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Safety devices for protection against excessive pressure —

Part 10: Sizing of safety valves for gas/liquid two-phase flow

Dispositifs de sécurité pour protection contre les pressions excessives —

Partie 10: Dimensionnement des soupapes de sûreté pour les débits diphasiques gaz/liquide

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Foreword

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ISO 4126-10 was prepared by Technical Committee ISO/TC 185, *Safety devices for protection against excessive pressure*.

ISO 4126 consists of the following parts, under the general title *Safety devices for protection against excessive pressure*:

— *Part 1: Safety valves*

— *Part 2: Bursting disc safety devices*

— *Part 3: Safety valves and bursting disc safety devices in combination*

— *Part 4: Pilot-operated safety valves*

— *Part 5: Controlled safety pressure-relief systems (CSPRS)*

— *Part 6: Application, selection and installation of bursting disc safety devices*

— *Part 7: Common data*

— *Part 9: Application and installation of safety devices excluding stand-alone bursting disc safety devices*

— *Part 10: Sizing of safety valves for gas/liquid two-phase flow*

Introduction

Well-established recommendations exist for the sizing of safety devices and the connected inlet and outlet lines for steady-state, single-phase gas/vapour or liquid flow. However, in the case of a two-phase vapour/liquid flow, the required relieving area to protect a system from overpressure is larger than that required for single-phase flow when the same vessel condition and heat release are considered. The requirement for a larger relief area results from the fact that, in two-phase flow, the liquid partially blocks the relieving area for the vapour flow, by which most of the energy is removed by evaporation from the vessel.

This part of ISO 4126 includes a widely usable engineering tool for the sizing of the most typical safety valves in fluid services encountered in various industrial fields. It is based on the omega parameter method, which is extended by a thermodynamic non-equilibrium parameter. Without this extension for considering non-equilibrium, the proposed method is in accordance with API RP 520. A balance is attempted between the accuracy of the method and the unavoidable uncertainties in the input and property data under the actual sizing conditions. There are other sizing methods available, which are referred to in this part of ISO 4126.

In case of two-phase flow, the fluid state and, hence, the mass flow rate required to be discharged are dependent on the size of the safety valve. Furthermore, the two-phase mass flow rate through a safety valve essentially depends on the mass flow quality (mass fraction of vapour) of the fluid at the inlet of the valve. Because these parameters are, in most cases, not readily at hand during the design procedure of a relief device, this part of ISO 4126 also includes a comprehensive procedure that covers the determination of the fluid-phase composition at the safety valve inlet. This fluid-phase composition depends on a scenario that leads to the pressure increase. Therefore, the recommended sizing procedure starts with the definition of the sizing case and includes a method for the prediction of the mass flow rate required to be discharged and the resulting mass flow quality at the inlet of the safety valve.

If flow is confirmed to be single-phase up to the narrowest flow cross-section, it is appropriate to use ISO 4126-1. The equations of ISO 4126-1 are also included in this part of ISO 4126, modified to SI units, to calculate the flow rates at the limiting conditions of single-phase flow.

Safety devices for protection against excessive pressure —

Part 10:
Sizing of safety valves for gas/liquid two-phase flow

1 Scope

This part of ISO 4126 specifies the sizing of safety valves for gas/liquid two-phase flow in pressurized systems such as reactors, storage tanks, columns, heat exchangers, piping systems or transportation tanks/containers. The possible fluid states at the safety valve inlet that can result in two-phase flow are given in Table 1.

NOTE The expression “safety valve” is a synonym for valves as described in ISO 4126-1, ISO 4126-4 and ISO 4126-5.

Table 1 — Possible fluid state at the inlet of the safety valve that can result in two-phase flow

Fluid state at valve inlet	Cases	Examples
liquid	subcooled (possibly flashing in the safety valve) saturated with dissolved gas	cold water boiling water CO_2/water
gas/vapour	near saturated vapour (possibly condensing in the safety valve)	steam
gas/liquid	vapour/liquid non-evaporating liquid and non-condensable gas (constant quality) gas/liquid mixture, when gas is desorbed or produced	steam/water air/water

2 Normative references

The following referenced documents are indispensable for the application 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, *Safety devices for protection against excessive pressure — Part 1: Safety valves*

