HANDBOOK

# SAFETY DEVICES

Castel

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# SELECTION CRITERIA FOR SAFETY VALVES

## CALCULATION OF THE DISCHARGE CAPACITY (REF. EN 13136:2013)

The evaluation of the minimum required discharge capacity of safety valves is closely linked to the type of system where the equipment protected by the valve is installed, with the causes that may cause the safety valve to open, i.e.:

- **External heat sources** (Para. 6.2.1 - EN 13136:2013). The minimum required discharge capacity is determined by the following formula:

$$Q_{md} = \frac{3600 \times \varphi \times A_{surf}}{h_{vap}} \text{ [kg/h]}$$

  where:
  - $\varphi$ = density of heat flow rate, assumed to be 10 [kW/m$^2$]
  - $A_{surf}$ = external surface area of the vessel [m$^2$]
  - $h_{vap}$ = latent heat of vaporization of liquid at $p_o$ [kJ/kg]

- **Internal heat sources** (Para. 6.2.2 - EN 13136:2013). The minimum required discharge capacity is determined by the following formula:

$$Q_{md} = \frac{3600 \times Q_h}{h_{vap}} \text{ [kg/h]}$$

  where $Q_h$ = rate of heat production [KW]

- **Increased pressure caused by a positive displacement compressor** (Para. 6.3 - EN 13136:2013). The minimum required discharge capacity is determined by the following formula:

$$Q_{md} = 60 \times V \times n \times \rho_{10} \times \eta_v \text{ [kg/h]}$$

  where:
  - V = theoretical displacement of compressor [m$^3$]
  - n = rotational frequency of compressor [min$^{-1}$]
  - $\rho_{10}$ = vapour density of refrigerant, from the saturation curve at a temperature of 10 °C [kg/m$^3$].
  - Table 18 provides the values of $\rho_{10}$ for:
    - traditional HCFC and HFC refrigerants most commonly used
    - new HFO and HFC/HFO blend refrigerants
    - natural HC fluids

  (for R744, the $\rho_{-40}$ vapour density value for $CO_2$ is indicated, from the saturation curve at a temperature of -40 °C [kg/m$^3$]).
  - $\eta_v$ = volumetric efficiency of the compressor, estimated at suction pressure and discharge pressure equivalent to the safety valve setting.

## SIZING OF SAFETY VALVES DESIGNED TO DISCHARGE GAS OR VAPOUR AT CRITICAL FLOW (Ref. EN ISO 4126-1: 2013 and EN 13136 :2013)

Critical flow occurs when the back-pressure $p_b$ (the pressure existing immediately at the outlet of the valve) is lower than or equal to the critical pressure:

$$p_b \leq p_o \times \left(\frac{2}{k+1}\right)^{\left(\frac{k}{k-1}\right)} \text{ [bar abs]}$$

where:

- $p_o$ = actual relieving pressure, upstream the valve. It's equal to the set pressure plus overpressure; that is, the pressure increase over the set pressure at which the shutter has its total lift [bar abs]
- k = isentropic exponent of gas or vapour, based on the actual temperature and pressure conditions upstream of the valve during the discharge phase under full glow.

If k is unknown or difficult to determine, it is possible to assume:

$$p_{critica} = 0{,}5 \times p_o \text{ [bar abs]}$$

A valve that discharges to the atmosphere, is under in critical flow conditions.
The safety valves designed to discharge gas or vapour at critical flow must be sized using the following calculation, shown in Paragraph 7.2.5.2 of the EN 13136:2013 standard.

$$A_c = 3{,}469 \times \frac{Q_{md}}{C \times 0{,}9 \times K_d} \times \sqrt{\frac{v_o}{p_o}} \text{ [mm}^2\text{]}$$

where:

- $A_c$ = minimum net cross-section area of the valve orifice [mm$^2$]
- $Q_{md}$ = minimum required discharge capacity of safety valve [kg/h]
- $K_d$ = certified discharge ratio of safety valve
- $p_o$ = actual pressure upstream of the safety valve during discharge of the entire flow, see definition above. [bar abs]
- $v_o$ = specific volume of gas or vapour at discharge conditions $p_o$ and $T_o$, where $T_o$ is the fluid temperature at valve inlet, defined by the user or by the designer [m$^3$/kg]
- C = expansion rate as a function of the k coefficient in the isentropic equation calculated with the following formula:

$$C = 3{,}948 \times \sqrt{k \times \left|\frac{2}{k+1}\right|^{\frac{(k+1)}{(k-1)}}}$$

for this calculation, the value of k refers to a temperature of 25 °C. (Para. 7.2.3, EN 13136:2013 standard).
Table 18 provides the k and C values for:

