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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
ISO 21009-1:2008(E)

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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 21009-1 was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels*.

ISO 21009 consists of the following parts, under the general title *Cryogenic vessels — Static vacuum-insulated vessels*:

— *Part 1: Design, fabrication, inspection and tests*

— *Part 2: Operational requirements*.

This corrected version incorporates the following corrections:

— a single safety factor is given for the knuckle-region;

— the straight flange length requirement is expressed in terms of s;

— the formulae specifying cones which come under the field of application have been corrected;

— the cone angle is specified for internal pressure calculation;

— the formulae used for internal pressure calculation have been corrected;

— the formulae used for external pressure calculation have been corrected;

— the symbols used to denote wall thickness in Figure 7 have been changed;

— the Greek symbols used in Figures 10.1 to 10.8 (with the exception of φ) have been replaced by Latin symbols;

— the relationship to the pressure vessel code has specified with regard to calculations made for austenitic stainless steels;

— the cross-references in Annex G have been corrected;

— the formula for calculating moment of inertia, I, in relation to stiffening rings has been corrected;

— the formulae for calculating limits of reinforcement normal to the vessel wall by increased nozzle thickness have been corrected.

Cryogenic vessels — Static vacuum-insulated vessels —

Part 1:
Design, fabrication, inspection and tests

1 Scope

This part of ISO 21009 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 part of ISO 21009 applies to static vacuum-insulated cryogenic vessels for fluids as specified in 3.4 and does not apply to vessels designed for toxic fluids.

For static vacuum-insulated cryogenic vessels designed for a maximum allowable pressure of not more than 0,5 bar this International Standard may be used as a guide.

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 4126-2, *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 9606-1, *Approval testing of welders — Fusion welding — Part 1: Steels*

ISO 9606-2, *Qualification test of welders — Fusion welding — Part 2: Aluminium and aluminium alloys*

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

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

ISO 14732, *Welding personnel — Approval testing of welding operators for fusion welding and of resistance weld setters for fully mechanized and automatic welding of metallic materials*

ISO 15607, *Specification and qualification of welding procedures for metallic materials — General rules*

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

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

ISO 15614-2, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 2: Arc welding of aluminium and its alloys*

ISO 17636, *Non-destructive testing of welds — Radiographic testing of fusion-welded joints*

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

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 °C*

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

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

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

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

EN 10028-7, *Flat products made of steels for pressure purposes — Part 7: Stainless steels*

EN 13068-3, *Non-destructive testing – Radioscopic testing — Part 3: General principles of radioscopic testing of metallic materials by X- and gamma rays*

ASME Boiler and Pressure Vessel Code, *Section V: Nondestructive Examination*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
accessories
service equipment which has a safety related function with respect to pressure containment and/or control

EXAMPLE Accessories include protective or limiting devices, controlling and monitoring devices, valves and indicators.

3.2
automatic welding
welding in which the parameters are automatically controlled

NOTE Some of these parameters may be adjusted to a limited extent, either manually or automatically, during welding to maintain the specified welding conditions.

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

NOTE 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 This includes totally evaporated liquids and supercritical fluids.

EXAMPLE In ISO 21009, 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	
	1913	Neon, refrigerated liquid
	1951	Argon, refrigerated liquid
	1963	Helium, refrigerated liquid
	1970	Krypton, refrigerated liquid
	1977	Nitrogen, refrigerated liquid
	2187	Carbon dioxide, refrigerated liquid
	2591	Xenon, refrigerated liquid
	3136	Trifluoromethane, refrigerated liquid
	3158	Gas, refrigerated liquid, not otherwise specified (NOS)
3° O	Oxidizing gases	
	1003	Air, refrigerated liquid
	1073	Oxygen, refrigerated liquid
	2201	Nitrous oxide, refrigerated liquid, oxidizing
	3311	Gas, refrigerated liquid, oxidizing, NOS
3° F	Flammable gases	
	1038	Ethylene, refrigerated liquid
	1961	Ethane, refrigerated liquid
	1966	Hydrogen, refrigerated liquid
	1972	Methane, refrigerated liquid or natural gas, refrigerated liquid, with high methane content
	3138	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
	3312	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 may 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 consisting of:

- all certificates establishing the conformity with this part of ISO 21009 (e.g. material, pressure test, cleanliness, safety devices);
- a short description of the vessel (including characteristic data, etc.);
- 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 (including characteristic data, etc.),
  - a statement that the vessel is in conformity with this part of ISO 21009, and
  - the instructions for normal operation.

3.6
gross volume of the inner vessel
internal volume of the inner vessel , excluding nozzles, pipes etc. determined at minimum design temperature and atmospheric pressure

3.7
handling loads
loads exerted on the static cryogenic vessel in all normal transport operations including loading, unloading, pressure loading during transportation, installation, etc.

