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Refrigerating systems and heat pumps — Pressure relief devices and their associated piping — Methods for calculation

Systèmes de réfrigération et pompes à chaleur — Dispositifs de limitation de pression et tuyauteries associées — Méthodes de calcul

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Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 1, *Safety and environmental requirements for refrigerating systems*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 182, *Refrigerating systems, safety and environmental requirements,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is based on EN 13136:2013+A1:2018 and applicable parts of ISO 4126-1:2013, ISO 4126-2:2018 and ISO 21922:2021.

It is suited to the specific requirements, and includes the data, of refrigerating systems. It provides means of satisfying the pressure relief devices requirements of EN 378-2:2016 and ISO 5149-2:2014.

Refrigerating systems and heat pumps — Pressure relief devices and their associated piping — Methods for calculation

1 Scope

This document describes the calculation of:

— mass flow for sizing pressure relief devices for parts of refrigerating systems;

— discharge capacities for pressure relief valves and other pressure relief devices in refrigerating systems including the necessary data for sizing these when relieving to atmosphere or to part of the refrigerating system at lower pressure;

— the pressure loss in the inlet and outlet lines of pressure relief valves and other pressure relief devices and includes the necessary data.

This document specifies the requirements for selection of pressure relief devices to prevent excessive pressure due to internal and external heat sources, the sources of increasing pressure (e.g. compressor, heaters, etc.) and thermal expansion of trapped liquid.

NOTE The term "refrigerating system" used in this document includes heat pumps.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4126-1:2013/Amd 1:2016, *Safety devices for protection against excessive pressure — Part 1: Safety valves*

ISO 4126-2:2018, *Safety devices for protection against excessive pressure — Part 2: Bursting disc safety devices*

ISO 21922:2021, *Refrigerating systems and heat pumps — Valves — Requirements, testing and marking*

EN 13501-1:2018, *Fire classification of construction products and building elements — Part 1: Classification using data from reaction to fire tests*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 21922:2021, ISO 4126-1:2013/Amd 1:2016, and ISO 4126-2:2018 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
refrigerant
fluid used for heat transfer in a refrigerating system

Note 1 to entry: A refrigerant absorbs heat at a low temperature and a low pressure of the fluid and rejects it at a higher temperature and a higher pressure of the fluid, usually involving changes of the phase of the fluid.

[SOURCE: ISO 817:2024, 3.1.37]

3.2
part of the refrigerating system
several components assembled together and exposed to the same pressure in operation or pressure source, respectively, as determined by the manufacturer

3.3
pressure relief device
pressure relief valve or bursting disc device designed to relieve excessive pressure automatically

3.4
pressure relief valve
pressure actuated valve held shut by a spring or other means and designed to relieve excessive pressure automatically by starting to open at a set pressure and re-closing after the pressure has fallen below the set pressure

Note 1 to entry: For the purposes of this document, the definition of a safety valve as given in ISO 4126-1:2013 is regarded equivalent to a pressure relief valve.

3.5
pressure vessel
any refrigerant-containing component of a refrigerating system other than:

— coils (including their headers) consisting of pipes with air as secondary fluid;

— piping and its valves, joints and fittings;

— control devices;

— pressure switches, gauges, liquid indicators;

— safety valves, fusible plugs, bursting discs;

— equipment comprising casings or machinery where the dimensioning, choice of material and manufacturing rules are based primarily on requirements for sufficient strength, rigidity and stability to meet the static and dynamic operational effects or other operational characteristics and for which pressure is not a significant design factor. Such equipment may include: pumps and compressors.

Note 1 to entry: The semi-hermetic and open type compressors used in refrigerating systems may be subject to the exclusion article 1.2.j of the EU Directive 2014/68/EU by referring to the working party group guidelines WPG A-11, A-12 and B-34. The compressor manufacturer has to decide on the basis of a case by case assessment, if the exclusion article 1.2.j of the EU Directive 2014/68/EU is applicable.

Note 2 to entry: This definition is aligned to EU Directive 2014/68/EU.

3.6
nominal size
DN
alphanumeric designation of size for components of a pipework system, which is used for reference purposes comprising the letters *DN* followed by a dimensionless whole number which is indirectly related to the physical size, in millimetres, of the bore or outside diameter of the end connections

Note 1 to entry: The number following the letters *DN* does not represent a measurable value and should not be used for calculation purposes except where specified in this document.

Note 2 to entry: Where the nominal size is not specified, for the purpose of this document it is assumed to be the internal diameter of the pipe or component in mm (*DN*/*ID*).

Note 3 to entry: Nominal size is not the same as port size which is commonly used for the size of the valve seat opening.

[SOURCE: ISO 6708:1995, 2.1, modified — Note 2 and 3 to entry added.]

4 Symbols

Symbol	Designation	Unit
A_{actual}	Actual flow area of the pressure relief device. The flow area at the most narrow cross section when the pressure relief device is fully open	mm^2
$A_{\text{effective}}$	Effective area of the pressure relief device	mm^2
A_{liq}	Calculated flow area of liquid after expansion	mm^2
A_{R}	Inside area of tube	mm^2
A_{surf}	External surface area of the vessel	m^2
A_{vap}	Calculated flow area of vapour after expansion	mm^2
DN	Nominal size	–
d	Actual most narrow flow diameter of the pressure relief device	mm
d_{R}	Inside diameter of tube	mm
f	Darcy friction factor	-
Δh_{vap}	Heat of vaporisation	kJ/kg
K_{cap}	Capacity correction factor	–
K_{d}	Certified coefficient of discharge considering the backpressure ratio p_{b}/p_0 and the possible reduced stroke of the pressure relief valve	–
K_{dr}	De-rated coefficient of discharge	–
K_{drl}	De-rated coefficient of discharge for liquid	–
K_{vs}	Valve constant (the rate of water flow for a pressure loss of 1 bar at the rated full opening)	m^3/h
K_{visc}	Viscosity correction factor	–
K_{volume}	Trapped liquid factor	mm^2/l
L	Length of pipe	mm
m	mass	kg
n	Rotational frequency	min^{-1}
p_{atm}	Atmospheric pressure (1,013 25 bar)	bar
p_{b}	Back pressure at outlet of pressure relief device, absolute	bar
p_{c}	Critical absolute pressure	bar
$p_{\text{connection}}$	Pressure in connection point	bar
$p_{\text{r,choked}}$	Choked pressure ratio	–
p_{set}	Set pressure, gauge (the pre-determined pressure at which a pressure relief device under operation starts to open)	bar
Δp	Pressure loss	bar
Δp_{common}	Pressure loss in common outlet line	bar
Δp_{in}	Pressure loss in the inlet line to the pressure relief device	bar
Δp_{out}	Pressure loss in the outlet line from the pressure relief device	bar
p_0	Actual absolute relieving pressure	bar
p_1	Absolute pressure at the inlet to the outlet line of the pressure relief device	bar
Q_{h}	Rate of heat production, internal heat source	kW
$Q_{m,\text{adjusted}}$	Adjusted discharge capacity, of the pressure relief device. Used for pressure drop calculation in piping	kg/h
$Q_{m,\text{common}}$	Mass flow in common outlet line	kg/h
$Q_{m,\text{liq}}$	Flow of liquid after expansion	kg/h
$Q_{m,\text{relief}}$	Calculated refrigerant mass flow rate of the pressure relief device	kg/h
$Q_{m,\text{required}}$	Minimum required discharge capacity, of refrigerant, of the pressure relief device	kg/h
NOTE 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.		

