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Cryogenic vessels — Pressure-relief accessories for cryogenic service —

Part 3: Sizing and capacity determination

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Récipients cryogéniques — Dispositifs de sécurité pour le service cryogénique —

Partie 3: Détermination de la taille et du volume

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Foreword

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This document was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 268, *Cryogenic vessels and specific hydrogen technologies applications,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 21013-3:2016), which has been technically revised.

The main changes are as follows:

— precision added on the total outer surface area of the pipe network containing flow of fluid;

— inclusion of the symbol of coefficient of discharge;

— precision added on the overall convective heat transfer coefficient of the ambient air vaporizer,

— additional information added on the fire case and PBU conditions;

— correction of the molar mass in kg/kmol and modification of Formulae (32) and (43);

— supplementary information added on cryostats.

A list of all parts in the ISO 21013 series can be found on the ISO website.

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Cryogenic vessels — Pressure-relief accessories for cryogenic service —

Part 3: Sizing and capacity determination

1 Scope

This document specifies calculation methods for determining the required mass flow to be relieved for each specified conditions described in Table 1.

Table 1 — Subclause required for calculating mass flow rate based on specified condition [a]

<table>
<tr><th>Condition</th><th>Type of insulation system</th><th>Vacuum status</th><th>Inner vessel temperature</th><th>Insulation system (outer jacket + insulating material) condition</th><th>Ambient conditions</th><th>Pressure buildup system condition</th><th>Use clauses including any subclauses</th></tr>
<tr><td>1</td><td rowspan="2">non-vacuum</td><td rowspan="2">N/A</td><td rowspan="6">temperature of the contents at the specified relieving pressure</td><td>intact</td><td>normal (ambient temperature)</td><td rowspan="3">normal condition</td><td>4.2.3,4.2.4, 4.5.1, 4.5.2, 4.5.7, 5, 6, 7</td></tr>
<tr><td>2</td><td>fully or partially in place</td><td>fire (922 K)</td><td>4.3.1, 4.5.1, 4.5.7, 5, 6, 7</td></tr>
<tr><td>3</td><td rowspan="6">vacuum</td><td rowspan="2">normal</td><td rowspan="3">intact</td><td rowspan="3">normal (ambient temperature)</td><td>4.2.1, 4.2.4, 4.5.1, 4.5.2, 4.5.7, 5, 6, 7</td></tr>
<tr><td>4</td><td>full open</td><td>4.2.1, 4.2.2, 4.2.4, 4.5.1, 4.5.3, 4.5.7, 5, 6, 7</td></tr>
<tr><td>5</td><td rowspan="2">loss of vacuum</td><td rowspan="5">normal condition</td><td>4.2.3, 4.2.4, 4.5.1, 4.5.4, 4.5.7 ,5, 6, 7</td></tr>
<tr><td>6</td><td>fully or partially in place</td><td>fire (922 K)</td><td>4.3.1, 4.4.3, 4.5.1, 4.5.5, 4.5.7, 5, 6, 7</td></tr>
<tr><td>7</td><td rowspan="3">loss of vacuum with air or nitrogen in the vacuum space</td><td rowspan="3">contents with relieving temperature below 75 K</td><td rowspan="2">intact</td><td>normal (ambient temperature)</td><td>4.4.2, 4.5.1, 4.5.4, 4.5.7, 5, 6 ,7</td></tr>
<tr><td>8</td><td rowspan="2">fire (922 K)</td><td>4.4.3, 4.5.1, 4.5.5, 4.5.7, 5, 6, 7</td></tr>
<tr><td>9</td><td>Vacuum and non-vacuum</td><td>totally lost</td><td>4.5.1, 4.5.6, 4.5.7, 5, 6, 7</td></tr>
<tr><td colspan="8">When no appropriate calculation method is provided for a condition, the required mass flow is determined using good engineering practice based on well-established theoretical physical science.</td></tr>
</table>

Recommendations for pressure relief devices for cryostats are given in Annex A.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and symbols

No terms and definitions are listed in this document.