3 Terms and definitions

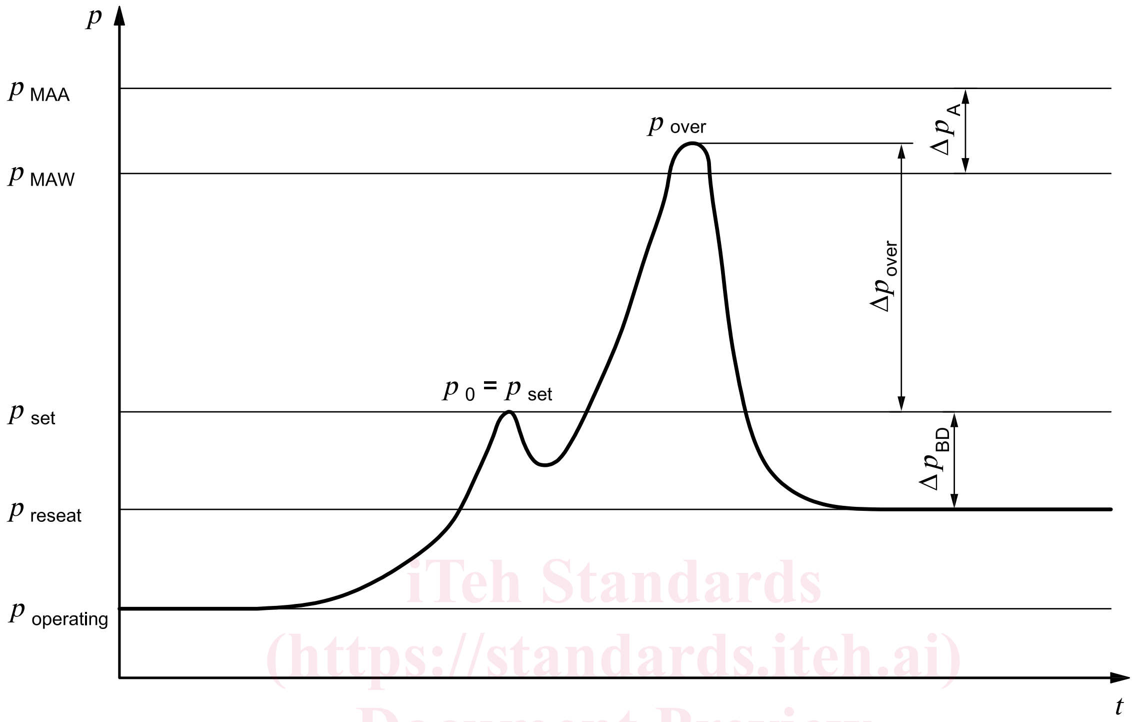
For the purposes of this document, the terms and definitions given in ISO 4126-1 and the following apply.

3.1
pressurized system
equipment such as reactors, storage tanks, columns, heat exchangers, piping systems and transport tanks/containers being protected against impermissible pressure accumulation by a safety valve

