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ISO 21009-1

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Cryogenic vessels — Static vacuum-insulated vessels —

Part 1:
Design, fabrication, inspection and tests

Récipients cryogéniques — Récipients isolés sous vide statiques —

Partie 1: Exigences de conception de fabrication, d'inspection, et d'essais

Reference number
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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 documents 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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels*.

This second edition cancels and replaces the first edition (ISO 21009-1:2008), which has been technically revised.

The main changes are as follows:

— correction of the formulae;

— Clauses 11 and 12 have been revised;

— Annex C has been aligned with the modification performed in the other ISO/TC 220 design standards.

A list of all parts in the ISO 21009 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.

Cryogenic vessels — Static vacuum-insulated vessels —

Part 1: Design, fabrication, inspection and tests

1 Scope

This document specifies requirements for the design, fabrication, inspection and testing of static vacuum-insulated cryogenic vessels designed for a maximum allowable pressure of more than 0,5 bar.

This document applies to static vacuum-insulated cryogenic vessels for fluids and does not apply to vessels designed for toxic fluids.

This document also gives guidance for static vacuum-insulated cryogenic vessels designed for a maximum allowable pressure of not more than 0,5 bar.

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 4126-2, *Safety devices for protection against excessive pressure — Part 2: Bursting disc safety devices*

ISO 4136, *Destructive tests on welds in metallic materials — Transverse tensile test*

ISO 9016, *Destructive tests on welds in metallic materials — Impact tests — Test specimen location, notch orientation and examination*

ISO 9328-4, *Steel flat products for pressure purposes — Technical delivery conditions — Part 4: Nickel-alloy steels with specified low temperature properties*

ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 10474:2013, *Steel and steel products — Inspection documents*

ISO 14732, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

ISO 15613, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test*

ISO 15614-1:2017, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

ISO 17636-1, *Non-destructive testing of welds — Radiographic testing of fusion-welded joints — Part 1: X- and gamma-ray techniques with film*

ISO 17636-2, *Non-destructive testing of welds — Radiographic testing of fusion-welded joints — Part 2: X- and gamma-ray techniques with digital detectors*

ISO 21009-2, *Cryogenic vessels — Static vacuum insulated vessels — Part 2: Operational requirements*

ISO 21010, *Cryogenic vessels — Gas/material compatibility*

ISO 21011, *Cryogenic vessels — Valves for cryogenic service*

ISO 21013-3, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination*

ISO 21028-1, *Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperatures below -80 degrees C*

ISO 21028-2, *Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 2: Temperatures between -80 degrees C and -20 degrees C*

ISO 23208, *Cryogenic vessels — Cleanliness for cryogenic service*

EN 13445-3, *Unfired pressure vessels — Design*

ASME *Boiler and Pressure Vessel Code, Section VIII, Division 2: Alternative Rules*

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
accessories
service equipment which has a safety-related function with respect to either pressure containment or control or both

EXAMPLE Protective or limiting devices, controlling and monitoring devices, valves and indicators.

3.2
automatic welding
welding in which all operations are performed without welding operator intervention during the process

Note 1 to entry: Manual adjustment of welding variables by the welding operator during welding is not possible.

[SOURCE: ISO 14732:2013, 3.1]

3.3
bursting disc device
non-reclosing pressure relief device ruptured by differential pressure

Note 1 to entry: The bursting disc device is the complete assembly of installed components including, where appropriate, the bursting disc holder.

3.4
cryogenic fluid
refrigerated liquefied gas
gas which is partially liquid because of its low temperature

Note 1 to entry: This includes totally evaporated liquids and supercritical fluids.

Note 2 to entry: In the ISO 21009 series, the refrigerated, but non-toxic gases, and mixtures of them, shown in Table 1, are referred to as cryogenic fluids.