Symbol	Designation	Unit
$Q_{m,\mathrm{vap}}$	Flow of vapour after expansion	kg/h
q_m	Theoretical discharge capacity	kg/h·mm^2
q'_m	Actual discharge capacity determined by tests	kg/h·mm^2
R	Bending radius of bend	mm
Re	Reynolds number	–
s	Thickness of insulation	m
u	Velocity in line	m/s
V	Theoretical displacement (volume)	m^3
v	Specific volume of vapour or liquid	m^3/kg
v_0	Specific volume of vapour in inlet line	m^3/kg
v_1	Specific volume at the inlet to the outlet line of the pressure relief device	m^3/kg
w_0	Actual flow speed of liquid in the smallest section of pressure relief valve	m/s
w_1	Speed at the inlet into the outlet line	m/s
x	Vapour fraction of refrigerant at p_b	–
α	Flush connection angle	°
γ	Heat capacity ratio	–
ε_R	Pipe roughness	mm
ζ	Pressure loss coefficient	–
ζ_DN	Pressure loss coefficient related to *DN*	–
ζ_fittings	Pressure loss coefficient of fittings	–
ζ_pipes	Pressure loss coefficient of pipes in outlet line	–
ζ_total	Total pressure loss coefficient in outlet line	–
η_v	Volumetric efficiency estimated at suction pressure and discharge pressure equivalent to the pressure relief device setting	–
ν	Kinematic viscosity	m^2/s
ρ	Density of vapour or liquid	kg/m^3
ρ_0	Density of vapour in inlet line	kg/m^3
ρ_{10}	Vapour density at refrigerant saturation pressure/dew point at 10 °C	kg/m^3
ϕ	Density of heat flow rate	kW/m^2
ϕ_red	Reduced density of heat flow rate	kW/m^2
NOTE 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.		

5 General

This document describes the calculation of:

— The required discharge capacity of a pressure relief device.

— The actual capacity of a pressure relief device.

— Pressure losses in inlet and outlet lines from the pressure relief device.

The capacity of the pressure relief device (calculated in Clause 7), shall be larger than the required capacity (calculated in Clause 6), and the pressure losses (calculated in Clause 8) shall be within given limits for the pressure relief device to operate correctly.

The Formulae in Clause 7 are only valid for discharge of refrigerant gas or vapour.

NOTE 1 Calculations of flow areas for pressure relief devices for non-flashing and flashing liquids are given in Annex B. Example calculations with corresponding piping are given in Annex C.

NOTE 2 Requirements for protection against excessive pressure in refrigerating systems and heat pumps are given in EN 378-2 and ISO 5149-2.

For design and manufacturing of bodies, bonnets and bolts for pressure relief devices (safety valves and bursting discs) and for the specification of strength pressure test, ISO 21922:2021 applies.

For other aspects, the requirements of ISO 4126-1:2013/Amd 1:2016, Clause 5, Clause 7, and Clause 10, and ISO 4126-2:2018, Clause 17, apply.

The actual absolute relieving pressure of a pressure relief device is calculated as:

$$p_0 = 1{,}1 \cdot p_{set} + p_{atm} \quad (1)$$

For calculation of the required discharge capacity of a pressure relief device, knowledge of the heat of vaporisation Δh_{vap} of the refrigerant is required.

For calculation of the actual discharge capacity of a pressure relief device, knowledge of the density ρ_0 (or specific volume v_0) and the heat capacity ratio γ of the refrigerant is required.

For calculation of pressure losses in inlet and outlet lines, knowledge of the density ρ_0 (or specific volume v_0) is required.

The values are found at the following conditions:

a) If the pressure p_0 is less than the critical pressure of the refrigerant:

- If the saturated gas temperature corresponding to p_0 is higher than the critical temperature minus 5 K, then ρ_0, v_0 and Δh_{vap} are found at saturated gas at critical temperature minus 5 K.
- Else ρ_0, v_0 and Δh_{vap} are found at saturated gas at pressure p_0. If the inlet temperature is given (superheated gas), then ρ_0, v_0 and Δh_{vap} are found at pressure p_0 and the inlet temperature.

b) If the pressure p_0 is higher than the critical pressure of the refrigerant, then ρ_0, v_0 and Δh_{vap} are found at saturated gas at critical temperature minus 5 K.

The value of the heat capacity ratio γ shall be found at 25 °C and 1,013 25 bar. Values of γ for different refrigerants can be found in Table A.1.

To check if the velocity in the outlet line is larger than the speed of sound, the density and the speed of sound of the refrigerant at the outlet of the outlet line are needed. The refrigerant properties at the outlet of the outlet line are found assuming isenthalpic expansion from the relieving condition (p_0, v_0) to the pressure at the outlet of the outlet line. If the isenthalpic expansion results in either a mixture of gas and liquid or a mixture of gas and solid, then the density and speed of sound of saturated gas at the pressure at the outlet of the outlet line are used.

6 Minimum required discharge capacity for protection of parts of a refrigerating system

6.1 General

Calculations are based on known or assumed processes, which result in an increase in pressure. All foreseeable processes shall be considered. The commonly relevant processes are covered in 6.2, 6.3 and 6.4.

NOTE Information about necessary protection measures against excessive pressure can be found in system safety standards such as ISO 5149-2 and EN 378-2. For instance due to standstill pressure, pressure to internal or external heat sources, or trapped fluid.

In case of supercritical pressure, the pressure relief valve shall be suitable for both gas and liquid.

In case of relieving CO_2 to a pressure below the triple point (e.g. atmospheric pressure), there is a possibility to create solid CO_2. Necessary precautions shall be taken to ensure safe operation.

Even if a vessel contains only gas, it might in some situations contain liquid and should therefore for the purpose of this document be treated as a vessel containing both liquid and gas.

6.2 Excessive pressure caused by heat sources

6.2.1 External heat sources

The minimum required discharge capacity of the pressure relief device for pressure vessels is calculated as in Formula (2):

$$Q_{m,\text{required}} = \frac{3\,600 \cdot \phi \cdot A_{\text{surf}}}{\Delta h_{\text{vap}}} \quad (2)$$

For pressure vessels in this document, the density of heat flow rate ϕ is assumed to be 10 kW/m^2, but a higher value shall be used if necessary.

When the thickness, s, of the insulation of the pressure vessel is higher than 0,04 m and the insulation is tested for reaction to fire according to EN 13501-1:2018 and classified better than class C, a reduced density of heat flow rate shall be used as a minimum value:

$$\phi_{\text{red}} = \phi \cdot \frac{0{,}04}{s} \quad (3)$$

For pressure vessels the total external surface area of the vessel is calculated depending on geometry.

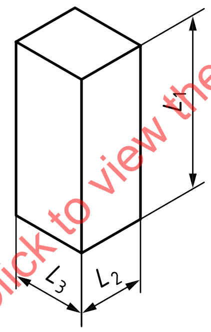


Figure 1 — Plate heat exchanger (PHE)

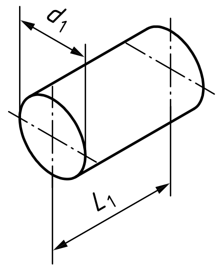


Figure 2 — Plate and shell heat exchanger (PSHE)

For plate heat exchangers (see Figure 1) the surface area is calculated as per Formula (4):

$$A_{surf} = 2 \cdot (L_1 \cdot L_2 + L_2 \cdot L_3 + L_1 \cdot L_3) \qquad (4)$$

For plate and shell heat exchangers (see Figure 2) the surface area is calculated as per Formula (5):

$$A_{surf} = 2 \cdot (\frac{\pi}{4} \cdot d_1{}^2) + (\pi \cdot d_1 \cdot L_1) \qquad (5)$$

Higher values for density of heat flow rate than 10 kW/m^2 may be necessary where, in case of fire, full engulfment of the pressure vessel is to be expected and/or in the case the pressure vessel is insulated with a flammable insulation. Other calculation methods could be necessary in case of heat radiation with a higher heat flow directed to one side of the vessel.

6.2.2 Internal heat sources

For conditions, which arise due to an internal source of excessive heat, the minimum required discharge capacity of the pressure relief device is calculated as per Formula (6):

$$Q_{m,required} = \frac{3\,600 \cdot Q_h}{\Delta h_{vap}} \qquad (6)$$

6.3 Excessive pressure caused by compressors

The minimum required discharge capacity of the pressure relief device for excessive pressure caused by compressors is calculated as:

$$Q_{m,required} = 60 \cdot V \cdot n \cdot \rho \cdot \eta_v \qquad (7)$$

In Formula (7) the saturated gas density value at the highest allowable suction pressure shall be used. The highest allowable suction pressure is defined by the compressor manufacturer.

