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Safety devices for protection against excessive pressure —

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

Dispositifs de sécurité pour protection contre les pressions excessives —

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

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Contents

Page

Foreword ... v

Introduction ... vi

1 Scope ... 1

2 Normative references ... 1

3 Terms and definitions ... 1
  3.1 General ... 1
  3.2 Pressure ... 2
  3.3 Flow rate ... 4
  3.4 Flow area ... 5
  3.5 Fluid state ... 5
  3.6 Temperature ... 5

4 Symbols and abbreviated terms and figures ... 6
  4.1 Symbols ... 6
  4.2 Abbreviated terms ... 8
  4.3 Figures ... 9

5 Application range of the method ... 11
  5.1 General ... 11
  5.2 Limitations of the method for calculating the two-phase mass flux in safety devices ... 11
    5.2.1 Flashing flow ... 11
    5.2.2 Condensing flow ... 12
    5.2.3 Flashing flow for multi-component liquids ... 12
    5.2.4 Dissolved gases ... 12
    5.2.5 Compressibility coefficient ω ... 13
  5.3 Limitations of the method for calculating the mass flow rate required to be discharged ... 13
    5.3.1 Rate of temperature and pressure increase ... 13
    5.3.2 Immiscible liquids ... 13

6 Sizing steps ... 13
  6.1 General outline of sizing steps ... 13
  6.2 Step 1 — Identification of the sizing case ... 14
  6.3 Step 2 — Flow regime at the inlet of the vent line system ... 15
    6.3.1 General ... 15
    6.3.2 Phenomenon of level swell ... 15
    6.3.3 Influence of liquid viscosity and foaming behaviour on the flow regime ... 15
    6.3.4 Prediction of the flow regime (gas/vapour or two-phase flow) ... 17
  6.4 Step 3 — Calculation of the mass flow rate required to be discharged ... 20
    6.4.1 General ... 20
    6.4.2 Pressure increase caused by an excess in-flow ... 20
    6.4.3 Pressure increase due to external heating ... 22
    6.4.4 Pressure increase due to thermal runaway reactions ... 25
  6.5 Step 4 — Calculation of the dischargeable mass flux through and pressure change in the vent line system ... 29
    6.5.1 General ... 29
    6.5.2 Two-phase flow discharge coefficient, $K_{dr,2ph}$ ... 32
    6.5.3 Dimensionless mass flow rate, C ... 33
    6.5.4 Compressibility coefficient, ω (numerical method) ... 34
    6.5.5 Calculation of the downstream stagnation condition ... 35
    6.5.6 Slip correction for non-flashing two-phase flow ... 35
    6.5.7 Slip correction for two-phase flow in straight pipes ... 36
  6.6 Step 5 — Ensure proper operation of safety valve vent line systems under plant conditions ... 36
  6.7 Simultaneous calculation of the dischargeable mass flux and pressure change in the vent line system ... 36
  6.8 Summary of calculation procedure ... 37

Annex A (informative) **Identification of sizing scenarios** 44
Annex B (informative) **Example calculation of the mass flow rate to be discharged** 46
Annex C (informative) **Example of calculation of the dischargeable mass flux and pressure change through connected vent line systems** 50
Annex D (informative) **Environmental factor** 67
Bibliography 68

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 185, *Safety devices for protection against excessive pressure*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 69, *Industrial valves*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 4126-10:2010), which has been technically revised.

The main changes are as follows:

- opening of the method for sizing of bursting discs;
- more thorough iteration for the calculation of the flow rate;
- allowing for slip;
- allowing for velocity in the outlet line and pressure losses in front and after the safety device;
- added an example for flow rate to be discharged (Annex B);
- added an example for dischargeable mass flow rate added and method to estimate pressure drop in pipe flow (Annex C);
- various correction.

A list of all parts in the ISO 4126 series can be found on the ISO website.

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

Well-established recommendations exist for the sizing of safety valves and bursting discs 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 document includes a widely applicable method for the sizing of the most typical safety valves and bursting discs in fluid services encountered in various industrial fields (see Table 1). It is based on the omega parameter method, which is extended by a thermodynamic non-equilibrium parameter. 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.

In case of two-phase flow, the safety device size can influence the fluid state and, hence, the mass flow rate to be discharged. Furthermore, the two-phase mass flow rate through a safety device essentially depends on the mass flow quality (mass fraction of vapour) of the fluid at the inlet of the device. Because these parameters are, in most cases, not readily at hand during the design procedure of a relief device, this document also includes a comprehensive procedure that covers the determination of the fluid-phase composition at the safety device 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 device.

