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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

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21013-3 was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels*.

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*

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 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 relieving pressure; pressure regulator of the pressure build-up system functioning at full potential.
- Vacuum-insulated vessels with insulation system remaining in place but with loss of vacuum, or non-vacuum-insulated vessels with insulation system intact; outer jacket at ambient temperature; inner vessel at temperature of the contents at the relieving pressure; 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, and fire engulfment; inner vessel at temperature of the contents at the relieving pressure.
- Vessels with insulation system totally lost and fire engulfment.

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

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*

ISO 4126-6:2003, *Safety devices for protection against excessive pressure — Part 6: Application, selection and installation of bursting disc safety devices*

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

3.1 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 4.3.

The quantity of heat transferred per unit time (in watts) by supports and piping located in the interspace to be included in W_1, W_2 and W_3 is calculated as follows:

$$W_c = (T_a - T)(w_1 + w_2 + \ldots + w_n + \ldots)$$

where

w_n is the heat leak per degree K contributed by one of the supports or the pipes, in W/K,

$$w_n = k_n \frac{A_n}{l_n}$$

where

k_n is the thermal conductivity of the support or pipe material between T and T_a, in W/(m·K);

A_n is the support or pipe section area, in m^2;

l_n is the support or pipe length in the vacuum interspace, in m.

3.2 Under conditions other than fire

3.2.1 For vacuum-insulated vessels under normal vacuum, the quantity of heat transferred per unit time (in watts) by heat leak through the insulation system is

$$W_1 = (T_a - T)U_1 A$$

where

U_1 is the overall heat transfer coefficient of the insulating material under normal vacuum, in W/(m²·K),

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

where

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 m;

A is the arithmetic mean of the inner and outer surface areas of the vessel insulating material, in m².

3.2.2 Quantity of heat transferred per unit time (in watts) by the pressure build-up device circuit with the regulator fully open:

W_2 determined from the type (ambient air, water or steam, electrical, etc.) and the design of the pressure build-up device circuit. For example, in the case of an ambient air vaporizer,

$$W_2 = U_2 A_2 (T_a - T)$$

where

U_2 is the overall convective heat transfer coefficient of the ambient air vaporizer, in W/(m²·K);

A_2 is the external heat transfer surface area of the vaporizer, in m².

W_1 shall be included in W_2.

3.2.3 For vacuum-insulated vessels in case of loss of vacuum or non-vacuum-insulated vessels, quantity of heat transferred per unit time (in watts) by heat leak through the insulating material:

$$W_3 = (T_a - T)U_3 A$$

where

U_3 is the overall heat transfer coefficient of the insulating material when saturated with gaseous lading or air at atmospheric pressure, whichever is greater, in W/(m²·K);

If the insulation is fully effective for conduction, convection and radiation heat transfer at 328 K, then U_3 may be calculated as

$$U_3 = \frac{k_3}{e_3}$$

Vacuum space, gas space, or space occupied by the deteriorated insulation shall not be included in the thickness of the insulation. The effectiveness of these spaces or deteriorated insulation in reducing conduction, convection, or radiation heat transfer may be evaluated separately and included in the overall heat transfer coefficient, U_3, using methods found in published heat transfer literature. Deterioration of the insulation can be caused by the following:

— moisture condensation;

— air condensation;

— increase in density of the insulation due to sudden loss of vacuum.

k_3 is the thermal conductivity of the insulating material saturated with gaseous lading or air at atmospheric pressure, whichever provides the greater coefficient, between T and T_a, in W/(m·K);

e_3 is the minimum insulating material thickness taking into account the manufacturing tolerances or effects of sudden loss of vacuum, in m.

NOTE This formula may not be applicable at very low temperatures with a small thickness of insulating material, as the maximum heat transfer coefficient would be given by air condensation.

3.2.4 Quantity of heat transferred per unit time (in watts) by supports and piping located in the interspace:

$$W_4 = (T_a - T)(w_1 + w_2 + \ldots + w_n + \ldots)$$

where

w_n is the heat leak per degree K contributed by one of the supports or the pipes, in W/K,

$$w_n = k_n \frac{A_n}{l_n}$$

where

k_n is the thermal conductivity of the support or pipe material between T and T_a, in W/(m·K);

A_n is the support or pipe section area, in m^2;

l_n is the support or pipe length in the vacuum interspace, in m.

3.3 Under fire conditions

3.3.1 Quantity of heat transferred per unit time (in watts) by heat leak through the vessel walls

3.3.1.1 Insulation system remains fully or partially in place during fire conditions:

$$W_5 = 2{,}6(922 - T)U_5 A^{0{,}82}$$

where

U_5 is the overall heat transfer coefficient of the container-insulating material when saturated with gaseous lading or air at atmospheric pressure, whichever is greater, in W/(m·K).

