 0.185 \frac{1.0605 \cdot 830 \cdot 174.2}{0.01824}\left(\frac{2.6142 - 0.01824}{8536.66}\right)^2$$

$$\omega = 14.39$$

The critical pressure ratio is the solution of Eq. 7.4.7.1-4, calculated by means of an iterative trial and error procedure. For $\omega > 2$ a good approximation[9] is given by the following explicit solution
$\eta_c = 0.55 + 0.217 \ln \omega - 0.046 \ln^2(\omega) + 0.004 \ln^3(\omega) = 0.877$

Which leads to the (fluid dynamical) critical pressure ratio of
$P_c = 174.2\,psi \cdot 0.877 = 152.84\,psi$

The flow is critical, since $P_c > P_a$ and therefore the mass flux is given by Eq. 7.4.7.1-5

$$G = 68.09 \cdot \eta_c \cdot \sqrt{\frac{1}{\omega}\frac{P_1}{v_0}} = 68.09 \cdot 0.877 \cdot \sqrt{\frac{1}{14.39} \cdot \frac{174.2}{0.01824}} = 1539.06\ \ \frac{lb}{s \cdot ft^2}$$

The minimum required effective orifice area is calculated from Eq. 7.4.7.1-7

$$A = 0.04 \cdot \frac{1}{K_b K_c K_d} \cdot \frac{W}{G} = 0.04 \cdot \frac{1}{1 \cdot 1 \cdot 0.85} \cdot \frac{275600}{1539.06} = 8.427\ \ in^2$$

which leads to the selection of an orifice **6Q8** ($A = 11.050\ \ in^2$) **(5262.6572)**.

[9] J.C. Leung *Venting of runaway reactions with gas generation,* **AIChE J.**, 1992, 38, 5, 723-732

7.4.10.7 Two-Phase Flow - Highly Subcooled Liquid and a Gas.

**Example 7.4.10.7.** A safety valve must be sized for a mixture of air and water ( $x_0 = 0.10$ ) at 10 bar g (145 psig) and 25°C (536.67°R) for the mass flow rate of 125 000 kg/h (275 600 lb/hr).

*Solution*. The relieving pressure is again 174.2 psi. The required fluid properties at the relieving conditions (174.2 psi ; 536.67°R) are

| | Metric units | US units |
|---|---|---|
| $v_{v0}$ | 0.0698 m³/kg | 1.1184 ft³/lb |
| $v_{l0}$ | 0.0010029 m³/kg | 0.016065 ft³/lb |
| $v_0$ | 1984.3 kJ/kg | 853.667 Btu/lb |
| $k$ | 1.4 | 1.4 |

The specific volume of the mixture is given as

$$v_0 = x_0 v_{v0} + (1 - x_0) v_{l0} = 0.1 \cdot 1.1184 + 0.9 \cdot 0.016065 = 0.1263 \quad ft^3/lb$$

The Omega Parameter is calculated from Eq. 7.4.7.2-1

$$\omega = \frac{x_0 v_{vg0}}{v_0 k} = \frac{0.1 \cdot 1.1184}{0.1263 \cdot 1.4} = 0.6325$$

The iterative solution of Eq. 7.4.7.1-4 with this value of the Omega-parameter gives a critical pressure ratio of $\eta_c = 0.5464$, which corresponds to a critical pressure of $P_c = 95.24 \quad psi$

The flow is again critical and the mass flow rate can be calculated again from Eq. 7.4.7.1-5

$$G = 68.09 \cdot \eta_c \cdot \sqrt{\frac{1}{\omega} \frac{P_1}{v_0}} = 68.09 \cdot 0.5464 \cdot \sqrt{\frac{1}{0.6325} \cdot \frac{174.2}{0.1263}} = 1737.4 \quad \frac{lb}{s \cdot ft^2}$$

The minimum required effective orifice area is calculated from Eq. 7.4.7.1-7

$$A = 0.04 \cdot \frac{1}{K_b K_c K_d} \cdot \frac{W}{G} = 0.04 \cdot \frac{1}{1 \cdot 1 \cdot 0.85} \cdot \frac{275600}{1737.4} = 7.46 \quad in^2$$

which leads again to the selection of an orifice **6Q8** ( $A = 11.050 \quad in^2$ ) **(5262.6572)**.

7.4.10.8 Two-Phase Flow - Subcooled Liquid

**Example 7.4.10.8**. It is required to size a safety valve for a heating oil at a set pressure of 12 bar g (174.0 psig) and 400°C (1211.7 R) with a flow rate of 12.5 m³/h (55.03 gpm). The back pressure is 2 bar.