The formulae of ISO 4126-7:2013/Amd 1:2016 for single-phase flow up to the narrowest flow cross-section are included in this document, modified to SI units, to calculate the flow rates at the limiting conditions of single-phase gas and liquid flow.

In this document, the unit bar for pressures is being used 100 000 Pa = 1 bar.

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

Fluid state at device inlet	Cases	Examples
liquid	subcooled (possibly flashing in the safety device) saturated with dissolved gas	cold water boiling water CO_2/water
gas/vapour	near saturated vapour (possibly condensing in the safety device)	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

Safety devices for protection against excessive pressure —

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

1 Scope

This document specifies the sizing of safety valves and bursting discs for gas/liquid two-phase flow in pressurized systems such as reactors, storage tanks, columns, heat exchangers, piping systems or transportation tanks/containers, see Figure 2. The possible fluid states at the safety device inlet that can result in two-phase flow are given in Table 1.

NOTE The pressures used in this document are absolute pressures, not gauge pressures.

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 4126-7:2013/Amd 1:2016, *Safety devices for protection against excessive pressure — Part 7: Common data*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4126-7:2013/Amd 1:2016 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 General

3.1.1
pressurized system
equipment being protected against excessive pressure accumulation by a safety device

EXAMPLE Equipment can be reactors, storage tanks, columns, heat exchangers, piping systems and transport tanks/containers, etc.

3.1.2
critical filling threshold
ϕ_{limit}
maximum initial liquid filling threshold (liquid hold-up) in the *pressurized system* (3.1.1) at sizing conditions, up to where vapour disengagement occurs and single-phase gas or vapour flow can be expected

Note 1 to entry: The critical filling threshold is expressed as a ratio of the total volume of the system.

Note 2 to entry: For filling levels above the critical filling threshold, two-phase flow is assumed to occur.

3.1.3
initial liquid filling level
ϕ_0
liquid hold-up in the *pressurized system* (3.1.1) at the sizing conditions

Note 1 to entry: The initial liquid filling level is expressed as a ratio of the total volume of the system.

3.1.4
inlet line
piping and associated fittings connecting the *pressurized system* (3.1.1) to the safety device inlet

3.1.5
outlet line
piping and associated fittings connecting the safety device outlet to a containment system or the atmosphere

3.1.6
vent line system
combination of safety device, *inlet line* (3.1.4) and *outlet line* (3.1.5)

3.1.7
cryogenic vessel
vacuum jacketed vessel intended for application at low temperature involving liquefied gases

3.2 Pressure

3.2.1
maximum allowable working pressure
p_{MAW}
maximum pressure permissible at the top of a *pressurized system* (3.1.1) in its operating position for designated temperature

3.2.2
maximum allowable accumulated pressure
p_{MAA}
sum of the *maximum allowable working pressure* (3.2.1) and the *maximum allowable accumulation* (3.2.3)

Note 1 to entry: The maximum allowable accumulation is established by applicable code for operating and fire contingencies.

3.2.3
maximum allowable accumulation
Δp_{MAA}
pressure increase over the *maximum allowable working pressure* (3.2.1) of a *pressurized system* (3.1.1) during discharge through the safety device

Note 1 to entry: 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_{open}
predetermined absolute pressure at which a safety valve under operating conditions at the latest commences to open

3.2.5
absolute overpressure
Δp_{over}
pressure increase over the *opening pressure* (3.2.4), p_{open}, of the safety device

Note 1 to entry: The maximum absolute overpressure is the same as the maximum accumulation, Δp_{MAA}, when the opening pressure of the safety valve is set at the *maximum allowable working pressure* (3.2.1) of the *pressurized system* (3.1.1).

Note 2 to entry: 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* (3.1.1) 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 device

Note 1 to entry: In the case of tempered and hybrid reactive systems, the sizing pressure shall be as low as reasonable possible, but should not affect the normal operation. In the case of non-reactive and *gassy systems* (3.5.3), the designer may choose a higher value for the sizing pressure, but it shall not exceed the *maximum allowable accumulated pressure* (3.2.2).

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* (3.1.5)

Note 1 to entry: At this pressure, the mass flow rate approaches a maximum at a given sizing condition in the *pressurized system* (3.1.1). 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 the bursting disc, critical pressure can occur downstream of the device at a minimum flow area, at the exit of the vessel or a change in pipe diameter. In long safety device outlet lines, multiple critical pressures can also occur.

3.2.9
stagnation condition

condition when fluid is at rest

EXAMPLE Fluid in large vessels, where the flow velocity is almost zero, even in case of a discharge of mass.

