

Cryogenic vessels — Large transportable vacuum-insulated vessels —

Part 1: Design, fabrication, inspection and testing

ICS 23.020.40

National foreword

This British Standard is the UK implementation of ISO 20421-1:2006, incorporating corrigendum August 2007.

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Cryogenic vessels — Large transportable vacuum-insulated vessels —

Part 1: Design, fabrication, inspection and testing

*Réipients cryogéniques — Réipients transportables isolés sous vide
de grande contenance —*

Partie 1: Conception, fabrication, inspection et essais



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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.

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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 20421-1 was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels*.

ISO 20421 consists of the following parts, under the general title *Cryogenic vessels — Large transportable vacuum-insulated vessels*:

- *Part 1: Design, fabrication, inspection and testing*
- *Part 2: Operational requirements*

Cryogenic vessels — Large transportable vacuum-insulated vessels —

Part 1: Design, fabrication, inspection and testing

1 Scope

This part of ISO 20421 specifies requirements for the design, fabrication, inspection and testing of large transportable vacuum-insulated cryogenic vessels of more than 450 l volume, which are permanently (fixed tanks) or not permanently (demountable tanks and portable tanks) attached to a means of transport, for one or more modes of transport.

This part of ISO 20421 applies to large transportable vacuum-insulated cryogenic vessels for fluids specified in 3.1 and does not apply to vessels designed for toxic fluids.

This part of ISO 20421 does not include the general vehicle requirements, e.g. running gear, brakes, lighting, etc., which are in accordance with the relevant standards/regulations.

This International Standard does not cover specific requirements for refillable liquid-hydrogen tanks that are primarily dedicated as fuel tanks in vehicles. For fuel tanks used in land vehicles, see ISO 13985.

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 5173, *Destructive tests on welds in metallic materials — Bend tests*

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*

AC1 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 procedure 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 15614-3, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 3: Fusion and pressure welding of non-alloyed and low-alloyed cast irons*¹⁾

ISO 17636, *Non-destructive testing of welds — Radiographic testing of fusion-welded joints* **AC1**

ISO 20421-2, *Cryogenic vessels — Large transportable vacuum-insulated vessels — Part 2: Operational requirements*

AC1 ISO 21010, *Cryogenic vessels — Gas/materials compatibility*

ISO 21011, *Cryogenic vessels — Valves for cryogenic service*¹⁾

ISO 21013-1, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves*¹⁾ **AC1**

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*

ASME VIII-2

EN 1708-1, *Welding — Basic weld joint details in steel — Part 1: Pressurized components*

EN 10028-4, *Flat products made of steels for pressure purposes — Part 4: Nickel alloy steels with specified low temperature properties*

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

EN 12300, *Cryogenic vessels — Cleanliness for cryogenic service*

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

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

EN 13445-4, *Unfired pressure vessels — Part 4: Fabrication*

UN Recommendations on the transport of dangerous goods — Model regulations (12th revised edition)

AC1¹⁾ To be published. **AC1**

3 Terms and definitions

For the purposes of this part of ISO 20421, the following terms and definitions apply.

3.1

cryogenic fluid

refrigerated liquefied gas

gas which is partially liquid because of its low temperature

NOTE 1 This includes totally evaporated liquids and supercritical fluids.

NOTE 2 In the context of this part of ISO 20421, the refrigerated but non-toxic gases and gas mixtures given in Table 1 are referred to as cryogenic fluids.

Table 1 — Refrigerated but non-toxic gases

Classification code	Identification number, name and description ^a	
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, N.O.S. (not otherwise specified)
3 °O	Oxidizing gases	
	1003	Air, refrigerated liquid
	1073	Oxygen, refrigerated liquid
	2201	Nitrous oxide, refrigerated liquid, oxidizing
	3311	Gas, refrigerated liquid, oxidizing, N.O.S.
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, N.O.S.
^a Classification codes, identification number, name and description according to the United Nations.		

3.2

large transportable cryogenic vessels

tank

thermally insulated vessel of more than 450 l intended for the transport of one or more cryogenic fluids, consisting of an inner vessel, an outer jacket, all of the valves and service equipment together with the structural parts

NOTE The large transportable cryogenic vessel comprises a complete assembly that is ready for service

3.3

thermal insulation

vacuum interspace 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.