3.8
inner vessel
pressure vessel intended to contain the **cryogenic fluid** to be stored

3.9
manufacturer of the static cryogenic vessel
company that carries out the final assembly, including the final acceptance test, of the static cryogenic vessel

3.10
maximum allowable pressure
maximum pressure permissible at the top of the vessel in its normal operating position

3.11
net volume of the inner vessel
volume of the inner vessel, below the inlet to the relief devices, excluding nozzles, pipes etc., determined at minimum design temperature and atmospheric pressure

3.12
normal operation
intended operation of the vessel either up to the **maximum allowable pressure** or subjected to **handling loads**

3.13
outer jacket
gas-tight enclosure which contains the **inner vessel** and enables the vacuum to be established

3.14
piping system
tubes, pipes and associated components which can come in contact with **cryogenic fluids** including valves, fittings, pressure relief devices, and their supports

3.15
pressure
gauge pressure
pressure relative to atmospheric pressure

3.16
relief plate
plate retained by atmospheric pressure which allows relief of excess internal pressure, generally from the vacuum jacket

3.17
relief plug
plug retained by atmospheric pressure which allows relief of excess internal pressure, generally from the vacuum jacket

3.18
service equipment
measuring instruments, filling, discharge, venting, safety, pressurizing, cooling and thermal insulation devices

3.19
static cryogenic vessels
thermally insulated vessel intended for use with one or more **cryogenic fluids** in a stationary condition

NOTE Static cryogenic vessels consist of inner vessel(s), an outer jacket and the piping system.

3.20
thermal insulation
vacuum inter-space between the inner vessel and the outer jacket

NOTE The space may or may not be filled with material to reduce the heat transfer between the inner vessel and the outer jacket.

3.21
year built
date of the final acceptance test of the final assembled cryogenic vessel at the manufacturer

4 Symbols

For the purposes of this document, the following symbols apply:

c	allowances for corrosion	mm
d_i	diameter of opening	mm
d_a	outside diameter of tube or nozzle	mm
f	narrow side of rectangular or elliptical plate	mm
l_b	buckling length	mm
n	number	—
p	design pressure as defined by 10.2.3.2.1 and 10.3.3.2	bar
p_e	allowable external pressure limited by elastic buckling	bar
p_k	strengthening pressure	bar

p_p	allowable external pressure limited by plastic deformation	bar
p_s	maximum allowable gauge pressure	bar
p_T	test pressure [see 10.2.3.2.3]	bar
r	radius e.g. inside knuckle radius of dished end and cones	mm
s	minimum wall thickness	mm
s_e	actual wall thickness	mm
v	factor indicative of the utilisation of the permissible design stress in joints or factor allowing for weakenings	—
x	(decay-length zone) distance over which governing stress is assumed to act	mm
A	cross sectional area of reinforcing element	mm^2
A_s	elongation at fracture	%
C_β	design factors	—
D	shell diameter	mm
D_a	outside diameter e.g. of a cylindrical shell	mm
D_i	internal diameter e.g. of a cylindrical shell	mm
E	Young's modulus	N/mm^2
H	Safety coefficient for pressure test	—
I	moment of inertia of reinforcing element	mm^4
K	material property used for design (see 10.3.2.3.1)	N/mm^2
Kt	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
R	radius of curvature e.g. inside crown radius of dished end	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	—
Z	auxiliary value	—
ν	Poisson ratio	—
u	out-of-roundness	—
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 to 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 documents referred to in 3.5, and all supporting documentation (including that from his subcontractors if any), for a period required by regulation(s) (e.g. product liability). In addition the manufacturer shall retain all supporting and background documentation (including that from his subcontractors if any) which establishes that the vessel conforms to this part of ISO 21009.

6 Mechanical loads

6.1 General

The static cryogenic vessel shall resist the mechanical loads mentioned in Clause 6 without such deformation which could affect safety and which could 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;

— 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:

$$p_{\mathrm{T}} \geqslant H\,(p_{\mathrm{S}} + 1)$$

where

p_T is the test pressure (in bar);

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;

p_s is the maximum allowable gauge pressure (in bar);

$+ 1$ is the allowance for external vacuum (in bar).

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

The materials used to manufacture the inner vessels and associated equipment shall meet the requirements defined in 9.1 to 9.2.

9.1 Selection of materials

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

9.1.2 Materials used at low temperatures shall follow the requirements of the relevant ISO 21028; for non-metallic materials low temperature suitability shall be validated by an experimental method, taking into account operating temperatures.

9.1.3 The base materials, listed in Annex K, subject to meeting the extra requirements given in the main body of this part of ISO 21009, are suitable for and may be employed in the manufacture of the cryogenic vessels conforming to ISO 21009-1.

9.2 Inspection certificate

9.2.1 The head and shell material shall be according to ISO 21028-1 or ISO 21028-2 and shall be declared by an inspection certificate 3.1.B in accordance with ISO 10474.

9.2.2 The material manufactured to a recognised international standard shall meet the testing requirements according to ISO 21028-1 or ISO 21028-2 and be declared by an inspection certificate 3.1.B in accordance with ISO 10474.

9.3 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 calculations may be required to ensure the design is satisfactory for the operating conditions including an allowance for external loads (e.g. seismic).

10.1.3 Design by calculation when adopting pressure strengthening (if allowed)

The pressure retaining capability of inner vessels manufactured from austenitic stainless steel, strengthened by pressure, shall be calculated in accordance with Annex C. In some cases, designs adopting pressure strengthening might not be allowed by the applicable authorities where the vessel is to be operated.

10.1.4 Design of components by calculation supplemented with experimental methods

Where it is not possible to design non-inner-vessel components by calculation alone, planned and controlled experimental means may be used, provided that the results confirm the safety factors required in 10.3. An example would be the application of strain gauges to assess stress levels.

10.2 Common design requirements

10.2.1 General

The requirements of 10.2.2 to 10.2.8 are applicable to all vessels irrespective of the design option used.