NOTE 1 In cases where discharge shut-off valves are not fitted, a high-pressure relief device will suffice, providing there are no intermediate shut-off valves.

NOTE 2 Non-positive displacement compressors need not have a pressure relief device providing it is not possible to exceed the maximum allowable pressure.

NOTE 3 Relieving to the low-pressure side can cause compressor overheating and / or uncontrolled internal pressure in compressors (e.g. in screw compressors).

NOTE 4 EN 12693 covers compressors, which can run against a closed discharge valve.

6.4 Excessive pressure caused by expansion of trapped liquid

For protection against pressure caused by expansion of trapped liquid, the effective area of the pressure relief device shall be calculated based on the volume of the trapped liquid:

$$A_{effective} = K_{volume} \cdot V_{trapped} \qquad (8)$$

where K_{volume} is 0,02 mm^2/l and the effective area of the pressure relief device is defined as:

$$A_{effective} = A_{actual} \cdot K_{dr} \qquad (9)$$

If the calculated effective area results in a flow diameter less than 1 mm, then the diameter shall be selected to 1 mm: $d \geq 1$ mm

For refrigerants where the temperature difference between relieving temperature and critical temperature is less than 20 K, the value of K_{volume} shall be at least 0,04 mm^2/l.

NOTE Liquids having a temperature close to the critical temperature expand considerably.

It is advisable to consider the backpressure ratio p_b/p_0 and the possibly reduced stroke of the pressure relief valve.

The possibility of contamination by dirt should be considered.

Where practicable, the pressure relief device shall relieve to the low-pressure side of the system and the pressure relief device shall meet the requirements even at maximum back pressure.

7 Discharge capacity of pressure relief devices

7.1 General

For the most common use of pressure relief devices in refrigerating systems, the back pressure is lower than approximately 0,5 times the relieving pressure ($p_b \leq 0{,}5 \cdot p_0$), which indicates that the flow through the pressure relief device is choked.

The flow of gas or vapor through an orifice, such as the flow areas of a pressure relief device, increases as the outlet pressure is decreased until choked flow is achieved. Further decrease in outlet pressure will not result in any further increase in the flow.

For pressure relief valves where the lift is a function of back pressure, the manufacturer shall state the maximum permissible back pressure ratio p_b/p_0 and the related certified coefficient of discharge considering the possibly reduced stroke of the pressure relief valve.

7.2 Discharge capacity of pressure relief valves

The mass flow of gas through a pressure relief valve can be calculated as:

$$Q_{m,\text{relief}} = 1{,}138\,4 \cdot A \cdot K_{\text{dr}} \cdot K_{\text{cap}} \cdot \sqrt{\frac{p_0}{v_0}} \tag{10}$$

NOTE 1 The factor $1{,}138\,4 = \sqrt{10^5 \cdot 10^{-6}} \cdot 3\,600$ is a result of converting between units.

The de-rated coefficient of discharge is calculated as:

$$K_{dr} = 0{,}9 \cdot K_d \tag{11}$$

where the coefficient of discharge is calculated from:

$$K_d = \frac{q'_m}{q_m} \tag{12}$$

NOTE 2 The factor 0,9 in Formula (11) is a safety factor used when calculating the discharge capacity of pressure relief valves.

The value of the capacity correction factor K_{cap} depends on whether the flow through the pressure relief valve is choked or not.

Choked flow occurs when the pressure ratio p_b/p_0 is less than or equal to the choked pressure ratio:

$$\frac{p_b}{p_0} \le p_{r,\text{choked}} \tag{13}$$

Where the choked pressure ratio is calculated as:

$$p_{r,\text{choked}} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \tag{14}$$

For choked flow the value of the capacity correction factor is:

$$K_{\text{cap}} = \sqrt{\gamma \cdot \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \tag{15}$$

If the flow is not choked, then the capacity correction factor is calculated as:

$$K_{\text{cap}} = \sqrt{\frac{2\cdot\gamma}{\gamma-1} \cdot \left[\left(\frac{p_b}{p_0}\right)^{\frac{2}{\gamma}} - \left(\frac{p_b}{p_0}\right)^{\frac{\gamma+1}{\gamma}}\right]} \tag{16}$$

The choked pressure ratio for different refrigerant is given in Annex A, Table A.1, and values of K_{cap} at choked and non-choked flow are given in Annex A, Table A.1 to Table A.3.

NOTE 3 Formula (10) to Formula (16) give identical results to corresponding Formulae in EN 13136:2013+A1:2018 and ISO 4126-7:2013.

When calculating pressure drop in inlet or outlet piping and fittings, and the discharge capacity of the pressure relief valve $Q_{m,\text{relief}}$ is considerable larger than the required capacity $Q_{m,\text{required}}$, then the refrigerant mass flow used in the pressure drop calculations can be adjusted according to the following rules:

$$\text{if } Q_{m,\text{relief}} < \left(1{,}25 \cdot Q_{m,\text{required}}\right) \text{ then } Q_{m,\text{adjusted}} = Q_{m,\text{required}} \tag{17}$$

$$\text{if } Q_{m,\text{relief}} \ge \left(1{,}25 \cdot Q_{m,\text{required}}\right) \text{ then } Q_{m,\text{adjusted}} = \frac{Q_{m,\text{relief}}}{1{,}25} \tag{18}$$

The adjusted mass flow rate is used when calculating pressure drop in piping and fittings.

7.3 Discharge capacity of bursting discs

Domed bursting discs shall be designed so that they burst due to tensile forces when the bursting pressure is applied to the concave side of the bursting disc. They shall be domed such that no further plastic flow will occur initially when the bursting disc is subject to its intended operating condition.

The discharge capacity of a bursting disc shall be calculated from the formula given in 7.2. The following values for K_{dr} shall be the maximum used depending on how the pipe between the vessel and the bursting disc is mounted on the vessel:

a) flush or flared connection (see Table A.2): K_{dr} = 0,70.

b) inserted connection (see Table A.2): K_{dr} = 0,55.

If the K_{dr} -value of the bursting disc itself is lower than the maximum value given above, then the smaller value shall be used in the calculation.

8 Pressure loss in inlet and outlet lines

8.1 General

To ensure correct operation of a pressure relief device, the pressure loss in both inlet and outlet lines, including any changeover device shall not exceed the following:

The values stated by the manufacturer of the pressure relief device, but not more than:

— Inlet line (including changeover device):

$$\Delta p_{in} \leq 0{,}03 \cdot p_0 \tag{19}$$

— Outlet line:

  — Back pressure dependent pressure relief device:

$$\Delta p_{out} \leq 0{,}10 \cdot p_0 \tag{20}$$

  — Back pressure independent pressure relief device:

$$\Delta p_{out} \leq 0{,}20 \cdot p_0 \tag{21}$$

The velocity in the inlet line shall not reach the speed of sound. If the velocity in the outlet line is larger than the speed of sound, then either the pipe diameter shall be increased and/or the pressure drop across the resulting shock shall be included in the total pressure drop of the outlet line. Annex D includes an example of how to calculate this.

The flow area of piping or changeover devices in the inlet and outlet lines shall not be less than the actual flow area A_{actual} of the pressure relief device.

NOTE It is expected that pipes in both inlet and outlet line are selected so that they can withstand the pressure and temperature during discharge.

8.2 Pressure loss in inlet line

The pressure loss in the inlet line is calculated using the Darcy-Weisbach Formula:

$$\Delta p = f \cdot \rho_0 \cdot \frac{L}{d_R} \cdot \frac{u^2}{2} \cdot 10^{-5} \tag{22}$$

When using the adjusted mass flow instead of velocity, the Formula can be written as:

$$\Delta p = 0{,}385\,8 \cdot f \cdot \frac{L}{d_R} \cdot v_0 \cdot \left(\frac{Q_{m,adjusted}}{A_R} \right)^2 \tag{23}$$

NOTE 1 The factor $0{,}385\,8 = \frac{1}{2} \cdot \left(\frac{10^6}{3\,600} \right)^2 \cdot 10^{-5}$ is a result of unit conversion and simplification.