3.4

inner vessel

pressure vessel intended to contain the cryogenic fluid to be transported

3.5

outer jacket

gas-tight enclosure which contains the inner vessel and enables the vacuum to be established

3.6

normal operation

the intended operation of the vessel at a pressure not greater than the maximum allowable working pressure including the **handling loads**

3.7

handling loads

loads exerted on the transportable cryogenic vessel in all normal conditions of transport including loading, unloading, moving and lifting

3.8

documentation

technical documents delivered by the manufacturer to the owner consisting of:

- all certificates establishing the conformity with this part of ISO 20421 (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) which consists of:
 - a short description of the vessel (including characteristic data, etc.);
 - a statement that the vessel is in conformity with this part of ISO 20421;
 - the instructions for normal operation.

3.9

pipng system

all pipes, tubes and associated components which can come in contact with cryogenic fluids including valves, fittings, pressure-relief devices and their supports

3.10**service equipment**

measuring instruments and filling, discharge, venting, safety, heating, cooling and insulating devices

3.11**manufacturer of the large transportable cryogenic vessel**

company that carries out the final assembly, including the final acceptance test, of the large transportable cryogenic vessel

3.12**gross volume of the inner vessel**

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

3.13**tare mass**

mass of the empty large transportable cryogenic vessel

3.14**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

3.15**net mass**

maximum allowable mass of the cryogenic fluid which may be filled

NOTE 1 The maximum allowable mass is equal to the mass of the cryogenic liquid occupying 98 % of the net volume of the inner vessel under conditions of incipient opening of the relief device with the vessel in a level attitude and the mass of the gas at the same conditions in the remaining volume of the inner vessel.

NOTE 2 Cryogenic liquid helium can occupy 100 % of the volume of the inner vessel at any pressure.

3.16**gross mass**

sum of tare mass plus net mass

3.17**pressure**

pressure relative to atmospheric pressure, i.e. gauge pressure

3.18**fixed tank**

tank vehicle

large transportable vessel permanently attached to a vehicle or to units of running gear

3.19**demountable tank**

large transportable vessel non-permanently attached to a vehicle

NOTE When attached to the carrier vehicle, the demountable tank meets the requirements prescribed for a fixed tank. It is designed to be lifted only when empty.

3.20**portable tank**

large transportable vessel designed primarily to be loaded onto a transport vehicle or ship

NOTE It can be lifted full and loaded and discharged without removal of structural element.

3.21

maximum allowable pressure

p_s

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

3.22

relief plate/plug

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

3.23

bursting disc device

a non-reclosing pressure-relief device ruptured by differential pressure

NOTE It is the complete assembly of installed components including where appropriate the bursting disc holder.

3.24

pressure-strengthened vessel

pressure vessel which has been subjected to a calculated and controlled internal pressure (strengthening pressure) after completion, the wall thickness of which 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 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.

4 Symbols

For the purposes of this part of ISO 20421, the following symbols apply (units of measurement are in the column at right):

c	allowance 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, l'_b	buckling length	mm
n	number of lobes	—
p	design pressure as defined in 10.3.2.2	bar
p	calculation pressure	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 pressure	bar
p_T	pressure test (see 6.2)	bar

r	radius, e.g. inside knuckle radius of dished end and cones	mm
s	minimum thickness	mm
s_e	actual wall thickness	mm
v	factor indicative of the utilization 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
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
I	moment of inertia of reinforcing element	mm ⁴
R_e	minimum guaranteed yield stress or 0,2 % proof stress at 20 °C (1 % proof stress for austenitic steel)	N/mm ²
R_m	minimum guaranteed tensile strength at 20 °C	N/mm ²
K	material property used for design (see 10.3.2.3)	N/mm ²
K_T	material property at temperature T in °C (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, in relation with R_e	—
S_k	safety factor against elastic buckling at design pressure	—
S_p	safety factor against plastic deformation	—
Z	auxiliary value	—
ν	Poisson's ratio	—
u	out of roundness (see 11.5.4.2)	—

5 General requirements

5.1 The large transportable 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 12 are fulfilled. The vessel shall be marked in accordance with Clause 13, tested in accordance with Clause 14 and operated in accordance with ISO 20421-2.

5.2 Large transportable 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 large transportable 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 3.8, 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 20421.

6 Mechanical loads

6.1 General

The large transportable cryogenic vessel shall resist the mechanical loads mentioned in 10.2.3 without such deformation which could affect safety and which could lead to leakage. This requirement can be validated by:

- the calculation;
- the calculation and pressure-strengthening method, if allowed;
- the calculation and experimental method.