Table 1 — Refrigerated but non-toxic gases

Classification code	Identification number, name and description	
3° A	Asphyxiant gases	
	1 913	Neon, refrigerated liquid
	1 951	Argon, refrigerated liquid
	1 963	Helium, refrigerated liquid
	1 970	Krypton, refrigerated liquid
	1 977	Nitrogen, refrigerated liquid
	2 187	Carbon dioxide, refrigerated liquid
	2 591	Xenon, refrigerated liquid
	3 136	Trifluoromethane, refrigerated liquid
	3 158	Gas, refrigerated liquid, not otherwise specified (NOS)
3° O	Oxidizing gases	
	1 003	Air, refrigerated liquid
	1 073	Oxygen, refrigerated liquid
	2 201	Nitrous oxide, refrigerated liquid, oxidizing
	3 311	Gas, refrigerated liquid, oxidizing, NOS
3° F	Flammable gases	
	1 038	Ethylene, refrigerated liquid
	1 961	Ethane, refrigerated liquid
	1 966	Hydrogen, refrigerated liquid
	1 972	Methane, refrigerated liquid or natural gas, refrigerated liquid, with high methane content
	3 138	Ethylene, acetylene and propylene mixture, refrigerated liquid, containing at least 71,5 % ethylene with not more than 22,5 % acetylene and not more than 6 % propylene
	3 312	Gas, refrigerated liquid, flammable, NOS
The flammable gases, and mixtures of them, may be mixed with: helium, neon, nitrogen, argon, carbon dioxide.		
Oxidizing and flammable gases shall not be mixed.		
NOTE The classification code, identification number, name and description are according to UN codes.		

3.5
documentation
technical documents delivered by the manufacturer to the owner

Note 1 to entry: Documentation consists of:

— all certificates establishing the conformity with this document (e.g. material, pressure test, cleanliness, safety devices);

— a short description of the vessel (e.g. including characteristic data);

— a list of fluids and their net mass for which the cryogenic vessel is designed;

— an operating manual (for the user) that contains:

  — a short description of the vessel (e.g. including characteristic data),

  — a statement that the vessel is in conformity with this document, and

  — the instructions for *normal operation* (3.10).

3.6
gross volume
<*inner vessel*> (3.7) internal volume of the inner vessel determined at minimum design temperature and atmospheric pressure

3.7
inner vessel
pressure vessel intended to contain the *cryogenic fluid* (3.4) to be stored

3.8
manufacturer of the static cryogenic vessel
company that carries out the final assembly, including the final acceptance test, of the *static cryogenic vessel* (3.17)

3.9
maximum allowable pressure
maximum *pressure* (3.13) permissible at the top of the vessel in its normal operating position

3.10
normal operation
intended operation of the vessel either up to the *maximum allowable pressure* (3.9) or subjected to handling loads

Note 1 to entry: Handling loads are exerted on the *static cryogenic vessel* (3.17) in all normal transport operations including, e.g. loading, unloading, pressure loading during transportation, installation.

3.11
outer jacket
gas-tight enclosure which contains the *inner vessel* (3.7) and enables the vacuum to be established

3.12
piping system
tubes, pipes and associated components which can come in contact with *cryogenic fluids* (3.4) including valves, fittings, pressure relief devices, and their supports

3.13
pressure
gauge pressure
pressure relative to atmospheric pressure

3.14
pressure strengthened vessel
pressure vessel, which has been subjected to a calculated and controlled internal pressure (strengthening pressure) after completion

Note 1 to entry: The wall thickness of such a vessel is calculated on the basis of the stress at the strengthening pressure and not on the basis of the conventional design stress value of the material used.

Note 2 to entry: Pressure vessels made from solution heat treated material will be subject to a controlled plastic deformation during the strengthening operation as its yield point is raised. Pressure vessels made from work-hardened material will be subject to little or no plastic deformation.

3.15
relief plate
plate retained by atmospheric pressure which allows relief of excess internal pressure, generally from the vacuum jacket

3.16
service equipment
accessories, equipment or instruments that will be used to measure the level, to fill or discharge the tank, to vent the tank, to protect the tank against overpressure and to raise the tank pressure and its thermal insulation

Note 1 to entry: The thermal insulation is a vacuum inter-space between the *inner vessel* (3.7) and the *outer jacket* (3.11).

3.17
static cryogenic vessel
thermally insulated vessel intended for use with one or more *cryogenic fluids* (3.4) in a stationary condition

Note 1 to entry: Static cryogenic vessels consist of *inner vessel(s)* (3.7), an *outer jacket* (3.11) and the *piping system* (3.12).