Depending on the type of component in the inlet line, Formula (23) can be formulated differently.

For pipes, Formula (23) is used directly. The friction factor, *f*, is calculated from von Karman's equation for fully developed turbulent flow:

$$f = \frac{1}{\left(2 \cdot \log_{10}\left(\frac{3{,}71 \cdot d_R}{\varepsilon_R}\right)\right)^2} \tag{24}$$

Values for pipe roughness can be found in Table A.5 in Annex A.

NOTE 2 If the flow is not fully turbulent other formulae can be used to calculate the friction factor (for example according to [Colebrook, 1939]).

For fittings the pressure loss is calculated by means of the pressure loss coefficient:

$$\zeta = f \cdot \frac{L}{d_R} \tag{25}$$

The pressure loss using Formula (23) is then calculated as:

$$\Delta p = 0{,}385\,8 \cdot \zeta \cdot v_0 \cdot \left(\frac{Q_{m,\text{adjusted}}}{A_R}\right)^2 \tag{26}$$

Pressure loss coefficients for typical fittings shall be according to Annex A, Table A.4 .

If the manufacturer provides the pressure loss coefficient ζ_{DN} for devices (valves) related to the nominal diameter (*DN*), it is converted to the pressure loss coefficient ζ for the actual internal diameter of the pipe from:

$$\zeta = \left[\frac{d_\text{R}}{DN}\right]^4 \cdot \zeta_{\text{DN}} \tag{27}$$

When the flow coefficient K_{vs} of a changeover device is given, then the pressure loss using Formula (23) is calculated as:

$$\Delta p = v_0 \cdot \left(\frac{Q_{m,\text{adjusted}}}{K_{VS}}\right)^2 \cdot 10^{-3} \tag{28}$$

8.3 Pressure loss in outlet line

The pressure loss in the outlet line is calculated using formulae for compressible isothermal flow of an ideal gas.

The pressure loss formula can be simplified to:

$$\frac{p_1^2 - p_b^2}{p_1} = 0{,}771\,6 \cdot Q_{m,\text{adjusted}}^2 \cdot \frac{v_1}{A_R^2} \cdot \zeta_{\text{total}} \tag{29}$$

NOTE The factor $0{,}771\,6 = \frac{10^{12}}{3\,600^2 \cdot 10^5}$ is a result of unit conversion and simplification.

When it is assumed that $p_1 \cdot v_1 = p_0 \cdot v_0$ then the inlet pressure, p_1, to the outlet line can be calculated as:

$$p_1 = \sqrt{0{,}771\,6 \cdot Q_{m,\text{adjusted}}^2 \cdot \frac{p_0 \cdot v_0}{A_R^2} \cdot \zeta_{\text{total}} + p_b^2} \tag{30}$$

For pipes, the pressure loss coefficient is calculated as:

$$\zeta_{\text{pipe}} = f \frac{L}{d_R} \tag{31}$$

Where the friction factor, *f*, is calculated using Formula (24).

For fittings, the pressure loss coefficients shall be according to Annex A, Table A.4.

The total pressure loss coefficient is calculated as the sum of the individual pressure loss coefficients:

$$\zeta_{total} = \zeta_{pipes} + \zeta_{fittings} \quad (32)$$

8.4 Total pressure loss

The total inlet pressure loss is calculated by summing the pressure loss of all elements (pipes, changeover valves and fittings) in the inlet line:

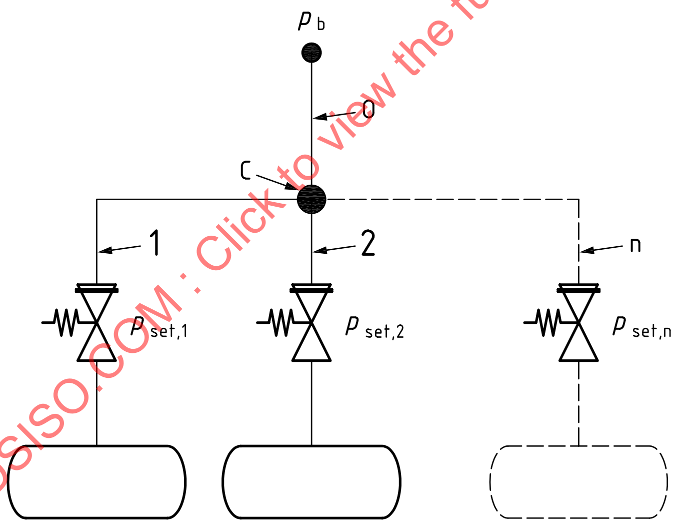
$$\Delta p_{in} = \sum \Delta p \quad (33)$$

The total outlet pressure loss is calculated as the difference between p_1, calculated using Formula (30), and the back pressure:

$$\Delta p_{out} = p_1 - p_b \quad (34)$$

8.5 Connection of outlets from several pressure relief valves to a common outlet line

If several pressure relief valves are connected to a common outlet line, then the outlet pressure loss for the common line is calculated using Formulae (29) to (34). The adjusted mass flow used in the calculations shall be the sum of the adjusted mass flows from all pressure relief valves connected to the common outlet line as shown in Figure 3 and calculated in Formula (35).



Key

1 outlet line from pressure relief valve 1
2 outlet line from pressure relief valve 2
n outlet line from pressure relief valve n
C connection point
O common outlet line

Figure 3 — Several pressure relief valves connected to common outlet line

$$Q_{\text{m,common}} = \sum_{i=1}^{n} Q_{\text{m,adjusted,i}} \tag{35}$$

The pressure and density (p_0, v_0) from the line with the highest actual relieving pressure, p_0, shall be used when calculating the common outlet line.

When the pressure drop in the common outlet line has been calculated, the pressure in the connection point can be calculated:

$$p_{\text{connection}} = p_b + \Delta p_{\text{common}} \tag{36}$$

The pressure in the connection point shall then be used as back pressure in Formula (30) when the pressure loss in the individual outlet lines from each pressure relief valve is calculated:

$$p_1 = \sqrt{0{,}771\,6 \cdot Q_{m,\text{adjusted}}^2 \cdot \frac{p_0 \cdot v_0}{A_R^2} \cdot \zeta_{\text{total}} + p_{\text{connection}}^2} \tag{37}$$

The total pressure drop in any of the individual outlet lines (including the common outlet line) shall be within the limits given by Formulae (20) and (21).

If the pressure relief valves are back pressure dependent, this means that the limit for the total pressure drop in the individual outlet lines for each of the pressure relief valves is given by:

$$\begin{aligned} &\Delta p_{\text{out},1} + \Delta p_{\text{common}} \le 0{,}10 \cdot \left(1{,}1 \cdot p_{\text{set},1} + p_{\text{atm}}\right) \\ &\Delta p_{\text{out},2} + \Delta p_{\text{common}} \le 0{,}10 \cdot \left(1{,}1 \cdot p_{\text{set},2} + p_{\text{atm}}\right) \\ &\vdots \\ &\Delta p_{\text{out},n} + \Delta p_{\text{common}} \le 0{,}10 \cdot \left(1{,}1 \cdot p_{\text{set},n} + p_{\text{atm}}\right) \end{aligned} \tag{38}$$

If the pressure relief valves are back pressure independent, then the limit for the total pressure drop in the individual outlet lines for each of the pressure relief valves is calculated correspondingly, except that limits from Formula (21) apply.

NOTE Mixing different refrigerants in a common outlet line can lead to problems due to chemical reactions.

