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Cryogenic vessels — Pressure-relief accessories for cryogenic service —

Part 3:
Sizing and capacity determination

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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The committee responsible for this document is ISO/TC 220, *Cryogenic vessels*.

This second edition cancels and replaces the first edition (ISO 21013-3:2006), which has been technically revised.

ISO 21013 consists of the following parts, under the general title *Cryogenic vessels — Pressure-relief accessories for cryogenic service*:

- *Part 1: Reclosable pressure-relief valves*
- *Part 2: Non-reclosable pressure-relief devices*
- *Part 3: Sizing and capacity determination*
- *Part 4: Pressure-relief accessories for cryogenic service*

Cryogenic vessels — Pressure-relief accessories for cryogenic service —

Part 3:
Sizing and capacity determination

1 Scope

This part of ISO 21013 provides separate calculation methods for determining the required mass flow to be relieved for each of the following specified conditions:

— vacuum-insulated vessels with insulation system (outer jacket + insulating material) intact under normal vacuum, outer jacket at ambient temperature, inner vessel at temperature of the contents at the specified relieving pressure;

— vacuum-insulated vessels with insulation system (outer jacket + insulating material) intact under normal vacuum, outer jacket at ambient temperature, inner vessel at temperature of the contents at the specified relieving pressure, pressure regulator of the pressure build-up system functioning at full potential;

— vacuum or non-vacuum-insulated vessels with insulation system remaining in place, but with loss of vacuum in the case of vacuum-insulated vessels, outer jacket at ambient temperature, inner vessel at temperature of the contents at the specified relieving pressure or vacuum or non-vacuum-insulated vessels with insulation system remaining fully or partially in place, but with loss of vacuum in the case of vacuum-insulated vessels, fire engulfment, inner vessel at temperature of the contents at the specified relieving pressure;

— vacuum-insulated vessels containing fluids with saturation temperature below 75 K at 1 bar with insulation system remaining in place, but with loss of vacuum with air or nitrogen in the vacuum space;

— vacuum insulated vessels containing fluids with saturation temperature below 75 K at 1 bar with insulation system remaining in place, but with loss of vacuum with air or nitrogen in the vacuum space with fire engulfment;

— vessels with insulation system totally lost and fire engulfment.

Good engineering practice based on well-established theoretical physical science needs to be adopted to determine the required mass flow where an appropriate calculation method is not provided for an applicable condition.

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

2 Normative references

There are no normative references in this document.

3 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 pipe network between the outer jacket and location x	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, $A_\mathrm{S}/A_\mathrm{L}$	—
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_p	constant pressure specific heat capacity at the average of T_n and T_e	kJ/(kg·K)
C_V	experimentally determined flow rate through a pipe element or device	gal/min/psi
e_1	nominal insulating material thickness, 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_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_dr	derated coefficient of discharge	—