4 Symbols

A	cross sectional area of reinforcing element	mm²
A	area of reinforcing ring	mm²
A_s	elongation at fracture	%
b	width of pad, ring or shell reinforcement	mm
C_β	design factors	—
c	allowances for corrosion	mm
D	shell diameter	mm
D_a	outside diameter e.g. of a cylindrical shell	mm
D_{a1}	outside diameter of connected cylinder (see Figure 7)	mm
D_{a2}	outside diameter at effective stiffening (see Figure 9)	mm
D_1, D_2	flat end diameters	mm
D_i	internal diameter e.g. of a cylindrical shell	mm
D_k	design diameter (see Figure 7)	mm
D_s	shell diameter at nozzle (see Figure 8)	mm
d_a	outside diameter of tube or nozzle	mm
d_i	diameter of opening	mm
d_1, d_2	opening diameter	mm
E	Young's modulus	N/mm²
f	narrow side of rectangular or torispherical plate	mm
H	Safety coefficient for pressure test	—
h	thickness of pad-reinforcement	mm

I	moment of inertia of reinforcing element	mm^4
K	material property used for design (see 10.3.2.3.1)	N/mm^2
K_t	material property at t °C used for design (e.g. K_{20} for material property at 20 °C) (see 10.3.2.3.2)	N/mm^2
L	cone length between effective stiffenings (see Figure 9)	mm
l	ligament (web) between two nozzles	mm
l_b	buckling length	mm
l'_s	length of nozzle reinforcement outstandings	mm
l_s	length of nozzle reinforcement in stand	mm
m	protruding length of nozzle	mm
n	number	—
p	design pressure as defined by 10.2.3.2.1 and 10.3.3.2	bar (or MPa)
p_e	external pressure	bar (or MPa)
p_{e1}	allowable external pressure limited by elastic buckling	bar (or MPa)
p_{e2}	allowable external pressure limited by elastic buckling including reinforcement	bar (or MPa)
p_k	strengthening pressure	bar (or MPa)
p_p	allowable external pressure limited by plastic deformation	bar (or MPa)
p_s	maximum allowable gauge pressure	bar (or MPa)
p_T	test pressure [see 10.2.3.2.3]	bar (or MPa)
R	radius of curvature e.g. inside crown radius of dished end	mm
r	inside radius of knuckle	mm
S	safety factor at design pressure	—
S_k	safety factor against elastic buckling at design pressure	—
S_p	safety factor against plastic deformation at design pressure	—
S_T	safety factor against plastic deformation at proof test pressure	—
s	minimum wall thickness	mm
s_A	required wall thickness at opening edge	mm
s_e	actual wall thickness	mm
s_g	required wall thickness outside corner area	mm
s_l	required wall thickness within corner area	mm
s_S	wall thickness of nozzle	mm

T	temperature	°C
t	wall thickness of nozzle	mm
u	out-of-roundness	—
V	factor indicative of the utilization of the permissible design stress in joints or factor allowing for weakenings	—
ν	Poisson ratio	—
x	(decay-length zone) distance over which governing stress is assumed to act	mm
x_i	characteristic lengths (i = 1,2,3) to define corner area [Figures 7 a) and b) and 10.3.6.5.4]	mm
Z	auxiliary value	—
φ	cone angle	°
σ_k	design stress value	N/mm^2

5 General requirements

5.1 The static cryogenic vessel shall safely withstand the mechanical and thermal loads and the chemical effects encountered during pressure test and normal operation. These requirements are deemed to be satisfied if Clauses 6 through 11 are fulfilled. The vessel shall be tested in accordance with Clause 12, marked in accordance with Clause 13, and operated in accordance with ISO 21009-2.

5.2 Static cryogenic vessels shall be equipped with valves, pressure relief devices, etc., configured and installed in such a way that the vessel can be operated safely. The number of openings in the inner vessel for this equipment shall be kept to a minimum.

5.3 The static cryogenic vessel shall be clean for the intended service in accordance with ISO 23208.

5.4 The manufacturer shall retain the documentation, and all supporting documents (including those from subcontractors, if any), taking legal compliance into consideration (e.g. product liability). In addition, the manufacturer shall retain all supporting and background documents (including those from subcontractors, if any) which establish that the vessel conforms to this document.

6 Mechanical loads

6.1 General

The static cryogenic vessel shall resist the mechanical loads mentioned in this clause without such deformation which can affect safety and which can lead to leakage.