6.2 Load during the pressure test

The load exerted during the pressure test shall be:

$$p_T \geq 1,3(p_s + 1)$$

where

p_T = test pressure (in bar);

p_s = maximum allowable pressure (in bar);

+ 1 = 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 neglected.

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 interspace 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:

For the inner vessel and its associated equipment the full range of temperature expected.

For the outer jacket and equipment thereof (other than equipment covered in the previous paragraph):

- a minimum working temperature of $-20\text{ }^{\circ}\text{C}$;
- a maximum working temperature of $50\text{ }^{\circ}\text{C}$.

NOTE This does not apply if the jacket is designed for a lower temperature to be marked on the nameplate.

9 Materials

For the materials used to manufacture the transportable cryogenic vessels, the requirements defined in 9.1 to 9.3 shall be met.

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 parts of ISO 21028-1 and ISO 21028-2; 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 G, subject to meeting the extra requirements given in the main body of this part of ISO 20421, are suitable for and may be employed in the manufacture of the cryogenic vessels, in conformance with ISO 20421-1.

9.2 Inspection certificates

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

9.2.2 The material manufactured to a recognized International Standard shall meet the testing requirements of ISO 21028-1 and ISO 21028-2 and shall be declared by an inspection certificate 3.1b in accordance with ISO 10474.

9.2.3 The delivery of material which is not manufactured to a recognized International Standard shall be guaranteed by an inspection certificate 3.1a in accordance with ISO 10474 confirming that the material fulfils 9.1 of this part of ISO 20421-1. The material manufacturer shall follow a recognized International Standard for processing and establishing the guaranteed material properties.

9.2.4 The outer jacket and the equipment not subjected to low 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.

Metallic materials used at cryogenic temperatures shall meet the requirements of the relevant sections of ISO 21028-1 and ISO 21028-2.

In the case of 9 % Ni steel, the additional requirements in Annex C 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 dynamic loads.

10.1.3 Design by calculation and 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 D, if 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 providing 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 10.2.7 are applicable to all vessels irrespective of the design option used.

In the event of an increase in at least one of the following parameters, the initial design process shall be repeated to take account of these modifications:

- maximum allowable pressure;
- specific mass (density) of the densest gas for which the vessel is designed;
- maximum tare weight of the inner vessel;
- nominal length and/or diameter of the inner shell;

or, in the event of any change relative:

- to the type of material or grade (e.g. stainless steel to aluminium);
- to the fundamental shape;
- to the decrease in the minimum mechanical properties of the material being used;

- to the modification of the design of an assembly method concerning any part under stress, particularly as far as the support systems between the inner vessel and the outer jacket or the inner vessel itself or the protective frame, if any, are concerned.

10.2.2 Design specification

To enable the design to be prepared, the following information which defines a vessel type shall be available:

- maximum allowable pressure;
- fluids intended to be contained;
- gross volume of the inner vessel;
- dimensions and allowable weight, taking into account characteristics of the vehicle;
- location of fastening points and loads allowable on these points;
- filling and emptying rate;
- range of ambient temperature, if different from Clause 8;
- transportation mode (see Tables 2 and 3).

A design document in the form of drawings with text, if any, shall be prepared. It shall contain the information given above plus the following where applicable:

- definition of which components are designed by calculation, by pressure strengthening, by experiment and by satisfactory in-service experience;
- drawings with dimensions and thicknesses of load-bearing components;
- specification of all load-bearing materials including grade, class, temper, testing, etc., as relevant;
- applicable material test certificates;
- location and details of welds and other joints, welding and other joining procedures, filler, joining materials, etc., as relevant;
- calculations to verify compliance with this part of ISO 20421;
- design test programme;
- non-destructive testing requirements;
- pressure test requirements;
- piping configuration, including type, size and location of all valves and relief devices;
- details of fastenings.

10.2.3 Design loads

10.2.3.1 General

The large transportable cryogenic vessel shall be able to withstand safely the mechanical and thermal loads encountered during a pressure test and normal operation. The static forces used shall be obtained as required in 10.2.3.1.1 and 10.2.3.1.2.

10.2.3.1.1 The inner vessel, its fastenings and supports shall be designed for the static forces obtained by multiplying the load factors applicable for the transportation modes given in Table 2 with the maximum weight imposed on the inner vessel. The maximum weight imposed on the inner vessel shall include the weights of the inner vessel, its fastenings and supports, maximum permissible content, piping, insulation and any other item supported on the inner vessel. Each load case shall be considered separately, but all forces in a load case shall be considered acting simultaneously. The static forces obtained are equivalent to the dynamic loads experienced during normal operation of the transport vessel. The load factors for assessment of fatigue life are given in Table 3.