3.2 Pressure

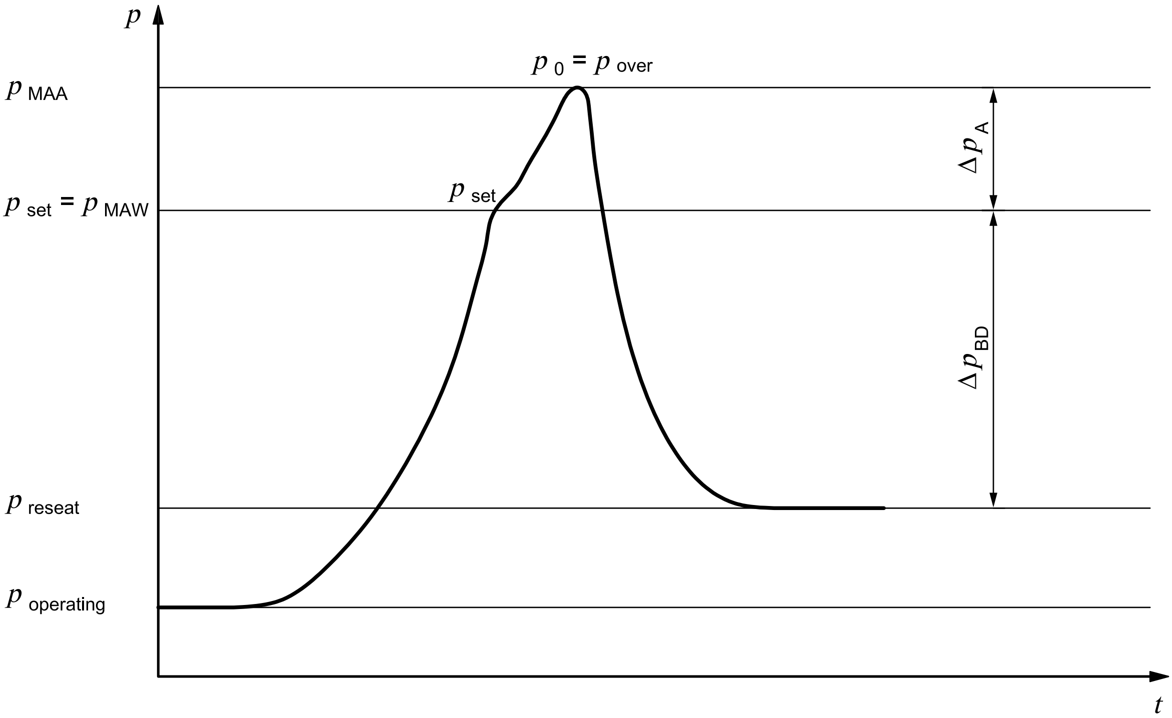
NOTE 1 See Figures 1 a) and 1 b) for an illustration of the relationship of the pressures defined in 3.2.1 to 3.2.7.

NOTE 2 In contrast to the definition used in other parts of this International Standard, for example ISO 4126-1, all pressures are absolute pressures and not gauge pressures.



a) Pressure history of a typical tempered reaction system that is adequately sized

Figure 1 — Relationship of the defined pressures (*continued*)



b) Typical pressure history for an externally heated gas vented system

Key

p_{MAA} maximum allowable accumulated pressure

p_{MAW} maximum allowable working absolute pressure

p_{set} opening pressure

p_{reseat} reseating pressure

$p_{operating}$ operating pressure

Δp_{BD} blowdown

p_0 sizing pressure equal to p_{set} as shown in Figure 1 a) and equal to p_{over} as shown in Figure 1 b)

p_{over} overpressure

Δp_A maximum allowable accumulation

Δp_{over} change in overpressure

Figure 1 — Relationship of the defined pressures

3.2.1
maximum allowable working absolute pressure

p_{MAW}

maximum pressure permissible at the top of a pressurized system in its operating position for designated temperature

3.2.2
maximum allowable accumulated pressure

p_{MAA}

sum of the maximum allowable working pressure and the maximum allowable accumulation

NOTE The maximum allowable accumulation is established by applicable code for operating and fire contingencies.

3.2.3
maximum allowable accumulation

Δp_A

pressure increase over the maximum allowable working pressure of a pressurized system during discharge through the safety valve

NOTE The maximum allowable accumulation is expressed in pressure units or as a percentage of the maximum allowable working pressure.

3.2.4
opening pressure
p_{set}
predetermined absolute pressure at which a safety valve under operating conditions at the latest commences to open

NOTE 1 The opening pressure is the set pressure defined in ISO 4126-1 expressed as absolute pressure.

NOTE 2 See Figures 1 a) and 1 b) for details.

3.2.5
absolute overpressure
Δp_{over}
pressure increase over the opening pressure of the safety valve, p_{set}

NOTE 1 The maximum absolute overpressure is the same as the maximum accumulation, Δp_A, when the opening pressure of the safety valve is set at the maximum allowable working pressure of the pressurized system.

NOTE 2 The absolute overpressure is expressed in pressure units or as a percentage of the opening pressure.

3.2.6
overpressure
p_{over}
maximum pressure in the pressurized system during relief, i.e. pressure less or equal to the maximum accumulated pressure

3.2.7
sizing pressure
p_0
pressure at which all property data, especially the compressibility coefficient, ω, are calculated for sizing the safety valve

NOTE In the case of tempered and hybrid reactive systems, the sizing pressure shall be equal to the opening pressure. In the case of non-reactive and gassy systems, the designer may choose a higher value for the sizing pressure, but it shall not exceed the maximum allowable accumulated pressure.