Annex A
(normative)

Values of factors and properties of refrigerants

Table A.1 — Properties of refrigerants

Refrigerant number[a]	Heat capacity ratio[b] γ	Choked pressure ratio[b] $p_{r,choked}$	Capacity correction factor for choked flow[b] K_{cap}
R-11	1,10	0,58	0,63
R-12	1,12	0,58	0,63
R-13	1,14	0,58	0,64
R-14	1,16	0,57	0,64
R-22	1,17	0,57	0,64
R-23	1,19	0,57	0,65
R-32	1,24	0,56	0,66
R-50	1,31	0,54	0,67
R-113 [c]	1,06	0,59	0,62
R-114	1,04	0,60	0,62
R-115	1,09	0,59	0,63
R-116	1,09	0,59	0,63
R-123 [c]	1,10	0,58	0,63
R-124	1,10	0,58	0,63
R-125	1,10	0,58	0,63
R-134a	1,12	0,58	0,63
R-141b [c]	1,10	0,58	0,63
R-142b	1,12	0,58	0,63
R-143a	1,13	0,58	0,63
R-152a	1,15	0,57	0,64
R-170	1,20	0,56	0,65
R-E170	1,16	0,57	0,64
R-218	1,07	0,59	0,62
R-227ea	1,07	0,59	0,62
R-236fa	1,08	0,59	0,62
R-245fa	1,10	0,58	0,63
R-290	1,14	0,57	0,65
R-C318	1,07	0,59	0,62
R-600	1,10	0,58	0,63
R-600a	1,10	0,58	0,63
R-601 [c]	1,07	0,59	0,62
R-601a [c]	1,07	0,59	0,62

[a] The R-numbers are in accordance with ISO 817:2024.

[b] The values are based on a temperature of 25 °C and a pressure of 1,013 25 bar.

[c] The values are based on a temperature of 100 °C and a pressure of 1,013 25 bar.

Table A.1 *(continued)*

Refrigerant number[a]	Heat capacity ratio[b] γ	Choked pressure ratio[b] $p_{r,choked}$	Capacity correction factor for choked flow[b] K_{cap}
R-717	1,31	0,54	0,67
R-718 [c]	1,32	0,54	0,67
R-744	1,30	0,55	0,67
R-764	1,27	0,55	0,66
R-1150	1,25	0,55	0,66
R-1224yd(Z)	1,10	0,59	0,63
R-1233zd(E)	1,10	0,58	0,63
R-1234yf	1,10	0,58	0,63
R-1234ze(E)	1,10	0,58	0,63
R-1270	1,14	0,58	0,64
R-1336mzz(Z) [c]	1,06	0,59	0,62
R-401A	1,15	0,57	0,64
R-401B	1,16	0,57	0,64
R-401C	1,14	0,58	0,64
R-402A	1,13	0,58	0,63
R-402B	1,15	0,57	0,64
R-403A	1,15	0,57	0,64
R-403B	1,13	0,58	0,63
R-404A	1,12	0,58	0,63
R-405A	1,12	0,58	0,63
R-406A	1,10	0,58	0,63
R-407A	1,14	0,58	0,64
R-407B	1,12	0,58	0,63
R-407C	1,14	0,58	0,64
R-407D	1,14	0,58	0,64
R-407E	1,15	0,57	0,64
R-407F	1,15	0,57	0,64
R-407G	1,12	0,58	0,63
R-407H	1,16	0,57	0,64
R-407I	1,14	0,58	0,64
R-408A	1,15	0,57	0,64
R-409A	1,15	0,57	0,64
R-409B	1,16	0,57	0,64
R-410A	1,17	0,57	0,64
R-410B	1,17	0,57	0,64
R-411A	1,18	0,57	0,64
R-411B	1,18	0,57	0,64
R-412A	1,16	0,57	0,64
R-413A	1,11	0,58	0,63

[a] The R-numbers are in accordance with ISO 817:2024.

[b] The values are based on a temperature of 25 °C and a pressure of 1,013 25 bar.

[c] The values are based on a temperature of 100 °C and a pressure of 1,013 25 bar.

Table A.1 *(continued)*

Refrigerant number[a]	**Heat capacity ratio**[b] γ	**Choked pressure ratio**[b] $p_{r,choked}$	**Capacity correction factor for choked flow**[b] K_{cap}
R-414A	1,14	0,58	0,64
R-414B	1,14	0,58	0,64
R-415A	1,18	0,57	0,64
R-415B	1,16	0,57	0,64
R-416A	1,11	0,58	0,63
R-417A	1,11	0,58	0,63
R-417B	1,11	0,58	0,63
R-417C	1,12	0,58	0,63
R-418A	1,18	0,57	0,64
R-419A	1,11	0,58	0,63
R-419B	1,11	0,58	0,63
R-420A	1,12	0,58	0,63
R-421A	1,11	0,58	0,63
R-421B	1,11	0,58	0,63
R-422A	1,11	0,58	0,63
R-422B	1,11	0,58	0,63
R-422C	1,11	0,58	0,63
R-422D	1,11	0,58	0,63
R-422E	1,11	0,58	0,63
R-423A	1,10	0,58	0,63
R-424A	1,11	0,58	0,63
R-425A	1,14	0,58	0,64
R-426A	1,12	0,58	0,63
R-427A	1,13	0,58	0,63
R-427B	1,14	0,58	0,64
R-428A	1,11	0,58	0,63
R-429A	1,14	0,58	0,64
R-430A	1,14	0,58	0,64
R-431A	1,14	0,58	0,64
R-432A	1,16	0,57	0,64
R-433A	1,14	0,58	0,64
R-433B	1,14	0,58	0,64
R-433C	1,14	0,58	0,64
R-434A	1,11	0,58	0,63
R-435A	1,16	0,57	0,64
R-436A	1,12	0,58	0,63
R-436B	1,12	0,58	0,63
R-436C	1,13	0,58	0,64
R-437A	1,12	0,58	0,63

a The R-numbers are in accordance with ISO 817:2024.

b The values are based on a temperature of 25 °C and a pressure of 1,013 25 bar.

c The values are based on a temperature of 100 °C and a pressure of 1,013 25 bar.

Table A.1 *(continued)*

Refrigerant number[a]	Heat capacity ratio[b] γ	Choked pressure ratio[b] $p_{r,choked}$	Capacity correction factor for choked flow[b] K_{cap}
R-438A	1,12	0,58	0,63
R-439A	1,17	0,57	0,64
R-440A	1,15	0,57	0,64
R-441A	1,12	0,58	0,63
R-442A	1,15	0,57	0,64
R-443A	1,15	0,57	0,64
R-444A	1,12	0,58	0,63
R-444B	1,16	0,57	0,64
R-445A	1,11	0,58	0,63
R-446A	1,19	0,57	0,65
R-447A	1,20	0,56	0,65
R-447B	1,20	0,56	0,65
R-448A	1,14	0,58	0,64
R-449A	1,14	0,58	0,64
R-449B	1,14	0,58	0,64
R-449C	1,13	0,58	0,64
R-450A	1,11	0,58	0,63
R-451A	1,10	0,58	0,63
R-451B	1,10	0,58	0,63
R-452A	1,12	0,58	0,63
R-452B	1,20	0,57	0,65
R-452C	1,12	0,58	0,63
R-453A	1,14	0,58	0,64
R-454A	1,15	0,58	0,64
R-454B	1,20	0,56	0,65
R-454C	1,13	0,58	0,63
R-455A	1,13	0,58	0,63
R-456A	1,12	0,58	0,63
R-457A	1,13	0,58	0,63
R-458A	1,14	0,58	0,64
R-459A	1,20	0,57	0,65
R-459B	1,13	0,58	0,63
R-460A	1,12	0,58	0,63
R-460B	1,14	0,58	0,64
R-460C	1,11	0,58	0,63
R-461A	1,11	0,58	0,63
R-462A	1,12	0,58	0,63
R-463A	1,17	0,57	0,64
R-464A	1,14	0,58	0,64

[a] The R-numbers are in accordance with ISO 817:2024.

[b] The values are based on a temperature of 25 °C and a pressure of 1,013 25 bar.