10.2.3.1.2 The outer jacket, its fastenings and supports shall be designed for the static forces obtained by multiplying the load factors applicable for the transportation modes given in Table 2 with the maximum weight imposed on the outer jacket. The maximum weight imposed on the outer jacket shall include the weights of the outer jacket, with all its enclosures including inner vessel filled to the maximum permissible capacity and the weights of all items fastened to or supported from/to the outer jacket such as piping, controls, cabinets, etc. Each load case shall be considered separately, but all forces in a load case shall be considered acting simultaneously. The static forces obtained are equivalent to the dynamic loads experienced during normal operation of the transport vessel. The load factors for assessment of fatigue life are given in Table 3.

10.2.3.1.3 Fatigue life calculation shall be conducted according to EN 13445-3, ASME VIII-2 or equivalent standards/codes, and shall be conducted for $\left[\frac{AC_1}{AC_2} \right] 10^9 \left[\frac{AC_1}{AC_2} \right]$ cycles or for the highest number of cycles given on the curve, whichever is lowest. Alternatively, the life of the vessel may be specified and marked on the nameplate.

In fatigue evaluation of any item designed to withstand more than one load case, the maximum loadings in each direction from all applicable load cases shall be considered to act simultaneously in determining the magnitude of alternating stresses. A pressure cycle occurs when the pressure variation is more than 50 % of the maximum allowable pressure p_s . The usage factor shall not exceed 1,00.

NOTE Fatigue analysis as stated above can be satisfied for existing designs through documented evidence of previous long-term satisfactory service under the same operating conditions.

Table 2 — Design load factors for normal operations in specified transportation modes

Transportation modes	Load case	Load factors				
		Forward	Backward	Up	Down	Lateral
Road and water	1	2,0			1,0	
	2		2,0		1,0	
	3			1,0		
	4				2,0	
	5 ^a				1,0	1,0
	5A ^a				1,0	2,0
Rail with cushioning devices ^b	1	2,0			1,0	
	2		2,0		1,0	
	3			2,0		
	4				2,0	
	5				1,0	2,0
Rail without cushioning devices ^b	1	4,0			1,0	
	2		4,0		1,0	
	3			2,0		
	4				2,0	
	5 ^a				1,0	2,0
	5A ^a				1,0	4,0
NOTE For mixed transportation modes, the higher appropriate design factor applies.						
^a Load case 5A should be considered instead of load case 5 if the direction of the travel is not known.						
^b The cushioning devices should be tested to demonstrate their ability to limit forces transmitted from the coupler to the tank is less than twice the weight of the tank filled to its rated capacity at a 16 kilometre per hour impact.						

Table 3 — Factors for fatigue analysis in specified transportation modes

Transportation modes	Load case	Load factors					
		Forward	Backward	Up	Down		Lateral
		cyclic	cyclic	cyclic	cyclic	steady	cyclic
Road and water	1	0,7				1,0	
	2		0,7			1,0	
	3			1,0			
	4				1,0	1,0	
	5					1,0	0,7
Rail with cushioning devices ^b	1	2,0				1,0	
	2		2,0			1,0	
	3			1,0			
	4				1,0	1,0	
	5 ^a					1,0	1,0
	5A ^a					1,0	2,0
Rail without cushioning devices ^b	1	4,0				1,0	
	2		4,0			1,0	
	3			1,0			
	4				1,0	1,0	
	5 ^a					1,0	1,0
	5A ^a					1,0	4,0
^a Load case 5A should be considered instead of load case 5 if the direction of the travel is not known.							
^b The cushioning devices should be tested to demonstrate their ability to limit forces transmitted from the coupler to the tank is less than twice the weight of the tank filled to its rated capacity at a 16 kilometre per hour impact.							