3.2.8
critical pressure
p_{crit}
fluid-dynamic critical pressure occurring in the narrowest flow cross-section of the safety valve and/or at an area enlargement in the outlet line

NOTE At this pressure, the mass flow rate approaches a maximum at a given sizing condition in the pressurized system. Any further decrease of the downstream pressure does not increase the flow rate further. Usually, the critical pressure occurs in the safety valve, either in the valve seat, inlet nozzle and/or valve body. In long safety valve outlet lines, multiple critical pressures can also occur.

3.2.9
critical pressure ratio
η_{crit}
ratio of critical pressure to the sizing pressure

3.2.10
back pressure
p_b
pressure that exists at the outlet of a safety valve as a result of pressure in the discharge system

NOTE Back pressure can be either constant or variable; it is the sum of superimposed and built-up back pressure.

3.2.11
built-up back pressure
pressure existing at the outlet of the safety valve caused by flow through the valve and discharge system

3.2.12
superimposed back pressure
pressure existing at the outlet of the safety valve at the time when the device is required to operate

NOTE Superimposed back pressure is the result of pressure in the discharge system from other sources.

3.2.13
inlet pressure loss
Δp_{loss}
irrecoverable pressure decrease due to flow in the piping from the equipment that is protected to the inlet of the safety valve

3.2.14
blowdown
Δp_{BD}
difference between opening and reseating pressure

NOTE Blowdown is normally stated as a percentage of the opening pressure.

3.3 Flow rate

3.3.1
mass flow rate required to be discharged from a pressurized system
$Q_{\text{m,out}}$
mass flow rate required to be discharged from a pressurized system, such that the pressure does not exceed maximum allowable accumulated pressure in the pressurized system during relief

3.3.2
feed mass flow rate into the pressurized system
$Q_{\text{m,feed}}$

maximum mass flow rate through a feed line or control valve fed into the pressurized system being protected

3.3.3
dischargeable mass flux through the safety valve
$\dot{m}_{\text{SV}}$
mass flow rate per unit area through a safety valve at the sizing conditions calculated by means of the certified discharge coefficients for gas and liquid flow

NOTE See Equation (35).

3.3.4
discharge coefficient for gas and liquid flow
$K_{\text{dr,g}}$ ⟨for gas⟩
$K_{\text{dr,l}}$ ⟨for liquid⟩
correction factor defined by the ratio of the theoretically dischargeable mass flux through the safety valve to an experimentally determined mass flux through a valve of the same manufacturer's type

NOTE The discharge coefficient is related to the valve seat cross-section and accounts for the imperfection of flow through a safety valve compared to that through a reference model (ideal nozzle). Certified values for gas and liquid flow, K_{d}, are usually supplied by valve manufacturers or determined by experiment. Rated discharge coefficients K_{dr}, equal to 0,9 K_{d}, are used to calculate the safety valve sizing area.

3.4 Flow area

3.4.1
safety valve sizing area
A_0
most essential result of the sizing procedure in accordance with this part of ISO 4126 required to select an adequately sized safety valve

NOTE It is important that the rated discharge coefficient and the dischargeable mass flux through the safety valve be related to this specific area. The sizing area is defined as the valve seat area.

3.4.2
effective flow area of the feed line or the control valve
A_{feed}
discharge flow area of a feed line or control valve in the line to the pressurized system

3.5 Fluid state

3.5.1
gas/liquid mixture
fluid mixture composed of both a liquid part and a gas part, in which the gas is not necessarily of the same chemical composition as the liquid

3.5.2
tempered system
fluid system in which some energy is removed from the liquid phase by evaporation or flashing

3.5.3
gassy system
fluid system in which permanent gas is generated (e.g. by chemical reaction or by evolution from solution) and in which no significant amount of energy is removed from the liquid by evaporation at the sizing conditions

3.5.4
hybrid system
fluid system that exhibits characteristics of both tempered and gassy systems to a significant extent at the sizing conditions

3.5.5
thermal runaway reaction
uncontrolled exothermic chemical reaction

3.6
thermodynamic critical pressure
p_c
state property, together with thermodynamic critical temperature, at the thermodynamic critical point

3.7
thermodynamic critical temperature
T_c
state property, together with thermodynamic critical pressure, at the thermodynamic critical point

3.8
sizing temperature
T_0
temperature of the pressurized system at the sizing conditions

3.9
overtemperature
T_{over}
maximum temperature in the pressurized system during relief

3.10
saturation temperature difference
ΔT_{over}
difference between the saturation temperature at the maximum pressure during relief, p_{over}, and the saturation temperature at the sizing pressure, p_0

3.11
sizing condition
condition in the pressurized system defined by the sizing pressure and sizing temperature

3.12
critical filling threshold
ϕ_{limit}
maximum initial liquid filling level (liquid hold-up) in the pressurized system at the sizing conditions for which single-phase gas or vapour flow occurs during venting

NOTE For higher filling levels, two-phase flow is assumed to occur.