- traditional HCFC and HFC refrigerants most commonly used
- new HFO and HFC/HFO blend refrigerants
- natural HC fluids and R744

To calculate the flow rate of a safety valve, under specific operating conditions, use the following formula, provided in Para. 7.2.5.2 of EN 13136:2013.

$$Q_m = 0{,}2883 \times C \times A \times 0{,}9 \times K_d \times \sqrt{\frac{p_o}{v_o}}$$

where:

- $Q_m$ = maximum discharge capacity of safety valve [kg/h]
- A = net cross-section area of the valve orifice [$mm^2$]

This formula was used to calculate the maximum discharge flow of the safety valve shown in:

- Table 3 and 4 for valves in series 3030
- Table 7, 8, 9, 10 and 11 for valves in series 3060
- Table 14 for valves in series 3061
- Table 17 for valves in series 3065

## INSTALLATION OF A SAFETY VALVE (Ref. EN 13136:2013)

As far as the installation of safety valves is concerned, remember these basic points:

- Safety valves must be installed near an area of the system where vapours or gases are present and where there is no fluid turbulence. They must be placed in as close to an upright position as possible, with the inlet connector turned downwards.

- Vessels joined by piping, of a diameter deemed by the manufacturer and the user to be adequate, without any stop valves between them, may be considered as a single vessel for the installation of a safety valve.

- The fitting between the valve and the equipment to be protected must be as short as possible. Furthermore, the cross-section of the piping must not be smaller than the valve inlet. In any case, EN 13136:2013 states that the pressure drop between the protected vessel and the safety valve, at discharge capacity, shall not exceed 3% of the setting value, po, including any accessory on the line.

- The location selected for installation of the safety valve must consider that valve operation involves the discharge of the refrigerant fluid under pressure, sometimes at high temperature. Where there is the risk of causing injuries to people nearby, exhaust piping must be provided, sized so as to not compromise valve operation. EN 13136:2013 states that this piping must not generate, at discharge capacity, a back-pressure exceeding 10% of pressure po , for unbalanced, conventional valves. In the event of multiple valves installed in parallel, it is highly recommended that each valve be fit with a dedicated exhaust line rather than a single manifold for all of the valves. The risk of the latter solution is to create an overpressure in the manifold determined when a valve discharges. This overpressure can modify the operating characteristics of all the other valves installed in parallel.

**Pressure losses in the upstream line**

To calculate the pressure losses in the upstream line (between vessel and safety valve) refer to Section 7.4 of EN 13136:2013.
The upstream pressure loss is given by:

$$\frac{\Delta p_{in}}{p_o} = 0{,}032 \times \left[\frac{A_c}{A_{in}} \times C \times K_{dr}\right]^2 \times \xi$$

where:

- $A_c$ = minimum calculated flow cross-section area [$mm^2$]
- $A_{in}$ = cross-section area of inlet tube to valve [$mm^2$]
- $K_{dr}$ = $K_d$ x 0.9, reduced discharge coefficient
- C = expansion rate as a function of the k coefficient in the isentropic equation for the refrigerant fluid
- ξ = sum of the of pressure loss coefficients $\xi_n$ of the individual components and piping.
  The coefficients $\xi_n$ refer to:
  - pipe element losses, such as fittings and elbows
  - valve losses
  - losses along the piping

  and are listed in standard EN 13136:2013, Table A.4.

**Pressure losses in the downstream line**

To calculate the pressure losses in the downstream line (between safety valve and atmosphere) refer to Section 7.4 of EN 13136:2013.
The downstream pressure loss is given by:

$$p_1 = \sqrt{0{,}064 \times \xi \times \left(\frac{A_c}{A_{out}} \times C \times K_{dr} \times p_o\right)^2 + p_2^{\,2}}$$

where:

- $P_1$ = inlet pressure to discharge line [bar abs]
- $P_2$ = outlet pressure to discharge line, equal to atmospheric pressure [bar abs]
- $A_c$ = minimum calculated flow cross-section area [$mm^2$]
- $A_{out}$ = cross-section area of valve outlet pipe [$mm^2$]
- $K_{dr}$ = $K_d$ x 0.9 , reduced discharge coefficient

- C = expansion rate as a function of the k coefficient in the isentropic equation for the refrigerant fluid
- $p_o$ = actual pressure downstream of the safety valve during discharge of the entire flow [bar abs]
- $\xi$ = sum of the of pressure loss coefficients $\xi_n$ of the piping

  The coefficients $\xi_n$ refer to:
  - pipe element losses, bends
  - losses along the piping

  e sono elencati nella Tabella A.4 della norma EN 13136:2013.