10.2.3.2 Inner vessel

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

a) calculation pressure, p , where

$$p = p_s + p_L + 1 \text{ bar ;} \quad (1)$$

p_L is the pressure, in bar, exerted by the mass of the liquid contents when the vessel is filled to capacity and subject to each load defined in 10.2.3.1, with either:

- 1) boiling liquid at atmospheric pressure; or
 - 2) cryogenic fluid at its equilibrium triple point or melting-point temperature at atmospheric pressure;
- b) loads imposed on the inner vessel due to the mass of the inner vessel and its contents when subject to each of the loads defined in 10.2.3.1;
- c) loads imposed by the piping due to the differential thermal movement of the inner vessel, the piping and the outer jacket, in which the following cases shall be considered:
- cool down (inner vessel warm/piping cold);
 - filling and withdrawal (inner vessel cold/piping cold); and
 - transport and storage (inner vessel cold/piping warm);
- d) reactions at the support points of the inner vessel during operation when the vessel contains cryogenic liquid product. The reactions shall be determined as described in 10.2.3.1.1;
- e) reactions at the support points of the inner vessel during operation when the vessel contains only gaseous product at 20 °C. The reactions shall be determined as described in 10.2.3.1.1.

10.2.3.2.2 The design shall be evaluated for the following conditions:

Pressure test: the value used for validation purposes shall be:

$$p_T \geq 1,3(p_s + 1) \text{ bar} \quad (2)$$

considered for each element of the vessel, e.g. shell courses, head, etc.

p_s is the maximum allowable pressure, in bar.

The 1 bar is added to allow for the external vacuum. The primary membrane stress at test pressure shall not exceed the value prescribed in the relevant regulation but in no case the yield stress of the material.

The minimum test pressure of the inner vessel shall be 3 bar. This requirement does not apply to heating or cooling systems and related service equipments.

10.2.3.3 Outer jacket

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

- a) an external pressure of 1 bar;
- b) an internal pressure equal to the set pressure of the outer-jacket pressure relief device;
- c) load imposed by the inner-vessel and its contents at the support points in the outer jacket when subject to the forces specified in 10.2.3.1.1 and 10.2.3.1.2 and Tables 2 and 3.
- d) load imposed by piping as defined in 10.2.3.2.1 c);
- e) load imposed at the inner-vessel support points in the outer jacket when the inner vessel cools from ambient to operating temperature and during operation;
- f) reactions at the outer-jacket fastening points when subject to the forces specified in 10.2.3.1.2 and Tables 2 and 3.

10.2.3.4 Self-supporting vessels

In the case of vehicles in which the inner vessel and possibly the outer jacket constitute stressed self-supporting members of the vehicle, these shall be designed to withstand the stresses thus imposed in addition to stresses from other sources [see 10.2.3.2.1 c) and 10.2.3.3 f)].

10.2.3.5 Inner-vessel supports

The inner-vessel supports shall be designed for the loads specified in 10.2.3.1 and 10.2.3.2 to a maximum allowable stress value equal to $\frac{2}{3} K_{20}$.

10.2.3.6 Surge plates

The inner-vessel shall be divided by surge plates to provide stability and limit dynamic loads to the requirements of 10.2.3, unless it is to be filled equal to or more than 80 % of its capacity or nominally empty. The cross-sectional area of the surge plate shall be at least 70 % of the cross-section of the vessel.

The volume between surge plates shall not exceed $\frac{10\,500}{s_g}$ litres where s_g is the specific gravity of the cryogenic fluid at 1 bar saturation.

Surge plates and their attachments to the shell shall be designed to resist the stresses caused by a pressure evenly distributed across the area of the surge plate. The pressure is calculated by considering the mass of liquid between the plates decelerating at 2 g (10.2.3).

10.2.3.7 Outer-jacket supports

The outer-jacket supports shall be suitable for the load defined in 10.2.3.3.

10.2.3.8 Fastening points

Fastening points shall be suitable for fastening the large transportable cryogenic vessel to the vehicle when filled to capacity and subject to each of the loads defined in 10.2.3.

10.2.3.9 Protection of upper fittings

The fittings and accessories mounted on the upper part of the vessel shall be protected in such a way that damage caused by overturning cannot impair operational integrity. This protection may take the form of cylindrical profile of the vessel, of strengthening rings, protective canopies or transverse or longitudinal members so shaped that effective protection is given (e.g. structures of frame such as in ISO 1496-3).

10.2.3.10 Stability

The overall width of the ground-level bearing surface (distance between the outer points of contact with the ground of the right-hand tyre and the left-hand tyre of the same axle) shall be at least equal to 90 % of the height of the centre of gravity of the fully laden tank vehicle. In an articulated vehicle the mass on the axles of the load-carrying unit of the laden semitrailer shall not exceed 60 % of the nominal total laden mass of the complete articulated vehicle. However, applicable regulations where the vessel is to be operated shall apply.