3.13
initial liquid filling level
ϕ_0
initial liquid filling level (liquid hold-up) in the pressurized system at the sizing conditions

3.14
inlet line
piping and associated fittings connecting the pressurized system to the safety valve inlet

3.15
outlet line
piping and associated fittings connecting the safety valve outlet to a containment system or the atmosphere

4 Symbols and abbreviated terms

Variable	Definition	Unit
A_{feed}	effective flow area of the feed line or the control valve	m^2
A_{fire}	total wetted surface area exposed to a fire	m^2
A_{heat}	area of heat exchange in the pressurized system in case of external heat input	m^2
A_0	minimum required safety valve seat area (safety valve sizing area)	m^2
A_v	cross-sectional area in a vertical cylindrical vessel	m^2
B_{heat}	(maximum) overall heat transfer coefficient; see Equation (23)	$W/(m^2 \cdot K)$
C	flow coefficient	—
c_p	specific heat capacity at constant pressure	J/(kg·K)
D	inner vessel diameter of a vertical cylindrical vessel	m
$\frac{dp}{dt}$	rate of pressure increase in the pressurized system	Pa/s

Variable	Definition	Unit
$\frac{\mathrm{d}T}{\mathrm{d}t}$	reaction self-heat rate inside the pressurized system	K/s
F	environmental factor for heat input from fire (see 6.4.3.2)	—
g_n	acceleration due to gravity	m/s^2
H_l	height of liquid level in a vertical cylindrical vessel (bottom of vessel to liquid level)	m
k_∞	correlating parameter to calculate the characteristic bubble-rise velocity	—
$K_\mathrm{dr,2ph}$	two-phase flow valve discharge coefficient	—
$K_\mathrm{dr,g}$	certified valve discharge coefficient for single-phase gas/vapour flow	—
$K_\mathrm{dr,l}$	certified valve discharge coefficient for single-phase liquid flow	—
K_vs	liquid discharge factor for fully opened control valve in the feed line	m^3/h
$\dot{m}$	mass flux	$kg/(m^2 \cdot s)$
$\dot{m}_\mathrm{SV}$	dischargeable mass flux through the safety valve	$kg/(m^2 \cdot s)$
M_0	total liquid mass in the pressurized system at the sizing conditions	kg
M	molecular mass	kg/kmol
N	boiling delay factor accounting for thermodynamic non-equilibrium	—
p	pressure in the pressurized system	Pa
p_b	back pressure	Pa
p_c	thermodynamic critical pressure	Pa
p_crit	fluid-dynamic critical pressure	Pa
p_MAW	maximum allowable working absolute pressure	Pa
p_MAA	maximum allowable accumulated pressure	Pa
p_0	sizing pressure	Pa
p_over	maximum pressure in a pressurized system during relief; see Figures 1 a) and 1 b)	Pa
p_set	opening pressure	Pa
q_fire	dimensionless fire exposure flux	—
$Q_\mathrm{m,out}$	mass flow rate required to be discharged from a pressurized system	kg/s
$Q_\mathrm{m,feed}$	feed mass flow rate into the pressurized system	kg/s
$Q_\mathrm{m,SV}$	dischargeable mass flow rate through the safety valve	kg/s
$\dot{Q}$	heat input into the pressurized system, either by runaway reaction or by external heating	W
$\dot{Q}^*_\mathrm{acc}$	ratio of the sensible heat to the latent heat	—
$\dot{Q}^*_\mathrm{in}$	ratio of total heat rate input to energy removed per unit time by evaporation	—
$\dot{Q}^*_\mathrm{mean}$	average dimensionless heat input; see Table 2, Equation (50)	—
$\dot{Q}_0$	heat rate into the pressurized system at the sizing conditions; see Table 2, Equation (52)	W
R	universal gas constant (8 314,2 J/(kmol·K)	J/(kmol·K)