*Solution*. The relieving pressure is

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 174.0 \ \ psig + 17.4 \ \ psig + 14.7 \ \ psi = 206.1 \ \ psi$$

The saturation pressure at 400°C , $P_s$, is 10.89 kPa (158 psi) and therefore the medium enters the safety valve subcooled ($P_1 > P_s$). The (thermodynamic) critical point is 500°C (1391.7°R) and 33.1 bar (480 psi).
The physical properties of the mixture at saturated conditions and the liquid properties at inlet condition for the calculation of the Omega-parameter are given in the table here below.

| | Metric units | US units |
|---|---|---|
| $v_{vls}$ | 0.02388 m³/kg | 0.38182 ft³/lb |
| $h_{vls}$ | 206.2 kJ/kg | 88.7 Btu/lb |
| $\rho_{l0}$ | 687 kg/m³ | 42.888 lb/ft³ |
| $C_p$ | 2650 J/(kg K) | 0.633 Btu/(lb R) |

The value of the Omega Parameter is calculated by means of Eq. 7.4.7.3-1, since $T_r = 0.87 < 0.9$ and $P_r = 0.43 < 0.5$.

$$\omega_s = 0.185 \rho_{l0} C_p T_0 P_s \left( \frac{v_{vls}}{h_{vls}} \right)^2 = 0.185 \cdot 42.888 \cdot 0.633 \cdot 1211.7 \cdot 158 \cdot \left( \frac{0.38182}{88.7} \right)^2 = 17.82$$

Determination of the extension of the subcooling region

$$P_1 \frac{2 \cdot \omega_s}{1 + 2 \cdot \omega_s} = 206.1 \cdot \frac{2 \cdot 17.82}{1 + 2 \cdot 17.82} = 200.5 \ \ psi$$ → high subcooling region!!!

This highly subcooled flow is critical since $P_s > P_a$ and therefore the critical mass flux is

$$G = 96.3 \left[ \rho_{l0} \cdot (P_1 - P_s) \right]^{0.5} = 96.3 \left[ 42.888 \cdot (206.1 - 158) \right]^{0.5} = 4373.88 \ \ lb/\left( ft^2 s \right)$$

The minimum required effective area of the safety valve from Eq. 7.4.7.3-3 is

$$A = 0.3208 \frac{1}{K_b K_c K_d} \frac{Q \cdot \rho_{l0}}{G} = 0.3208 \frac{1}{1 \cdot 1 \cdot 0.65} \frac{55.03 \cdot 42.888}{4373.88} = 0.2668 \ in^2$$

which is satisfied by choosing the orifice **1½F2** ($A = 0.307 \ \ in^2$) **(5262.0302)** as the minimum effective area.

7.4.10.9 Hydraulic (Thermal) Expansion acc. to API 521

**Example 7.4.10.9**. The vessel containing the heating oil of the previous example is exposed to sun light. Calculate the mass flow rate that would occur in case of thermal radiation and size the safety valve for the same relieving and back pressure, assuming a maximum heat transfer rate of 55.2 kJ/hr (58.24 BTU/hr).

*Solution:* The specific gravity of the heating oil at relieving conditions is $G = 687/999.1 = 0.6876$.
The gravity of the liquid in API for oils is calculated on the base of the well known formula

$$°API = \frac{141.5}{G} - 131.5 = \frac{141.5}{0.6876} - 131.5 = 74.28$$

which corresponds to a value of the cubical expansion coefficient B of approx. 0.0007.
The mass flow rate to be released according to Eq. 7.4.8.2-1 is

$$Q_{gpm} = \frac{1}{500}\frac{B \cdot H}{G \cdot C} = \frac{1}{500} \cdot \frac{0.0007 \cdot 58.24}{0.6876 \cdot 0.633} = 0.000187 \ \ gpm$$ (0.56 kg/hr)

The minimum effective safety valve flow area can be calculated as shown in the previous example. However, for such a small flow rate the smallest safety valve, orifice **1D2 (5262.0012)**, is by far enough.

7.4.10.10 External Fire acc. to API 521 - Unwetted Walls

**Example 7.4.10.10**. A carbon steel vessel ($T_w = 1560°R$) is filled with air at a set pressure of 100 psig. The exposed surface area A' is 250 ft². The normal temperature and pressure are 125°F (584.7°R) and 80 psig (94.7 psi).