10.2.3.11 Piping and valves

Piping including valves, fittings and supports shall withstand the following loads. With the exception of a), the loads shall be considered to act in combination where relevant.

- a) pneumatic pressure test: not less than the allowable working pressure p_s plus 1 bar for piping inside the vacuum jacket;
- b) pressure during operation: not less than the set pressure of the system pressure-relief device;
- c) thermal loads defined in 10.2.3.2 d);
- d) dynamic loads;
- e) set pressure of thermal-relief devices where applicable;
- f) loads generated during pressure-relief discharge.

Piping and accessories shall be designed such that their lowest natural frequency is equal to or higher than 30 cycles per second.

This equipment shall be protected or positioned so as to be protected against the risk of being wrenched off or damaged during transport.

In the particular case of liquid with a boiling temperature colder than that of liquid nitrogen, the possibility of air condensing on uninsulated parts shall be considered.

The leakproofness of this equipment shall be ensured in the event of overturning of the vehicle. The gaskets shall be made of a material compatible with the fluid carried, in accordance with ISO 21010.

Each bottom-filling or bottom-discharge opening shall be provided with at least two independent shut-off devices in series, the first being a stop valve situated as close as possible to the outer jacket and provided with protection against mechanical damage at least equal to that afforded by the outer jacket.

For flammable fluids only, in order to prevent leaks of flammable fluids, the first stop valve shall be an instant-closing safety device which closes automatically in the event of an unintended movement of the vehicle or of fire during the filling/emptying operation. It shall also be possible to operate the closing device by remote control. All vent pipes, including pressure-relief devices and purge valves, shall be connected to a vent pipe allowing safe discharge. The control cabinet shall be vented so that flammable gas cannot accumulate therein.

10.2.4 Fatigue

The design shall take into account the effect of cyclic stress on the inner vessel, outer jacket and their attachments during normal conditions of operation, including pressure cycles.

When considering the case of fatigue, the common requirement of designing with loads according to 10.2.3 will be such as to accommodate the effects of fatigue. It may be necessary to pay particular attention to specific details in the supports and piping systems to avoid stress raisers.

10.2.5 Corrosion allowance

Corrosion allowance is not required on surfaces in contact with the operating fluid. Corrosion allowance is not required on other surfaces if they are adequately protected against corrosion.

NOTE 1 Due to the combination of materials of construction and operating fluids, internal corrosion cannot occur.

NOTE 2 The inner vessel is inside the evacuated outer jacket and hence external corrosion of the inner vessel cannot occur.

10.2.6 Inspection openings

Inspection openings are not required in the inner vessel or the outer jacket, provided that the requirements of ISO 20421-2 are followed.

NOTE The elimination of inspection openings also assists in maintaining the integrity of the vacuum in the interspace.

10.2.7 Pressure relief

Relief systems shall be designed to meet the requirements given in 10.2.7.1 to 10.2.7.3.

10.2.7.1 Inner vessel

10.2.7.1.1 An inner vessel shall be provided with not less than two independent spring-loaded pressure-relief devices. The pressure-relief devices shall open automatically at a pressure not less than the maximum allowable pressure and be fully open at a pressure equal to 110 % of the maximum allowable pressure, in accordance with this part of ISO 20421. These devices shall, after discharge, close at a pressure not less than 10 % below the maximum allowable pressure, and shall remain closed at all lower pressures. The pressure-relief devices shall be of the type that will resist dynamic forces, including surge.

10.2.7.1.2 In the case of the loss of vacuum, an additional reclosing pressure-relief device, set at no more than 110 % of the maximum allowable pressure, may be used, and the combined capacity of all pressure-relief devices installed shall be sufficient so that the pressure (including accumulation) inside the vessel does not exceed 120 % of the maximum allowable pressure, in accordance with this part of ISO 20421. For non-flammable refrigerated liquefied gases (except oxygen) and hydrogen, this capacity may be achieved by the use of bursting discs in parallel with the required safety relief devices. Bursting discs shall rupture at nominal pressure equal to the test pressure.

10.2.7.1.3 Under the circumstances described in 10.2.7.1.1 and 10.2.7.1.2, together with complete fire engulfment, the combined capacity of all pressure-relief devices shall be sufficient to limit the pressure in the vessel to the test pressure.

10.2.7.1.4 The required capacity of the relief devices shall be calculated in accordance with ISO 21013-1.

The pressure-relief system shall be sized so that the pressure drop during discharge does not cause the valve to reseal instantly.