**EXAMPLE 1: Calculation of the flow rate ($Q_{md}$) and selection of the safety valve**
**(Increased pressure caused by a positive displacement compressor)**

**Compressor data**

- Bore: 82.5 mm
- Stroke: 69.8 mm
- Number of cylinders 4
- Rotational frequency 1450 rpm
- Clearance 4%
- Refrigerant fluid R407C

The theoretical displacement of the compressor is:

$$V = \frac{\pi}{4} \times 0{,}0825^2 \times 0{,}0698 \times 4 = 0{,}00149 \text{ [m}^3\text{]}$$

Maximum allowable pressure of the liquid condenser / receiver: PS = 25 bar Set pressure of the safety valve installed on the upper crown of the condenser housing: $p_{set}$ = 25 bar

**Calculation of the valve discharge pressure under full flow exhaust conditions:** using a safety valve in series 3065 with an overpressure of 10%:

$$p_0 = p_{set} \times \left(1 + \frac{10}{100}\right) + 1 = 28{,}5 \text{ [bar abs]}$$

Operating conditions of compressor at the safety valve discharge:

Condensation temperature: +65.2 °C (28.5 bar abs)

Evaporation temperature: +10 °C (6.33 bar abs)

These conditions, defined by the designer, are assumed to be the most unfavourable for the safety valve due to operating faults such as:

- Movement errors
- Non-operation of automatic safety devices that should have been triggered prior to the safety valve due to failures or other reasons

**Calculation of minimum full discharge capacity**

For cautionary reasons, ignoring the vapour overheating at the outlet of the evaporator, the volumetric efficiency of compressor is:

$$\eta_v = 1 - 0{,}04 \times \frac{p_{mandata}}{p_{aspirazione}} = 1 - 0{,}04 \times \frac{28{,}5}{6{,}33} = 0{,}82$$

and so the minimum required full discharge capacity:

$$Q_{md} = 60 \times V \times n \times \rho_{10} \times \eta_v =$$
$$60 \times 0{,}00149 \times 1450 \times 27{,}45 \times 0{,}82 = 2918 \text{ [kg/h]}$$

where $\rho_{10}$ = 27.45 [kg/m³] , saturated vapour density of R407C at a temperature of 10 °C

**Sizing of minimum flow cross-section area of the safety valve**

$$A_c = 3{,}469 \times \frac{Q_{md}}{C \times 0{,}9 \times K_d} \times \sqrt{\frac{v_o}{p_o}} =$$
$$3{,}469 \times \frac{2918}{2{,}51 \times 0{,}9 \times 0{,}87} \times \sqrt{\frac{0{,}0069}{28{,}5}} = 80{,}3 \text{ [mm}^2\text{]}$$

where:

- C = 2.51, corresponding to k exponent for R407C, equal to 1.14, according to Table 1
- $K_d$ = 0.87, certified discharge ratio of safety valve 3065/4
- $v_o$ = 0.0069 [m³/kg] , specific volume of the saturated vapour upstream of the safety valve during operation. This value refers to the following operating conditions upstream of the valve:
  - Pressure $p_o$ = 28.5 [bar abs]
  - Temperature $T_o$ = 65.2 [°C]

**Conclusion**: the selected safety valve is model 3065/4 with the following characteristics:

- certified discharge ratio, $K_d$ = 0.87
- nozzle cross-section area, A = 132.73 [mm²]
- set pressure, $p_{set}$ = 25 bar

**Verification of the system upstream the safety valve**

Assuming the valve installed is 3065/4C250, using a steel fitting with the following characteristics:

- $d_{in}$ = 17 [mm] , fitting inside diameter
- $A_{in}$ = 227 [mm²] , fitting inside cross-section area
- L = 60 [mm] , fitting length
- Condenser connection: Flush with the housing and with a sharp edge

The following information is taken from Table A.4 in standard EN 13136:2013:

- $\xi_{1\ (inlet)}$ = 0.25
- $\xi_{2\ (length)}$ = λ x L/ din = 0.02 x 60/17 = 0.07

  with λ = 0.02 for steel pipe
- $\xi_T = \xi_1 + \xi_2$ = 0.25 + 0.07 = 0.32

Between the safety valve and the steel fitting, a shut-off valve type 3064/44 is installed.