*Solution*:The relieving pressure according to Paragraph 7.4.8.4 is

$$P_1 = P_{set} + \Delta P_{overpressure} + P_{atm} = 100 \ \ psig + 21 \ \ psig + 14.7 \ \ psi = 135.7 \ \ psi$$

On the base of Eq. 7.4.8.4-3 the relieving temperature is

$$T_1 = T_n \frac{P_1}{P_n} = 584.7°R \cdot \frac{135.7\,psi}{94.7\,psi} = 837.84°R$$

The specific heat ratio at relieving conditions according to the NIST WebBook Database is almost $k \cong 1.4$ ($k = 1.392$). With this isentropic coefficient the value of the parameter C is calculated with Eq. 7.4.3-3

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} = 520\sqrt{1.4\left(\frac{2}{1.4+1}\right)^{\frac{1.4+1}{1.4-1}}} = 356.06\frac{\sqrt{lb_m lb_{mol}°R}}{lb_f hr}$$

The parameter F' is determined from Eq. 7.4.8.4-2

$$F' = \frac{0.1406}{C \cdot K_d}\left[\frac{(T_w - T_1)^{1.25}}{T_1^{0.6506}}\right] = \frac{0.1406}{356.06 \cdot 0.975}\left[\frac{(1560 - 837.84)^{1.25}}{837.84^{0.6506}}\right] = 0.019$$

Finally, the minimum effective relief area for the safety valve acc. to Eq. 7.2.8.4-1 is

$$A = \frac{F'A'}{\sqrt{P_1}} = \frac{0.019 \cdot 250}{\sqrt{135.7}} = 0.40 \ \ in^2$$

which is satisfied by an effective orifice **$1^1{}_2$G3 (5262.0452)**.

7.4.10.11 External Fire acc. to API 521 - Wetted Walls

**Example 7.4.10.11.** A vertical vessel with spherical ends at a set pressure of 200 psig contains benzene at 100°F (559.7°R). The vessel has a diameter of 15 ft, a length of 40 ft and an elevation of 15 ft. The maximum fluid level is 12 ft. Assume that the fire-fighting measures intervene promptly in the eventuality of fire and that adequate drainage is present.

*Solution* The amplitude of the wetted walls, heated by the flames, must be estimated to calculate the input thermal flow to the liquid. The free surface of benzene is 32 ft over the ground. Assuming that the fire level is at the ground, the height of the wetted walls, heated by the flames, is acc. to Eq. 7.4.8.3-5 equal to

$F_{eff} = \min(32\ ;\ 25) - 15 = 10\ \ ft$.

And the size of the wetted area from Table 7.4.8.3-3 is

$A_{wet} = \pi \cdot D \cdot F_{eff} = \pi \cdot 15 \cdot 10\ \ ft^2 = 471.23\ \ ft^2$

The thermal heat flow is calculated from Eq. 7.4.8.3-1, assuming the worst case of bare vessel (with *F=1* from Table 7.4.8.3-2)

$Q = 21000\ \ F\ A_{wet}^{0.82} = 21000 \cdot 1 \cdot 471.23^{0.82}$ Btu/hr = 3 267 911 Btu/hr

The relieving pressure $P_1$ in the vessel is equal to 256.7 psi (= 200*1.21+14.7 psi). From NIST WebBook Database the latent heat of vaporization of benzene at 256 psi ($T_{vap} = T_1 = 875.5°R$) is about 114.9 Btu/$lb_m$. The discharged mass flow of vapor is calculated from Eq. 7.4.8.3-6

$W = Q / h_{vl0} = 3\ 267\ 911 / 114.9 \cong 28441.4$ Btu/$lb_m$.

The parameter C at relieving conditions is calculated from Eq. 7.4.3-3 with the specific heat ratio at relieving conditions of $k \cong 1.23$ taken from the NIST WebBook Database.

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} = 520\sqrt{1.23\left(\frac{2}{1.23+1}\right)^{\frac{1.23+1}{1.23-1}}} = 340.23\frac{\sqrt{lb_m lb_{mol}\,°R}}{lb_f hr}$$

The required effective flow area is given by Eq. 7.4.3-1 for critical vapor flow assuming ideal gas behavior.

$$A = \frac{W}{C\ K_b K_c K_d P_1}\sqrt{\frac{T\,Z}{M}} = \frac{28\ 441.4}{340.23 \cdot 1 \cdot 1 \cdot 0.975 \cdot 256.7}\sqrt{\frac{875.5 \cdot 1}{78.11}} = 1.118\ \ in^2$$

For this requirement the orifice **3J4 (5262.1622)** would be large enough.

### 7.4.9 Lift Restriction according to Code Case 1945-4

Code Case 1945-4 of the ASME Boiler and Pressure Vessel Code provides the guidelines for restricting the lift of a safety valve to achieve a reduced relieving capacity. Safety valves of NPS ¾" or larger can be lift restricted to not less than 30% of the full rated lift, nor less than 0.08 inch / 2.0 mm.

A lift restriction according Code Case 1945-4 requires a certification by an ASME designated organization, which LESER currently does not have.

As LESER API safety valves have double certification by ASME VIII and PED / ISO 4126 , LESER can supply API 526 series with a lift restriction according to PED / ISO 4126. In this case the API valve will not carry an UV-stamp. For details please refer to section 7.5.8 and 7.6.5.