10.2.7.2 Outer jacket

Relief devices for the outer jacket shall be in accordance with Annex F.

A pressure-relief device shall be fitted to the outer jacket. The device shall be set to open at a pressure which prevents collapse of the inner vessel and is not more than 0,5 bar.

10.2.7.3 Piping

Any section of pipework containing cryogenic fluid which can be isolated shall be protected by a relief valve or other suitable relief device.

10.2.8 Valves

Valves shall conform to ISO 21011.

10.2.9 Insulation

For oxygen or gases having a boiling point below $-182\text{ }^{\circ}\text{C}$ at atmospheric pressure, the insulation installed on the tank shall be in accordance with ISO 21010.

10.2.10 Degree of filling

The degree of filling of large transportable vacuum-insulated vessels shall remain below the level at which, if the contents were raised to the temperature at which the vapour pressure equalled to opening pressure of the lowest set pressure relief valve or steam, the volume of the liquid would reach 98 % of the vessel's net volume. Degree of filling for helium may be 100 % of the net volume. Pre-trip inspection shall ensure that the above limits are not exceeded.

10.2.11 Electrical continuity

All metallic components of large transportable vacuum-insulated vessels intended for the carriage of flammable gases shall be electrically continuous. The electrical resistance, as measured by an ohmmeter, between the inner vessel and/or related metallic components to the vehicle chassis shall not exceed 10 ohms.

10.3 Design by calculation

10.3.1 General

The dimensions of the inner vessel and outer jacket shall not be less than that determined in accordance with this subclause.

10.3.2 Inner vessel

10.3.2.1 General

The minimum thickness of the inner vessel shall be the larger of the thickness value from Table 4 or 10.3.6.

Table 4 — Inner-vessel minimum wall thickness

Inner vessel Diameter, D , in millimetres	Minimum wall thickness, s_r , in millimetres for reference material ^a
$D \leq 1\,800$	3
$D > 1\,800$	4

^a Reference material is material having a product $R_m \times A_5$ of approximately 10 000, which yields the cube root of $R_m \times A_5 = 21,4$.

For other materials, the required minimum thickness of the metal used is:

$$s = \frac{21,4 \times s_r}{\sqrt[3]{R_m \times A_5}}$$

where

s is the required minimum equivalent thickness of the material used, in millimetres;

R_m is the minimum tensile strength of the metal used, in Newton per square millimetre, at a temperature not lower than the saturation temperature of the fluid at pressure P_s , according to national or international standards;

A_5 is the minimum elongation at fracture (in %) of the metal used at a temperature not lower than the saturation temperature of the fluid at pressure P_s , according to national or international standards.

Alternatively, the values of R_m and A_5 up to 15 % higher than guaranteed minimum values at 20 °C, according to national or international standards, may be used, provided this higher value is certified in the material certification for each cast (heat) of material used.

Values of R_m and A_5 at the same temperature shall be used.

Under these conditions, the reference material equivalent thickness of the inner vessel can be determined as follows:

$$s = s_e$$

$$s_r = s_e \frac{\sqrt[3]{R_m \times A_5}}{21,4} \quad (3)$$

where

s_e is the actual wall thickness of the inner vessel.

The R_m and A_5 values at a temperature not lower than the saturation temperature of the fluid at pressure p_s shall be determined from the appropriate material standard or shall be guaranteed by the material manufacturer.

10.3.2.2 Design pressure, p

The internal design pressure shall be p as defined in 10.2.3.2.1 a).

The inner vessel shall be designed for a minimum external pressure equal to the set pressure of the outer-jacket pressure-relief device.

10.3.2.3 Material properties, K

10.3.2.3.1 General

The material property, K , to be used in the calculations shall be as follows:

- for austenitic stainless steels, $R_e = 1$ % proof strength;
- for carbon steels, aluminium and aluminium alloys, $R_e =$ yield strength and, if not available, 0,2 % proof strength.

For calculation purposes the material property, K , of the inner vessel shall be limited to 0,57 of R_m , the minimum guaranteed tensile strength.

10.3.2.3.2 K_{20}

R_e and R_m shall be the minimum guaranteed values at 20 °C taken from the material standard.

In the case of austenitic stainless steels, the specified minimum values may be exceeded by up to 15 % for carrying all loads listed in 10.2.3.2, except for the design pressure, p , specified under 10.2.3.2.1 a).