[c] The values are based on a temperature of 100 °C and a pressure of 1,013 25 bar.

Table A.1 *(continued)*

Refrigerant number[a]	Heat capacity ratio[b] γ	Choked pressure ratio[b] $p_{r,choked}$	Capacity correction factor for choked flow[b] K_{cap}
R-465A	1,13	0,58	0,63
R-500	1,12	0,58	0,63
R-501	1,18	0,57	0,64
R-502	1,13	0,58	0,63
R-503	1,16	0,57	0,64
R-504	1,17	0,57	0,64
R-507A	1,10	0,58	0,63
R-508A	1,13	0,58	0,63
R-508B	1,14	0,58	0,64
R-509A	1,11	0,58	0,63
R-510A	1,15	0,57	0,64
R-511A	1,14	0,58	0,64
R-512A	1,15	0,57	0,64
R-513A	1,11	0,58	0,63
R-513B	1,11	0,58	0,63
R-515A	1,10	0,59	0,63
R-516A	1,11	0,58	0,63

[a] The R-numbers are in accordance with ISO 817:2024.

[b] The values are based on a temperature of 25 °C and a pressure of 1,013 25 bar.

[c] The values are based on a temperature of 100 °C and a pressure of 1,013 25 bar.

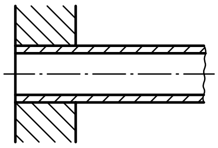
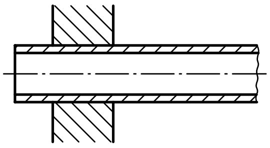
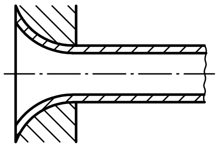
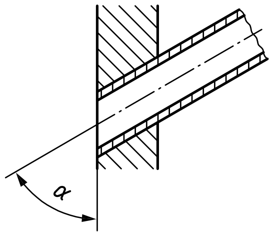
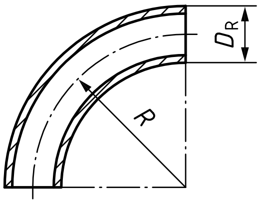
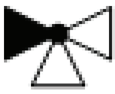
Table A.2 — Capacity correction factor for choked flow as function of γ

γ	1,01	1,05	1,10	1,15	1,20	1,25	1,30	1,35	1,40	1,45	1,50	1,55	1,60
K_{cap} for choked flow	0,61	0,62	0,63	0,64	0,65	0,66	0,67	0,68	0,68	0,69	0,70	0,71	0,72

Table A.3 — Capacity correction factors for non-choked flow K_{cap}

p_b/p_0	Heat capacity ratio γ												
	1,01	**1,05**	**1,10**	**1,15**	**1,20**	**1,25**	**1,30**	**1,35**	**1,40**	**1,45**	**1,50**	**1,55**	**1,60**
0,45	0,572	0,585	0,601	0,615	0,629	0,641	0,653	0,665	0,676	0,686	0,695	0,705	0,713
0,50	0,592	0,603	0,617	0,630	0,642	0,653	0,664	0,674	0,684	0,692	0,701	0,709	0,716
0,55	0,604	0,614	0,626	0,638	0,648	0,658	0,667	0,676	0,684	0,692	0,699	0,706	0,712
0,60	0,609	0,618	0,628	0,638	0,647	0,655	0,663	0,670	0,677	0,683	0,689	0,695	0,701
0,65	0,605	0,613	0,621	0,629	0,637	0,644	0,650	0,656	0,662	0,667	0,672	0,677	0,681
0,70	0,593	0,599	0,606	0,612	0,618	0,624	0,629	0,634	0,638	0,643	0,647	0,650	0,654
0,75	0,570	0,575	0,580	0,585	0,590	0,594	0,598	0,602	0,605	0,608	0,611	0,614	0,617
0,80	0,535	0,539	0,543	0,546	0,550	0,553	0,556	0,558	0,561	0,563	0,565	0,567	0,569
0,82	0,517	0,520	0,524	0,527	0,530	0,532	0,535	0,537	0,539	0,541	0,543	0,545	0,546
0,84	0,497	0,499	0,502	0,505	0,507	0,509	0,511	0,513	0,515	0,517	0,518	0,520	0,521
0,86	0,473	0,475	0,477	0,479	0,481	0,483	0,485	0,486	0,488	0,489	0,491	0,492	0,493
0,88	0,445	0,447	0,449	0,451	0,452	0,454	0,455	0,456	0,457	0,458	0,459	0,460	0,461
0,90	0,413	0,415	0,416	0,417	0,419	0,420	0,421	0,422	0,423	0,423	0,424	0,425	0,426
0,92	0,376	0,377	0,378	0,379	0,380	0,380	0,381	0,382	0,382	0,383	0,384	0,384	0,385
0,94	0,331	0,331	0,332	0,333	0,333	0,334	0,334	0,335	0,335	0,335	0,336	0,336	0,336
0,96	0,274	0,275	0,275	0,275	0,276	0,276	0,276	0,276	0,277	0,277	0,277	0,277	0,277
0,98	0,197	0,197	0,197	0,197	0,197	0,198	0,198	0,198	0,198	0,198	0,198	0,198	0,198

Table A.4 — Pressure loss coefficients of pipe elements

	Flush connection	Very sharp edged $\zeta = 0{,}5$ Broken edge $\zeta = 0{,}25$
	Inserted connection	Very sharp edged $\zeta = 1$ Broken edge $\zeta = 0{,}56$
	Flared connection	According to the radius: Between: $\zeta = 0{,}005$ and $\zeta = 0{,}06$ Normally: $\zeta = 0{,}05$ is used
	Angled flush connection	$\zeta = 0{,}5 + 0{,}3 \cos\alpha + 0{,}2 \cos^2\alpha$
	Pipe bend 90°	$R = 2D_R$ $\zeta = 0{,}3$ $R = 3D_R$ $\zeta = 0{,}25$ $R = 4D_R$ $\zeta = 0{,}23$ $R = 5D_R$ $\zeta = 0{,}18$
	Changeover valves	K_{vs} or ζ shall be given by the valve manufacturer

NOTE The values for ζ given in Table A.4 are generally accepted and used values. Slightly different values can be used providing their selection can be justified (e.g. by published papers).

Table A.5 — Roughness values for pipes of different material

Material	**Roughness** [mm]
Steel	0,045
Stainless steel	0,030
Copper	0,001 5
Flexible rubber tubing	0,30

Annex B
(informative)

Calculation of flow areas for non-flashing and flashing liquids

B.1 Calculation of the flow area of a pressure relief valve for non- flashing liquids

Pressure relief valves for non-flashing liquids are used to for example protect liquid pumps against too high pressure difference.

The flow area of a pressure relief valve for a non- flashing liquid is calculated using Formula (26) with the pressure loss coefficient equal to:

$$\zeta = \frac{1}{K_{\mathrm{drl}} \cdot K_{\mathrm{visc}}} \tag{B.1}$$

where K_{drl} for liquids is approximately 20 % below the value of K_{dr} for gases and vapours.