If the insulation is fully effective for conduction, convection, and radiation heat transfer for an external temperature of 922 K, U_5 may be calculated as

$$U_5 = \frac{k_5}{e}, \text{ in W/(m}^2\text{·K)}$$

Vacuum space, gas space, or space occupied by the deteriorated insulation shall not be included in the thickness of the insulation. The effectiveness of these spaces or deteriorated insulation in reducing conduction, convection, or radiation heat transfer may be evaluated separately and included in the overall heat transfer coefficient, U_5, using methods found in published heat transfer literature. Deterioration of the insulation can be caused by the following:

— moisture condensation;

— air condensation;

— increase in density of the insulation due to sudden loss of vacuum;

— degradation due to heat.

k_5 is the thermal conductivity of the insulating material saturated with gaseous lading or air at atmospheric pressure, whichever provides the greater coefficient, between T and 922 K, in W/(m·K);

e is the thickness of the insulating material remaining in place during fire conditions, in m;

A is the mean surface area of the insulating material remaining in place during fire conditions, in m^2.

If the outer jacket remains in place during fire conditions, but if the insulating material is entirely destroyed, U_5 is equal to the overall heat transfer coefficient with gaseous lading or air at atmospheric pressure in the space between the outer jacket and the inner vessel, whichever provides the greater coefficient, between T and 922 K. A is equal to the mean surface area of the interspace.

3.3.1.2 Insulation system does not remain in place during fire conditions:

$$W_5 = 7{,}1 \times 10^4 A_i^{0{,}82}$$

where

A_i is the total outside surface area of the inner vessel, in m^2.

3.3.2 Quantity of heat transferred by supports and piping located in the interspace can be neglected in this case.

4 Calculation of the mass flow Q_m to be relieved by the pressure-relief devices

4.1 The relieving pressure P in the vessel is less than 40 % of the critical pressure:

$$Q_m = 3{,}6 \frac{W}{L}$$

where

L is the latent vaporization heat of the cryogenic liquid in relieving conditions, in kJ/kg.

4.2 The relieving pressure P is below the critical pressure, but equal to or greater than 40 % of critical pressure:

$$Q_m = 3,6\left(\frac{v_g - v_l}{v_g}\right)\frac{W}{L}$$

where

v_g is the specific volume of saturated gas at the relieving pressure P, in m^3/kg;

v_l is the specific volume of saturated liquid at the relieving pressure P, in m^3/kg.

4.3 The relieving pressure P is equal to or greater than the critical pressure:

$$Q_m = 3,6\frac{W}{L'}$$

where

L' is the specific heat input $v\left[\frac{\partial h}{\partial v}\right]_P$ at the relieving pressure P and at the temperature T (in K), in kJ/kg.

$$\frac{\sqrt{v}}{v\left[\frac{\partial h}{\partial v}\right]_P}$$ is a maximum

where

v is the specific volume of critical or supercritical fluid at the relieving pressure P in the vessel and any temperature within the operating range, in m^3/kg;

h is the enthalpy of the fluid in the same conditions as above, in kJ/kg.

EXAMPLE Calculate the value of L' and T to be used for liquid hydrogen relieving at pressure P = 13,8 bar abs as given in Table 1.

Table 1

Temperature K	v m^3/kg	$v\left[\frac{\partial h}{\partial v}\right]_P$ kJ/kg	$\frac{\sqrt{v}}{v\left[\frac{\partial h}{2v}\right]_P}$
33,3	0,027 156 7	214,09	0,0007 697
34,7	0,058 296 1	236,56	0,001 020 6
34,8	0,058 845 0	237,49	0,001 021 4 max
34,9	0,059 348 8	238,65	0,001 020 8
38,9	0,085 537 1	304,53	0,000 960 3
44,4	0,110 970 7	384,77	0,000 865 7

At P = 13,8 bar abs, the maximum value of $\frac{\sqrt{v}}{v\left[\frac{\partial h}{\partial v}\right]_P}$ occurs at T = 34,8 K for hydrogen.

In these conditions, L' = 237,49 kJ/kg.

5 Rule for installation of pressure-relief devices

The pipe between the outer jacket and the pressure-relief device should not be longer than 0,6 m; otherwise, heat transfer to the released flow shall be taken into account. This heat transfer reduces the product density and consequently reduces the effective discharge rate of the relief system (see calculation methods in the bibliography). Any pressure drop in the relief device piping (inlet and outlet) shall be taken into account when determining relief capacity.

The maximum pressure drop of the pipework to the pressure-relief valve at the maximum flow capacity of the pressure-relief valve shall be 3 % of the set pressure of the pressure-relief valve.

6 Sizing of pressure-relief devices

6.1 General

For all pressure-relief devices which have to discharge together the mass flow Q_m at the same relieving pressure P, Q_m shall be less than or equal to the sum of the relieving capacity of all the individual relief devices.

6.2 Pressure-relief valves

ISO 4126-1 applies.

6.3 Bursting disc

ISO 4126-6:2003, Annex B applies.