The main characteristics of this valve are:

- $d_R$ = 13 [mm] , inside valve diameter
- $A_R$ = 132.7 [mm²] , inside valve cross-section area
- kv = 10 [m³/h] , valve kv coefficient

The pressure loss coefficient $\xi_R$ of the shut-off valve is given by:

$$\xi_R = 2{,}592 \times \left[\frac{132{,}7}{10}\right]^2 \times 10^{-3} = 0{,}45$$

Total loss coefficient: $\xi_T + \xi_R$ = 0.77

Recalling the previously calculated cross-section, the characteristics of safety valve 3065/4 and refrigerant fluid R407C:

- $A_c$ = 80.3 [mm²]
- $K_{dr}$ = 0.87 x 0.9 =0.783
- C = 2.51

The pressure loss is given by:

$$\frac{\Delta p_{in}}{p_o} = 0{,}032 \times \left[\frac{80{,}3}{227} \times 2{,}51 \times 0{,}783\right]^2 \times 0{,}77 = 0{,}012$$

The pressure loss value obtained is admissible because it is lower than the value of 0.03 indicated in standard EN 13136:2013.

**Verification of system downstream the safety valve**

Suppose it is necessary to construct a discharge pipe on safety valve 3065/4C250, using 1" gas pipe with the following characteristics:

- $d_{out}$ = 30 [mm] , inside pipe diameter
- $A_{out}$ = 707 [mm²] , inside pipe cross-section area
- L = 3000 [mm] , pipe length
- 90° elbow with bending radius, R, equal to three times external diameter of pipe

The following information is taken from Table A.4 in standard EN 13136:2013:

- $\xi_{1\ (elbow)}$ = 0.25
- $\xi_{2\ (length)}$ = λ x L/ $d_{out}$ = 0.02 x 3000/30 = 2 where λ = 0.02 for steel pipe
- $\xi_T = \xi_1 + \xi_2$ = 0.25 + 2 = 2.25

The pressure loss is given by:

$$p_1 = \sqrt{0{,}064 \times 2{,}25 \times \left(\frac{80{,}3}{707} \times 2{,}51 \times 0{,}783 \times 28{,}5\right)^2 + 1^2} = 2{,}61$$

$$= \frac{\Delta p_{out}}{p_o} = \frac{2{,}61 - 1}{28{,}5} = 0{,}056 \text{ [bar]}$$

The pressure loss value obtained is admissible because it is lower than the value of 0.10 indicated in standard EN 13136:2013.

N.B.: All steps performed in the previous example, that is:

- calculation of minimum discharge capacity
- sizing of minimum cross-sectional area of the valve orifice
- calculation of the load loss in the upstream system
- calculation of the load loss in the downstream system

can be performed using the selection software available on the Castel website.

**EXAMPLE 2: Calculation of the flow rate ($Q_{md}$) and selection of the safety valve**
**(Increase in pressure caused by internal heat source)**

**Data for the liquid receiver**

- Refrigerant fluid — R404A
- Pressure equipment — 300 l liquid receiver
- External surface area of the vessel — 3.2 m²
- PS of the vessel — 28 bar

**Calculation of the valve discharge pressure under full flow exhaust conditions:** using a safety valve in series 3061 with an overpressure of 10%:

$$p_0 = (p_{set} \times 1{,}1) + 1 = (28 \times 1{,}1) + 1 = 31{,}8 \text{ [bar abs]}$$

**Calculation of minimum discharge capacity**

Calculation of the flow rate for the external heat source considering that there are flammable substances in such quantities as to feed a fire near the vessel to be protected.

$$Q_{md} = \frac{3600 \times \varphi \times A_{surf}}{h_{vap}} = \frac{3600 \times 10 \times 3{,}2}{67{,}28} = 1712 \text{ [kg/h]}$$

where:

- φ = density of heat flow rate, assumed to be 10 [kW/m²]
- $A_{surf}$ = external surface area of the vessel [m²]
- $h_{vap}$ = latent heat of vaporization of R404A at pressure $p_o$ [kJ/kg]

**Sizing of minimum flow cross-section area of the safety valve**

The safety valves to discharge gas or vapour at critical flow must be sized using the following formula.