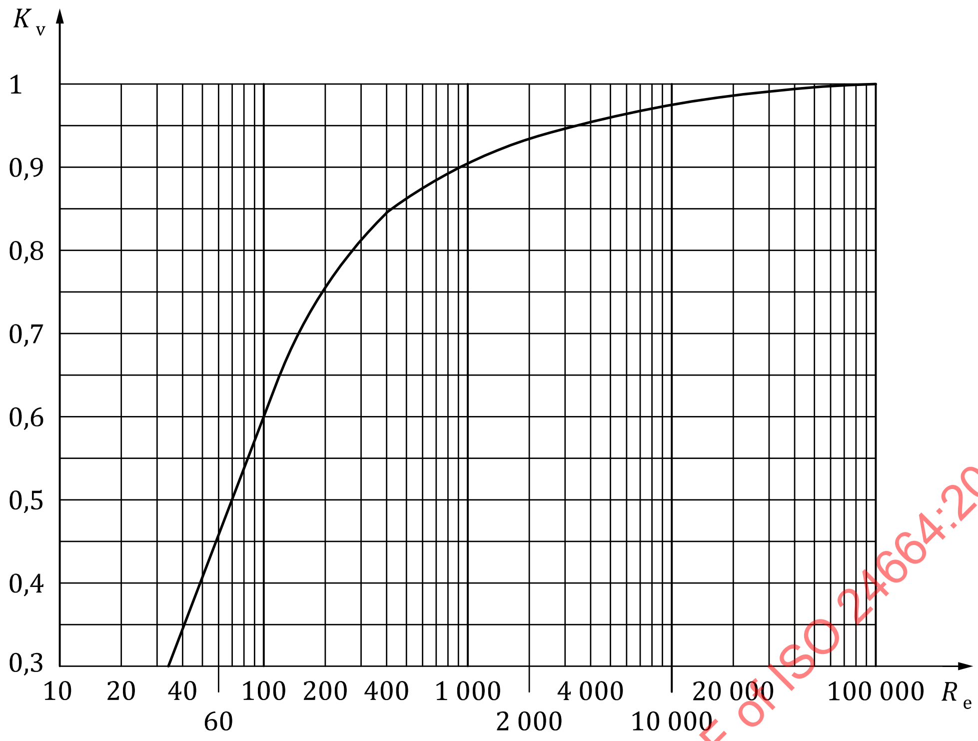
The viscosity correction factor K_{visc} is dependent on the Reynolds number and can be obtained from Figure B.1.

Solving Formula (26) for the flow area and using the required mass flow, then gives the minimum flow area of the pressure relief valve:

$$A = 0{,}6211 \cdot \frac{Q_{m,\mathrm{required}}}{K_{\mathrm{drl}} \cdot K_{\mathrm{visc}}} \cdot \sqrt{\frac{1}{\rho \cdot (p_0 - p_b)}} \tag{B.2}$$

The area found from Formula (B.2) is then used to find the proper size pressure relief valve.

Both the inlet and the outlet line is calculated according to Formulae in 8.2 (the outlet is liquid, i.e. non-compressible flow).



Key

1 K_{visc} viscosity correction factor

2 *Re* Reynolds number

Figure B.1 — Viscosity correction factor K_{visc} as a function of the Reynolds number

The Reynolds number is calculated according to the formula:

$$\mathrm{Re} = \frac{w_0 \cdot d \cdot 10^{-3}}{\nu} \tag{B.3}$$

where

$$w_0 = 353{,}68 \cdot \frac{Q_{m,\,\mathrm{required}}}{\rho \cdot d^2} \tag{B.4}$$

NOTE The factor $353{,}68 = \dfrac{4 \cdot 10^6}{\pi \cdot 3\,600}$ is a result of converting between units.

The values for the kinematic viscosity ν and the density ρ are found from the technical literature, and d is the actual most narrow flow diameter of the pressure relief valve when it is fully open.

B.2 Calculation of the flow area of a pressure relief valve for flashing liquids

When calculating the flow area of a pressure relief valve for flashing liquids (flashing due to pressure relief) the flow can be separated into two parts: liquid and vapour:

$$Q_{m,\text{required}} = Q_{m,\text{vap}} + Q_{m,\text{liq}} \quad \text{(B.5)}$$

where:

$$Q_{m,\text{vap}} = x \cdot Q_{m,\text{required}} \quad \text{(B.6)}$$

the value of x being the vapour fraction at p_b.

The minimum flow area of the pressure relief valve needed to handle the gas part can be calculated from Formula (10):

$$A_\text{vap} = \frac{Q_{m,\text{vap}}}{1{,}138\,4 \cdot K_{dr} \cdot K_\text{cap}} \cdot \sqrt{\frac{v_0}{p_0}} \quad \text{(B.7)}$$

And the minimum flow area of the pressure relief valve needed to handle the liquid part can be calculated from Formula (B.2):

$$A_\text{liq} = 0{,}621\,1 \cdot \frac{Q_{m,\text{liq}}}{K_\text{drl} \cdot K_\text{visc}} \cdot \sqrt{\frac{1}{\rho \cdot (p_0 - p_b)}} \quad \text{(B.8)}$$

where K_visc = 1,0 can be used for refrigerants flashing in the pressure relief valve.

The total necessary flow area for the pressure relief valve can be approximated by:

$$A = 1{,}2 \cdot \left[A_\text{vap} + A_\text{liq} \right] \quad \text{(B.9)}$$

Where the factor of 1,2 takes the difference between the actual flow of liquid/vapour mixture and the theoretical flow in this calculation into account.

Annex C
(informative)

Example calculation for sizing pressure relief devices with corresponding pipes and fittings

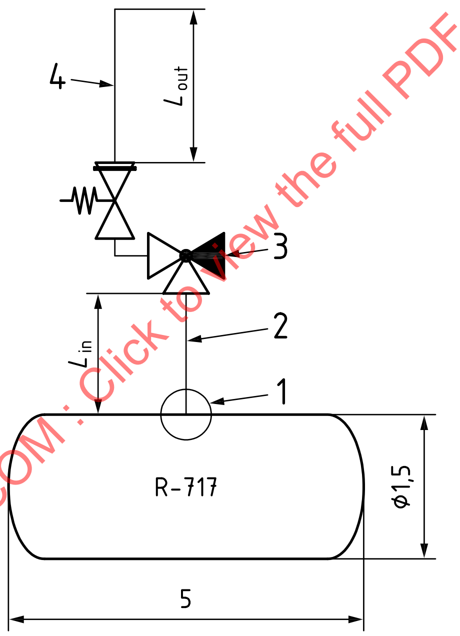
C.1 Refrigerant properties used in the examples

All refrigererant properties are taken from NIST Refprop 10 using the default reference point for enthalpy and entropy. Other data sources for refrigerant properties can be used as well.

C.2 Selection of pressure relief valve for single vessel

C.2.1 General information

Dimensions in metres



Key

1 inlet connection from vessel (flush connection, broken edge)

2 inlet pipe, L_{in} = 500 mm

3 changeover valve, K_{vs} = 20 m^3/h

4 outlet pipe, L_{out} = 5 000 mm

The outlet line shall be designed so that accumulation of rainwater in the piping is avoided.

Figure C.1 — Schematic diagram of pressure relief valve with changeover valve and connecting pipes

C.2.2 Assumptions for the calculation example

— Refrigerant: R-717

— Set pressure: $p_{set} = 20$ bar

— Actual absolute relieving pressure: $p_0 = 1{,}1 \cdot p_{set} + p_{atm} = 23$ bar

— Actual back pressure: $p_b = p_{atm} = 1$ bar

— Heat of vaporisation (at 23 bar): Δh_{vap} = 1 026 kJ/kg

— Length of vessel: 5 m

— Diameter of vessel: 1,5 m

C.2.3 Calculation of the required minimum discharge capacity at standard heat flow rate

Density of heat flow rate:

ϕ = 10 kW/m^2

External surface of vessel:

$$A_{surf} = 2 \times \frac{1{,}5^2 \times \pi}{4} + 1{,}5 \times \pi \times 5{,}0 = 27{,}1 \text{ m}^2$$

Using Formula (2) from 6.2.1:

$$Q_{m,required} = \frac{3\,600 \cdot \phi \cdot A_{surf}}{\Delta h_{vap}} = \frac{3\,600 \cdot 10 \cdot 27{,}1}{1\,026} = 951 \text{ kg/h}$$

C.2.4 Calculation of the required minimum discharge capacity at reduced heat flow rate

The reduced heat flow can be used when the vessel has a fire resistant insulation according to the requirements in 6.2.1.