The mechanical loads to be considered are:

— loads exerted during the pressure test as specified in 6.2;

— loads imposed during installation and removal of the vessel;

— dynamic loads during transport of the vessel.

The following loads shall be considered to act in combination where relevant:

— a pressure equal to the maximum allowable pressure in the inner vessel and pipework;

— the pressure exerted by the liquid when filled to capacity;

— loads produced by the thermal movement of the inner vessel, outer jacket and inter-space piping;

— full vacuum in the outer jacket;

— a pressure in the outer jacket equal to the set pressure of the relief device protecting the outer jacket;

— mass of vessel when filled to capacity;

— wind loads and other site conditions (e.g. seismic loads, thermal loads) to the vessel when filled to capacity.

6.2 Load during the pressure test

The load exerted during the pressure test used for calculation shall be:

$$p_T \geq H(p_s + 1) \text{ bar or } [p_T \geq H(p_s + 0{,}1) MPa]$$

where

H is 1,43 in Europe and 1,3 in North America and for other parts of the world, a value consistent with the applicable pressure vessel code;

+ 1 (in bar) or [+0,1 (in MPa)] is the allowance for external vacuum.

7 Chemical effects

Due to operating temperatures and the materials of construction, the possibility of chemical action on the inner surfaces in contact with the cryogenic fluids can be discounted.

Due to the fact that the inner vessel is inside an evacuated outer jacket, neither external corrosion of the inner vessel, nor corrosion on the inner surfaces of the outer jacket will occur. Therefore, inspection openings are not required in the inner vessel or the outer jacket.

Corrosion allowance is also not required on surfaces in contact with the operating fluid or exposed to the vacuum inter-space between the inner vessel and the outer jacket.

The material and the protection for the surfaces exposed to the atmosphere shall be suitable for intended use (e.g. resistant to industrial and marine atmospheres).

8 Thermal conditions

The following thermal conditions shall be taken into account:

a) for the inner vessel and its associated equipment, the full range of temperatures expected;

b) for the outer jacket and equipment thereof [other equipment than covered by a)]:

  — a minimum working temperature of −20 °C, unless otherwise specified and marked in accordance with Clause 13;

  — a maximum working temperature of 50 °C.

9 Material

9.1 General

The materials used to manufacture the inner vessels and associated equipment shall meet the requirements defined in 9.2 through 9.3.

9.2 Selection of materials

9.2.1 Materials which are or might be in contact with cryogenic fluids shall be in accordance with ISO 21010.

9.2.2 Materials used at low temperatures shall follow the requirements of the relevant ISO 21028-1 and ISO 21028-2; non-metallic materials shall be suitable for operating temperatures and the refrigerated gas.

9.2.3 The base materials, listed in Annex K, subject to meeting the extra requirements given in the main body of this document, are suitable for and may be employed in the manufacture of the cryogenic vessels conforming to this document.

9.3 Inspection certificate

9.3.1 The head and shell material shall be declared by an "inspection certificate 3.1", in accordance with ISO 10474:2013, 5.1, or "inspection certificate 3.2", in accordance with ISO 10474:2013, 5.2, if a specific manufacture qualification is not available.

9.3.2 The material manufactured to a recognized document shall be declared by an "inspection certificate 3.1", in accordance with ISO 10474:2013, 5.1, or "inspection certificate 3.2", in accordance with ISO 10474:2013, 5.2, if a specific manufacture qualification is not available.

9.4 Materials for outer jackets and service equipment

The outer jacket and the service equipment not subjected to cryogenic temperature shall be manufactured from material suitable for the intended service.

10 Design

10.1 Design options

10.1.1 General

The design shall be carried out in accordance with one of the options given in 10.1.2, 10.1.3 or 10.1.4.

In the case of 9 % Ni steel, the additional requirements of Annex B shall be satisfied.

For metallic materials used at cryogenic temperatures, the requirements of ISO 21028-1 and ISO 21028-2 shall be satisfied.

When further use of cold properties is allowed, the requirements of Annex E shall be satisfied.

10.1.2 Design by calculation

Calculation of all pressure and load bearing components shall be carried out. The pressure part thicknesses of the inner vessel and outer jacket shall not be less than required by 10.3. Additional