3.2.10
critical pressure ratio

η_{crit}

ratio of *critical pressure* (3.2.8) to the *sizing pressure* (3.2.7)

3.2.11
thermodynamic critical pressure

p_{c}

state property, together with *thermodynamic critical temperature* (3.6.1), at the thermodynamic critical point

3.2.12
back pressure

p_{b}

pressure that exists at the outlet of a safety device as a result of pressure in the discharge system

Note 1 to entry: Back pressure can be either constant or variable; it is the sum of superimposed and *built-up back pressure* (3.2.13).

3.2.13
built-up back pressure

pressure existing at the outlet of the safety device caused by flow through the valve or bursting disc and discharge system

3.2.14

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 device

3.2.15

blowdown

Δp_{BD}

difference between *opening pressure* (3.2.4) and reseating pressure of a safety valve

Note 1 to entry: Blowdown is normally stated as a percentage of the opening pressure.

3.2.16

dimensionless reduced pressure

p_{red}

local pressure divided by the *thermodynamic critical pressure* (3.2.11) of the substance

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 avoid that the pressure exceeds the *maximum allowable accumulated pressure* (3.2.2) in the *pressurized system* (3.1.1) 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* (3.1.1) being protected

3.3.3

dischargeable mass flux through the safety device

$\dot{m}_{\text{SD}}$

mass flow rate per area through a safety device at the sizing conditions calculated by means of the certified discharge coefficients for gas and liquid flow

Note 1 to entry: See Formula (48).

3.3.4

certified valve discharge coefficient for single-phase gas/vapour respectively liquid flow

$K_{\text{dr,g}}$ ⟨gas⟩

$K_{\text{dr,l}}$ ⟨liquid⟩

correction factor defined by the ratio of the theoretically *dischargeable mass flux through the safety device* (3.3.3) to an experimentally determined mass flux through a device of the same manufacturer's type

Note 1 to entry: The discharge coefficient of a safety valve is related to the valve seat cross-section and accounts for the imperfection of flow through the device 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.

Note 2 to entry: The discharge coefficient of a bursting disc is related to the disc cross-section and accounts for the imperfection of flow through the device compared to that through a reference model.

3.4 Flow area

3.4.1

safety device sizing area

A_0

most essential result of the sizing procedure in accordance with this document required to select an adequately sized safety device and defined as the minimum cross-section of flow area

Note 1 to entry: It is important that the *dischargeable mass flux through the safety device* (3.3.3) be related to this specific 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* (3.1.1)

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* (3.5.3) to a significant extent at the sizing conditions

3.5.5

thermal runaway reaction

uncontrolled or undesired exothermic chemical reaction

3.6 Temperature

3.6.1

thermodynamic critical temperature

T_c

state property, together with *thermodynamic critical pressure* (3.2.11), at the thermodynamic critical point

3.6.2

sizing temperature

T_0

temperature of the *pressurized system* (3.1.1) at the sizing conditions

3.6.3

overtemperature

T_{over}

maximum temperature in the *pressurized system* (3.1.1) during relief

3.6.4
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* (3.2.7), p_0

3.6.5
dimensionless reduced temperature

T_{red}

local temperature divided by the *thermodynamic critical temperature* (3.6.1) of the substance

4 Symbols and abbreviated terms and figures

4.1 Symbols

Variable	Definition	Unit
A_{feed}	effective flow area of the feed line or the control valve	m^2
A_{fire}	The wetted surface area to be considered for the heat transfer due to fire. In detail, it is the partial surface area of a vertical cylindrical vessel wetted by internal liquid and located within 7,5 m vertically from ground or from any surface capable of sustaining a pool fire. Depending on the fire case considered it may either include the wall of the bottom or the bottom wall of the vessel is not included.	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 device area (safety device sizing area). In general, for safety valves it is the safety valve seat area and for bursting discs the minimum net flow area.	m^2
A_{R}	cross-sectional area in a vertical cylindrical vessel	m^2
B_{heat}	(maximum) overall heat transfer coefficient, see Formula (24)	$\mathrm{W/(m^2{\cdot}K)}$
C	dimensionless mass flow rate	—
C_1	flow conversion factor 1	
C_2	flow conversion factor 2	
c_{p}	specific heat capacity at constant pressure	$\mathrm{J/(kg{\cdot}K)}$
D	inner vessel diameter of a vertical cylindrical vessel	m
d	diameter	m
$\frac{\mathrm{d}p}{\mathrm{d}t}$	rate of pressure increase in the pressurized system	Pa/s
$\frac{\mathrm{d}T}{\mathrm{d}t}$	reaction self-heat rate inside the pressurized system	K/s
F	environmental factor for heat input from fire (see 6.4.3.2)	—
g	acceleration due to gravity	$\mathrm{m/s^2}$
H_{l}	height of liquid level in a vertical cylindrical vessel (bottom of vessel to liquid level)	m
H_{fire}	maximum height of flames above ground	m
H_{vessel}	height of the bottom of the vessel flames above ground	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_{R}	velocity head loss for bursting disc	—