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 Symbols

A	arithmetic mean of inner and outer surface areas of vessel insulating material	m^2
A_B	actual flow area of a pipe element	m^2
A_e	total outer surface area of the pipe network containing flow of fluid, from the outer jacket up to the flow temperature location x under consideration; applicable only when l > 0,6 m (See 6.1.1)	m^2
A_F	minimum flow area (reference area) in a pipe network	m^2
A_{Fd}	minimum flow area (reference area) in the pipe network, downstream of relief valve	m^2
A_{Fu}	minimum flow area (reference area) in the pipe network, upstream of relief valve	m^2
A_i	total outside surface area of inner vessel	m^2
A_j	total outer surface area of pipe network between the inner and outer jackets (interspace)	m^2
A_L	larger flow area of a pipe element containing two different flow area sizes	m^2
A_n	cross-sectional area, support, or pipe material	m^2
A_R	area ratio, A_S/A_L	—
A_S	smaller flow area of a pipe element containing two different flow area sizes	m^2
A_V	actual flow (orifice) area of a pressure relief valve	mm^2
A_{Va}	actual flow (orifice) area of pressure relief valve selected for final analysis	mm^2
A_{V1}	minimum required relief valve flow (orifice) area	mm^2
A_2	external heat transfer surface area of ambient air vaporizer	m^2
C_V	experimentally determined flow rate through a pipe element or device	m^3/h
K_A	flow resistance coefficient of a pipe element in terms of A_F	—
K_B	flow resistance coefficient of a pipe element in terms of A_B	—
K_b	subcritical flow coefficient	—
K_d	coefficient of discharge	—

K_{dr}	derated coefficient of discharge	—
$K_{dr,a}$	derated coefficient of discharge of next largest available valve orifice area greater than A_{V1}	—
$K_{dr,1}$	derated coefficient of discharge of initially analysed valve	—
K_R	flow resistance coefficient of complete pipe network in terms of reference area, A_F	—
K_{RC}	flow resistance coefficient at the transition between critical and subcritical flow	—
K_{Rd}	overall flow resistance coefficient of pipe network, downstream of pressure relief valve	—
K_{Ru}	overall flow resistance coefficient of pipe network, upstream of pressure relief valve	—
K_{SUM}	total flow resistance coefficient of a series or parallel pipe network	—
K_V	experimentally determined flow rate through a pipe element or device	m^3/h/bar[1)]
L	latent heat of vaporization of cryogenic liquid at relieving conditions	kJ/kg
L_a	latent heat of vaporization of cryogenic liquid at a pressure of 1,013 bar[1)]	kJ/kg
L'	enthalpy-to-volume expansion ratio for critical or all-gas fluid flow conditions	kJ/kg
M	molar mass	kg/kmol
N	normal evaporation rate (NER)	%/day
P	relieving pressure, inner vessel in absolute pressure	bar
P_b	pressure, safety relief valve outlet in absolute pressure	bar
P_{b10}	pressure at relief valve outlet for a downstream built-up backpressure of 10 %	bar
P_{exit}	pressure at pipe network exit in absolute pressure	bar
P_i	pressure, safety relief valve inlet in absolute pressure	bar
P_S	pressure relief valve set pressure in absolute pressure	bar
Q_m	mass flow rate	kg/h
Q_{ma}	mass flow rate of a relief valve within a given pipe network	kg/h
Q_{mNER}	mass flow rate due to the normal evaporation rate	kg/h
R	universal gas constant	J/(mol·K)
T	relieving temperature, inner vessel	K
T_a	maximum external ambient temperature, non-fire condition	K
$T_{b,Pb}$	temperature at relief valve outlet	K
T_{b10}	temperature at relief valve outlet for a downstream built-up backpressure of 10 %	K
T_e	external temperature for a given condition	K

1) bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

$T_{exit,Pb}$	temperature at pipe network exit	K
T_f	external temperature, fire condition	K
T_i	temperature, safety relief valve inlet	K
T_n	temperature of fluid at a given flow start location along the pipe network	K
T_{sat}	saturation temperature of fluid at a pressure of 1 bar	K
T_x	temperature of fluid at a given location x along the pipe network	K
U_1	heat transfer coefficient of insulating material, normal vacuum, non-fire condition	W/ (m²·K)
U_2	overall convective heat transfer coefficient of ambient air vaporizer	W/ (m²·K)
U_3	heat transfer coefficient of insulating material with air or gaseous lading, non-fire condition	W/ (m²·K)
U_{3a}	heat transfer coefficient, air or nitrogen condensation, loss of vacuum, non-fire condition	W/m²
U_5	heat transfer coefficient of insulating material with air or gaseous lading, fire condition	W/ (m²·K)
U_{5a}	heat transfer coefficient, air or nitrogen condensation, loss of vacuum, fire condition	W/m²
U_p	overall heat transfer coefficient of a pipe network for given temperature conditions	W/ (m²·K)
W_T	total heat transfer rate for specified conditions	Watt [W]
W_{T1}	total heat transfer rate under normal operation	Watt [W]
W_{T1NER}	total NER heat transfer rate under normal operation	Watt [W]
W_{T2}	total heat transfer rate under normal operation, including pressure build-up device	Watt [W]
W_{T2NER}	total NER heat transfer rate under normal operation, including pressure build-up device	Watt [W]
W_{T3}	total heat transfer rate, loss of vacuum, insulation in place, non-fire condition, $T_{sat} > 75$ K	Watt [W]
W_{T3a}	total heat transfer rate, loss of vacuum, insulation in place, non-fire condition, $T_{sat} \leq 75$ K	Watt [W]
W_{T5}	total heat transfer rate, loss of vacuum, insulation in place, fire condition, $T_{sat} > 75$ K	Watt [W]
W_{T5a}	total heat transfer rate, loss of vacuum, insulation in place, fire condition, $T_{sat} \leq 75$ K	Watt [W]
W_{T6}	total heat transfer rate, loss of vacuum, insulation not in place, fire condition	Watt [W]
W_1	heat transfer rate through insulation system, normal vacuum, non-fire condition	Watt [W]
W_2	heat transfer rate through pressure build-up device, fully open regulator	Watt [W]
W_3	heat transfer rate through insulation system, loss of vacuum, non-fire condition	Watt [W]
W_{3a}	heat transfer rate through air or nitrogen condensation, loss of vacuum, non-fire condition	Watt [W]
W_4	heat transfer rate through interspace supports and piping	Watt [W]