Thickness of insulation:

s = 0,14 m

Density of heat flow rate:

$$\phi_{red} = 10 \cdot \frac{0{,}04}{0{,}14} = 2{,}86 \text{ kW/m}^2$$

External surface of vessel:

$$A_{surf} = 2 \times \frac{1{,}5^2 \times \pi}{4} + 1{,}5 \times \pi \times 5{,}0 = 27{,}1 \text{ m}^2$$

Using Formula (2) from 6.2.1:

$$Q_{m,required} = \frac{3\,600 \cdot \phi \cdot A_{surf}}{\Delta h_{vap}} = \frac{3\,600 \cdot 2{,}86 \cdot 27{,}1}{1\,026} = 272 \text{ kg/h}$$

C.2.5 Selection of pressure relief valve

This example is based on standard heat flow rate ϕ = 10 kW/m^2.

The minimum required discharge capacity of the pressure relief valve, under the above conditions, should be at least 951 kg/h.

From Table A.1 for R-717:

$\gamma = 1{,}31$
$p_{r,\text{ choked}} = 0{,}54$
K_{cap} choked flow = 0,67

From a "R-717-table"
Saturated specific volume at 23 bar: $v_0 = 0{,}055\,8\ \text{m}^3/\text{kg}$
Saturated density at 23 bar: $\rho_0 = 17{,}915\ \text{kg/m}^3$

The pressure ratio $p_\text{b}/p_0 = 1/23 = 0{,}043$ is less than $p_{r,\text{ choked}}$ so the flow is choked.

From a manufacturer's catalogue, a pressure relief valve with the following data is selected:

$d = 15$ mm, $A_\text{actual} = 177\ \text{mm}^2$, $K_\text{dr} = 0{,}41$

Calculation of discharge capacity from 7.2, Formula (10):

$$Q_{m,\text{relief}} = 1{,}138\,4 \cdot A \cdot K_\text{dr} \cdot K_\text{cap} \cdot \sqrt{\frac{p_0}{v_0}} = 1{,}138\,4 \cdot 177 \cdot 0{,}41 \cdot 0{,}67 \cdot \sqrt{\frac{23}{0{,}055\,8}} = 1\,124\ \text{kg/h}$$

As $Q_{m,\text{relief}}$ is less than $1{,}25 \cdot Q_{m,\text{required}}$, so $Q_{m,\text{adjusted}} = Q_{m,\text{required}} = 951\ \text{kg/h}$

C.2.6 Pressure loss in inlet line (from vessel to pressure relief valve)

Inlet pipe: Steel, DN 25, $L = 500$ mm, $d_\text{R} = 28{,}5$ mm, $A_\text{R} = 638\ \text{mm}^2$.

From Table A.5 pipe roughness = 0,045 mm.

The pressure loss in the inlet pipe is calculated using Formula (23) and (24) in 8.2:

Formula (24):

$$f = \frac{1}{\left(2 \cdot \log_{10}\left(\frac{3{,}71 \cdot d_R}{\varepsilon_R}\right)\right)^2} = \frac{1}{\left(2 \cdot \log_{10}\left(\frac{3{,}71 \cdot 28{,}5}{0{,}045}\right)\right)^2} = 0{,}022$$

Formula (22):

$$\Delta p_{in,\text{pipe}} = 0{,}385\,8 \cdot f \cdot \frac{L}{d_R} \cdot v_0 \cdot \left(\frac{Q_{m,\text{adjusted}}}{A_R}\right)^2 = 0{,}385\,8 \cdot 0{,}022 \cdot \frac{500}{28{,}5} \cdot 0{,}055\,8 \cdot \left(\frac{951}{638}\right)^2 = 0{,}018\ \text{bar}$$

The pressure loss related to the connection to the vessel, is calculated by finding the pressure loss coefficient for a flush connection with broken edge from Table A.4 and use Formula (26):

$$\Delta p_\text{in,connection} = 0{,}385\,8 \cdot \zeta \cdot v_0 \cdot \left(\frac{Q_{m,\text{adjusted}}}{A_R}\right)^2 = 0{,}385\,8 \cdot 0{,}25 \cdot 0{,}055\,8 \cdot \left(\frac{951}{638}\right)^2 = 0{,}012\ \text{bar}$$

The pressure loss in the changeover valve is calculated using Formula (28):

$$\Delta p_\text{in,changeover} = v_0 \cdot \left(\frac{Q_{m,\text{adjusted}}}{K_{VS}}\right)^2 \cdot 10^{-3} = 0{,}055\,8 \cdot \left(\frac{951}{20}\right)^2 \cdot 10^{-3} = 0{,}126\ \text{bar}$$

The total inlet pressure drop can then be calculated as:

$$\Delta p_\text{in} = \Delta p_\text{in,pipe} + \Delta p_\text{in,connection} + \Delta p_\text{in,changeover} = 0{,}018 + 0{,}012 + 0{,}126 = 0{,}156\ \text{bar}$$

$$\frac{\Delta p_{in}}{p_0} = \frac{0{,}156}{23} = 0{,}006\,8 < 0{,}03 \ \text{(see 8.1)}$$

Therefore, the inlet pressure loss allows the use of the selected valve. If the pressure loss is higher than stated in 8.1, then the arrangement of valve and piping shall be modified with the aim of reducing the pressure loss.

At 23 bar, the speed of sound of saturated ammonia vapour is 400 m/s. The velocity in the inlet pipe is calculated to 23,1 m/s (using A_R, $Q_{m,\text{adjusted}}$ and the saturated density at 23 bar), so the velocity is well below the speed of sound.

C.2.7 Pressure loss in outlet line (from pressure relief valve to atmosphere)

Inlet pipe: Steel, DN 32, L = 5 000 mm, d_R = 37,2 mm, A_R = 1 087 mm^2.

From Table A.5 Annex A, pipe roughness = 0,045 mm.

The friction factor of the outlet pipe is calculated as:

$$f = \frac{1}{\left(2 \cdot \log_{10}\left(\frac{3{,}71 \cdot d_R}{\varepsilon_R}\right)\right)^2} = \frac{1}{\left(2 \cdot \log_{10}\left(\frac{3{,}71 \cdot 37{,}2}{0{,}045}\right)\right)^2} = 0{,}021$$

The pressure loss coefficient of the outlet pipe is then calculated as:

$$\zeta_{pipe} = f \cdot \frac{L}{d_R} = 0{,}021 \cdot \frac{5\,000}{37{,}2} = 2{,}82$$

There is no fitting in the outlet line, so:

$$\zeta_{fittings} = 0$$

So, the total pressure loss coefficient can be calculated as:

$$\zeta_{total} = \zeta_{pipes} + \zeta_{fittings} = 2{,}82 + 0 = 2{,}82$$

The inlet pressure to the outlet line can then be calculated as:

$$p_1 = \sqrt{0{,}771\,6 \cdot Q_{m,\text{adjusted}}^2 \cdot \frac{p_0 \cdot v_0}{A_R^2} \cdot \zeta_{total} + p_b^2} = \sqrt{0{,}771\,6 \cdot 951^2 \cdot \frac{23 \cdot 0{,}055\,8}{1\,087^2} \cdot 2{,}82 + 1^2} = 1{,}771 \ \text{bar}$$

The total pressure drop in the outlet line (in bar) can then be calculated as:

$$\Delta p_{out} = p_1 - p_b = 1{,}771 - 1 = 0{,}771 \ \text{bar}$$

$$\frac{\Delta p_{out}}{p_0} = \frac{0{,}771}{23} = 0{,}034 < 0{,}10 \ \text{(see 8.1)}$$

Therefore, the outlet pressure loss allows the use of the selected valve. If the pressure loss is higher than stated in 8.1, then the arrangement of valve and piping shall be modified with the aim of reducing the pressure loss.

The expansion across the safety valve is assumed isenthalpic. As the enthalpy of saturated gas at 23 bar equals 1 636,7 kJ/kg, following constant enthalpy to the pressure at the outlet of the outlet line (= 1,0 bar) gives that the temperature of ammonia is equal to -0,7 °C, the density is equal to 0,763 kg/m^3 and the speed of sound is equal to 414 m/s.

The velocity in the outlet pipe is calculated to 318 m/s, so the velocity is below the speed of sound.