Variable	Definition	Unit
K_{vs}	Liquid discharge factor for fully opened control valve in the feed line, which characterizes A_{feed} of the feed line or control valve of a frictionless valve with the same pressure difference for the same flow rate.	m^3/h
L	Vertical length of a flow restriction to account for potential energy change. For safety valves and bursting discs L may be set to 0. For inlet and outlet lines the heights of the system shall be considered.	m
$\dot{m}$	mass flux	$\mathrm{kg}/(\mathrm{m}^2\cdot\mathrm{s})$
$\dot{m}_{\mathrm{SD}}$	dischargeable mass flux through the safety device	$\mathrm{kg}/(\mathrm{m}^2\cdot\mathrm{s})$
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 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 Figure 1	Pa
p_{open}	opening pressure	Pa
$\dot{q}_{\mathrm{fire}}$	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
$Q_{\mathrm{m,SD}}$	dischargeable mass flow rate through the safety device	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 input to energy flow removed by evaporation	—
R	universal gas constant (8 314,2 J/(kmol·K))	J/(kmol·K)
R_{2ph}	two-phase multiplier	—
T	temperature in the pressurized system	K
T_{c}	thermodynamic critical temperature	K
T_{heat}	maximum possible temperature of the external heat source	K
T_0	temperature of the pressurized system at the sizing conditions	K
T_{over}	maximum temperature in the pressurized system during relief	K
$u_{\mathrm{g},0}$	superficial gas velocity in the free-board gas volume of a vertical cylindrical vessel at the sizing conditions	m/s
u_{∞}	characteristic bubble-rise velocity of the gas/vapour in the liquid	m/s
u^{*}	dimensionless bubble-rise velocity	—
v	specific volume in the pressurized system	m^3/kg
V	volume of the pressurized system	m^3
$\dot{x}$	mass flow quality, i.e. the ratio of the gas mass flow rate to the total mass flow rate of a two-phase mixture	—
Z	real gas factor	—
β	ratio of the vent inlet diameter to the throat diameter	—

Variable	Definition	Unit
ε_0	void fraction in the pressurized system at the sizing conditions for a homogeneous two-phase mixture	—
$\varepsilon_{\text{seat}}$	void fraction in the narrowest cross-section, see Formula (50)	—
$\zeta_{\text{v,ref}}$	Resistance coefficient of reference, either inlet or outlet	—
η	pressure ratio, either η_{crit} or η_{b}	—
η_{b}	ratio of the safety valve back pressure to the sizing pressure	—
η_{crit}	critical pressure ratio	—
η_{S}	ratio of the saturation pressure corresponding to the sizing temperature and the sizing pressure (measure of liquid subcooling), see Formula (64)	—
θ	Angle of a vent line to the horizontal	°
κ	isentropic coefficient	—
ρ	fluid density	kg/m^3
ρ_{H2O}	density of water during experiments to measure the K_{vs} value at a temperature of 5 °C	kg/m^3
σ	surface tension	N/m
ϕ_{limit}	critical filling threshold	—
ϕ_0	initial liquid filling level at the sizing conditions, i.e. the liquid volume divided by the total volume of the pressurized system considered	—
ω	compressibility coefficient	—
ω_{eq}	compressibility coefficient at equilibrium condition ($N = 1$)	—
$\mathit{\Gamma}_{\text{g}}$	gas production rate per liquid mass, i.e. the gas mass flow rate per liquid mass inventory in the pressurized system	kg/(s·kg)
$\mathit{\Gamma}$	dimensionless velocity ratio	—
Δh_{v}	latent heat of vaporization	J/kg
Δp	pressure drop in the inlet or outlet line	Pa
Δp_{MAA}	maximum allowable accumulation	Pa
Δp_{feed}	pressure loss between the outlet of the control valve in the feed line and the pressurized system	Pa
Δp_{H2O}	pressure drop across a control valve during experiments to measure the K_{vs} value defined at a pressure difference of 10^5 Pa	Pa
Δp_{loss}	inlet line pressure loss	Pa
Δp_{over}	absolute overpressure	Pa
ΔT_{over}	saturation temperature difference	K
$\mathit{\Psi}$	Boiling area ratio	—
$\mathit{\Omega}$	dynamic viscosity	Pa·s

4.2 Abbreviated terms

Index	Meaning
0	sizing condition
2ph	two-phase flow
b	back
CV	upstream of the control valve
c	thermodynamic critical property
crit	critical condition with respect to flow
ct	churn turbulent
feed	into the pressurized system
fire	heat externally by fire