W_5	heat transfer rate through vessel walls, insulation in place, fire condition	Watt [W]
W_{5a}	heat transfer rate through air or nitrogen condensation, loss of vacuum, fire condition	Watt [W]
W_6	heat transfer rate through vessel walls, insulation not in place, fire condition	Watt [W]
X	number of insulation layers	—
Y	heat transfer rate U_{3a} or U_{5a}	—
Z_i	compressibility factor at pressure P_i and temperature T_i	—
a		
c_p	constant pressure specific heat capacity at the average of T_n and T_e	kJ/(kg·K)
e_1	nominal insulating material thickness, in normal vacuum, non-fire condition	m
e_3	minimum insulating material thickness, considering loss of vacuum, non-fire condition	m
e_5	insulating material thickness remaining in place during fire conditions	m
f_T	pipe flow friction coefficient	—
h	enthalpy of fluid at conditions of v	kJ/kg
h_r	specific enthalpy at relief valve inlet and outlet	kJ/kg
k_1	mean thermal conductivity of insulating material, normal vacuum, non-fire condition	W/(m·K)
k_3	mean thermal conductivity of insulating material with air or gaseous lading, non-fire condition	W/(m·K)
k_n	mean thermal conductivity of an individual support or pipe, between T and T_a	W/(m·K)
l	length, pipe element	m
l_n	length of support or pipe in vacuum interspace	m
m_{max}	maximum mass capacity of vessel	kg
r	pipe elbow transition radius	m
x	lengthwise location along a pipe network	m
φ	pressure ratio $\frac{P-P_{exit}}{P}=1-\frac{P_{exit}}{P}$	—
κ	isentropic exponent	—
λ	subcritical flow coefficient	—
v	specific volume of critical or all-gas fluid at a given temperature at pressure P	m^3/kg
v_{b10}	specific volume at relief valve outlet for a downstream built-up backpressure of 10 %	m^3/kg
$v_{b,Pb}$	specific volume at pressure relief valve outlet, evaluated at h_r and a trial value of P_b	m^3/kg

v_{d10}	average downstream specific volume, for a downstream built-up backpressure of 10 %	m^3/kg
v_{dmax}	maximum average downstream specific volume, as per desired backpressure limit	m^3/kg
v_{exit10}	specific volume at pipe network exit for a downstream built-up backpressure of 10 %	m^3/kg
$v_{exit,Pb}$	specific volume at pipe network exit, evaluated at P_{exit} and $T_{exit,Pb}$	m^3/kg
v_g	specific volume of saturated gas at relieving pressure, P	m^3/kg
v_{ga}	specific volume of saturated gas at a pressure of 1,013 bar	m^3/kg
v_i	specific volume, safety relief valve inlet	m^3/kg
v_l	specific volume of saturated liquid at relieving pressure, P	m^3/kg
v_{la}	specific volume of saturated liquid at a pressure of 1,013 bar	m^3/kg
v_u	average specific volume of flowing fluid upstream of pressure relief valve inlet	m^3/kg
ψ	expression for determining Q_m and T for critical or gas-full-vessel fluid flow conditions	$m^{3/2}\cdot kg^{1/2}/kJ$

4 Calculation of the total quantity of heat transferred per unit time from the hot wall (outer jacket) to the cold wall (inner vessel)

4.1 General

P (in bar absolute) is the actual relieving pressure inside the vessel which is used for calculating the required mass flow through pressure relief devices.

T_a (in K) is the maximum ambient temperature for conditions other than fire (as specified, for example, by a regulation or standard).

T_f (in K) is the external environment temperature under fire conditions which is taken to be 922 K in this document.

T (in K) is the relieving temperature in the vessel to be taken into account.

a) For subcritical fluids, T is the saturation temperature of the liquid at pressure P.

b) For critical or supercritical fluids, T is calculated from 5.2.