$K_{\mathrm{dr,a}}$	derated coefficient of discharge of next largest available valve orifice area greater than A_{V1}	—
$K_{\mathrm{dr,1}}$	derated coefficient of discharge of initially analyzed valve	—
k_{n}	mean thermal conductivity of an individual support or pipe, between T and T_{a}	W/(m·K)
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	$\mathrm{m^3/h/bar}$
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)
L	latent heat of vaporization of cryogenic liquid at relieving conditions	kJ/kg
l	length, pipe element	m
L_{a}	latent heat of vaporization of cryogenic liquid at a pressure of 1,013 bar	kJ/kg
l_{n}	length of support or pipe in vacuum interspace	m
L'	enthalpy-to-volume expansion ratio for critical or all-gas fluid flow conditions	kJ/kg
M	molar mass	kg/mol
m_{max}	maximum mass capacity of vessel	kg
N	normal evaporation rate (NER)	%/day
P	relieving pressure, inner vessel	bar
P_{b}	pressure, safety relief valve outlet	bar
P_{b10}	pressure at relief valve outlet for a downstream built-up backpressure of 10 %	bar
P_{exit}	pressure at pipe network exit	bar
P_{i}	pressure, safety relief valve inlet	bar
P_{S}	pressure relief valve set 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)
r	pipe elbow transition radius	m
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
$T_{exit,Pb}$	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_p	overall heat transfer coefficient of a pipe network for given temperature conditions	W/ (m^2·K)
U_1	heat transfer coefficient of insulating material, normal vacuum, non-fire condition	W/ (m^2·K)
U_2	overall convective heat transfer coefficient of ambient air vaporizer	W/ (m^2·K)
U_3	heat transfer coefficient of insulating material with air or gaseous lading, non-fire condition	W/ (m^2·K)
U_{3a}	heat transfer coefficient, air or nitrogen condensation, loss of vacuum, non-fire condition	W/m^2
U_5	heat transfer coefficient of insulating material with air or gaseous lading, fire condition	W/ (m^2·K)
U_{5a}	heat transfer coefficient, air or nitrogen condensation, loss of vacuum, fire condition	W/m^2
w_n	heat leak from an individual support or pipe	W/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	lengthwise location along a pipe network	m
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	—
φ	pressure ratio P_{exit}/P	—
κ	isentropic exponent	—
λ_1	subcritical flow coefficient	—
λ_2	subcritical flow coefficient	—
ν	specific volume of critical or all-gas fluid at a given temperature at pressure, P	m^3/kg
ν_{b10}	specific volume at relief valve outlet for a downstream built-up backpressure of 10 %	m^3/kg
$\nu_{b,Pb}$	specific volume at pressure relief valve outlet, evaluated at h_r and a trial value of P_b	m^3/kg
ν_{dmax}	maximum average downstream specific volume, as per desired backpressure limit	m^3/kg
ν_{d10}	average downstream specific volume, for a downstream built-up backpressure of 10 %	m^3/kg

$v_{\mathrm{exit,Pb}}$	specific volume at pipe network exit, evaluated at P_{exit} and $T_{\mathrm{exit,Pb}}$	m^3/kg
v_{exit10}	specific volume at pipe network exit for a downstream built-up backpressure of 10 %	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	$\mathrm{m}^{3/2}\cdot\mathrm{kg}^{1/2}/\mathrm{kJ}$

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 abs) 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 part of ISO 21013.

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.

4.2 Under conditions other than fire

4.2.1 Vacuum-insulated vessels under normal vacuum

W_1 is the quantity of heat transferred per unit time (in watts) by heat leak through the insulation system.

$$W_1 = \left(U_1 \cdot A\right)\left(T_{\mathrm{a}} - T\right) \tag{1}$$

where

U_1 is the overall heat transfer coefficient of the insulating material under normal vacuum, in W/(m^2·K);

$$U_1 = \frac{k_1}{e_1};$$

k_1 is the mean thermal conductivity of the insulating material under normal vacuum, between T and T_a, in W/(m·K);

e_1 is the nominal insulating material thickness, in metres;

A is the arithmetic mean of the inner and outer surface areas of the vessel insulating material, in m^2.

4.2.2 Pressure build-up device

W_2 is the quantity of heat transferred per unit time (in watts) by the pressure build-up device circuit with the regulator fully open. W_2 is determined from the type (ambient air, water or steam, electrical, etc.) and design of the pressure build-up device circuit. For example, in the case of an ambient air vaporizer.

$$W_2 = (U_2 \cdot A_2)(T_a - T) \qquad (2)$$

where

U_2 is the overall convective heat transfer coefficient of the ambient air vaporizer, in W/(m^2·K);

A_2 is the external heat transfer surface area of the vaporizer, in m^2.

As a first approximation, the following may be used:

$$U_2(T_a - T) = 19\,000 \text{ W/m}^2 \text{ for } T \le 75 \text{K} \qquad (3)$$

$$U_2(T_a - T) = 2\,850 \text{ W/m}^2 \text{ for } T > 75 \text{K} \qquad (4)$$

4.2.3 Vacuum-insulated vessels in the case of loss of vacuum and non-vacuum insulated vessels

W_3 is the quantity of heat transferred per unit time (in watts) by heat leak through the insulating material.

$$W_3 = (U_3 \cdot A)(T_a - T) \qquad (5)$$

where

If the insulation is fully effective for conduction, convection, and radiation heat transfer at 328 K, U_3 may be calculated using Formula (6).