$$A_c = 3{,}469 \times \frac{Q_{md}}{C \times 0{,}9 \times K_d} \times \sqrt{\frac{v_o}{p_o}} =$$

$$3{,}469 \times \frac{1712}{2{,}5 \times 0{,}9 \times 0{,}89} \sqrt{\frac{0{,}004231}{31{,}8}} = 34{,}2 \text{ [mm}^2\text{]}$$

where:

- $A_c$ = minimum net cross-section area of the valve orifice [mm²]
- $Q_{md}$ = minimum required discharge capacity of safety valve [kg/h]
- C = expansion rate as a function of the k coefficient in the isentropic equation for the R404A refrigerant fluid
- $K_d$ = certified discharge ratio of safety valve 3061/4
- $p_o$ = pressure downstream of the valve during operation [bar abs]
- $v_o$ = specific volume of the saturated vapour upstream of the safety valve during operation.
  This value refers to the following operating conditions upstream of the valve:
  - Pressure $p_o$ = 31.8 [bar abs]
  - Temperature $T_o$ = 64.7 [°C] (saturation temperature)

**Conclusion**: the selected safety valve is model 3061/4 with the following characteristics:

- certified discharge ratio, $K_d$ = 0.89
- nozzle cross-section area, A = 44.2 [mm²]
- set pressure, $p_{set}$ = 28 bar

of standard EN 13136:2013.

**Verification of the system upstream the safety valve**

Assuming the valve installed is 3061/4C280, using a steel fitting with the following characteristics:

- $d_{in}$ = 17 [mm] , fitting inside diameter
- $A_{in}$ = 227 [mm$^2$] , fitting inside cross-section area
- L = 60 [mm] , fitting length
- Receiver connection: Flush with the housing and with a sharp edge

The following data is taken from Table A.4:

- $\xi_{1\ (inlet)} = 0.25$
- $\xi_{2\ (length)} = \lambda \times L / d_{in} = 0.02 \times 60/17 = 0.07$ with $\lambda = 0.02$ for steel pipe
  - $\xi_T = \xi_1 + \xi_2 = 0.25 + 0.07 = 0.32$

Between the valve and the fitting, an exchange valve (type 3032/44) has been installed.
The main characteristics of this valve are:

- $d_R$ = 13 [mm] , inside valve diameter
- $A_R$ = 132.7 [mm$^2$] , inside valve cross-section area
- kv = 3.3 [m$^3$/h] , valve kv coefficient

The pressure loss coefficient $\xi_R$ of the exchange valve is given by:

$$\xi_R = 2{,}592 \times \left[\frac{132{,}7}{3{,}3}\right]^2 \times 10^{-3} = 4{,}19$$

Total loss coefficient: $\xi_T + \xi_R = 4.51$

Recalling the previously calculated cross-section, the characteristics of safety valve 3061/4 and refrigerant fluid R404A:

- $A_c$ = 34.2 [mm$^2$]
- $K_{dr}$ = 0.89 x 0.9 =0.801
- C = 2.50

The pressure loss is given by:

$$\frac{\Delta p_{in}}{p_o} = 0{,}032 \times \left[\frac{34{,}2}{227} \times 2{,}50 \times 0{,}801\right]^2 \times 4{,}51 = 0{,}013$$

The pressure loss value obtained is admissible because it is lower than the value of 0.03 indicated in standard EN 13136:2013.

TABLE 18 : Exponent K of the isoentropic equation. Expansion coefficient C. Vapour density ϱ

| | R134a | R22 | R32 | R404A | R407C | R410A | R448A | R449A | R450A | R452A | R507 | R1234yf | R1234ze | R290 | R600 | R600a | R744 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group PED | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 2 |
| k | 1,12 | 1,17 | 1,24 | 1,12 | 1,14 | 1,17 | 1,14 | 1,14 | 1,11 | 1,11 | 1,10 | 1,07 | 1,07 | 1,19 | 1,10 | 1,10 | 1,30 |
| C | 2,50 | 2,54 | 2,59 | 2,50 | 2,51 | 2,54 | 2,51 | 2,51 | 2,49 | 2,49 | 2,48 | 2,45 | 2,45 | 2,55 | 2,48 | 2,48 | 2,63 |
| ϱ [kg/m$^3$] (1) | 20,23 | 28,82 | 30,23 | 41,66 | 27,45 | 41,92 | 30,63 | 31,11 | 18,49 | 40,62 | 44,03 | 24,27 | 16,45 | 13,78 | 3,87 | 5,87 | 26,12 |

(1) $\varrho_{10}$ [kg/m$^3$] for all refrigerant, excluded R744
$\varrho_{-40}$ [kg/m$^3$] for R744

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