The 15 % higher values of K_{20} may be used provided this higher value is attested in the inspection certificate and the following conditions are met:

- the material manufacturer shall guarantee compliance with this higher value, in writing, when accepting the order;
- the increased properties shall be verified by testing each cast (production lot);
- the welding procedure shall be suitably qualified.

Ratios of R_e/R_m exceeding 0,85 are not allowed for steels in the construction of welded tanks. In determining the ratio R_e/R_m , the minimum specified value of R_e and R_m in the material inspection certificate shall be used.

10.3.2.3.3 K_t

The permissible values of R_e and R_m shall be determined for the material at the operating temperature corresponding to a temperature not lower than the saturation temperature of the fluid at pressure p_s . The values of R_e , R_m and E shall be determined from the appropriate material standard (see EN 10028-7 Annex F for austenitic stainless steels) or shall be guaranteed by the material manufacturer.

10.3.2.3.4 Brittleness

The material shall not be subject to brittle fracture at its minimum operating temperature (see ISO 21028-1 and ISO 21028-2).

10.3.2.3.5 Elongation

For steel, the elongation at fracture in % shall be not less than

$$\frac{10\,000}{\text{determined tensile strength in N/mm}^2} \text{ at } 20\text{ °C} \quad (4)$$

and in any case it shall be not less than 16 % for fine grained steels and not less than 20 % for other steels. For aluminium and aluminium alloys the elongation at fracture shall not be less than 12 %.

Elongation and determined tensile strengths are the actual values indicated in the material certificates.

10.3.2.4 Safety factors S , S_p and S_k

Safety factors are the ratio of material property K , K_{20} , or K_f over the maximum allowable stress.

a) Internal pressure (pressure on the concave surface):

$$s = 1,73$$

This may be reduced to 1,5 for road transportation mode, if allowed by the applicable authorities where the vessel is to be operated.

b) External pressure (pressure on the convex surface):

— cylindrical shells: $S_p = 1,4$

$$S_k = 2,0$$

— spherical region: $S_p = 2,1$

$$S_k = 2,0 + 0,001\,8\,R/s_e$$

— knuckle region: $S_p = 1,6$

10.3.2.5 Weld joint factor, v

$v = 1$ for all butt double-welded joints and single-welded butt joints with removable backing strips with complete penetration and full fusion and circumferential seams with permanent backing strip and circumferential joggle joints.

10.3.2.6 Corrosion allowances, c

$$c = 0$$

No corrosion allowance is required.

10.3.3 Outer jacket

10.3.3.1 General

The following shall be used to determine the pressure part thickness in conjunction with the calculation formula of 10.3.6.

The reference material equivalent thickness of the outer jacket shall be determined as follows:

$$s_r = s_e \frac{\sqrt[3]{R_m \times A_5}}{21,4} \quad (5)$$

where

s_r is the reference material equivalent thickness, in mm;

s_e is the actual wall thickness of the outer jacket, in mm;

R_m is the minimum tensile strength, in N/m², at 20 °C;

A_5 is the elongation at fracture, in %, at 20 °C.

The aggregate reference material equivalent thickness of the outer-jacket wall and inner-vessel wall shall be not less than 5 mm if the diameter of the inner vessel is not more than 1 800 mm, and not less than 6 mm if this diameter is more than 1 800 mm.

10.3.3.2 Calculation pressure, p

The internal calculation pressure, p , shall be not less than the set pressure of the outer, jacket pressure, relief device.

The external calculation pressure shall be 1 bar.

10.3.3.3 K_{20}

See 10.3.2.3.2.

10.3.3.4 Safety factors S , S_p and S_k in relation to K , K_{20} or K_t

a) Internal pressure (pressure on the concave surface):

$S = 1,73$ may be reduced to 1,5 for road transportation mode, if allowed.

b) External pressure (pressure on the convex surface):

— cylindrical shells $S_p = 1,1$

$S_k = 2,0$

— spherical region $S_p = 1,6$

S_k (see applicable method in Annex H)

— knuckle region $S_k = 1,2$

10.3.3.5 Plastic deformation

Resistance to plastic deformation is determined by using 10.3.6.1.3 with the appropriate safety factor, S_p , defined in 10.3.2.4 and 10.3.3.4.

10.3.3.6 Weld joint factor, ν

For internal pressure (pressure on the concave surface), $\nu = 0,85$.

For external pressure (pressure on the convex surface), $\nu = 1,0$.

10.3.3.7 Corrosion allowances, c

For austenitic stainless steel, $c = 0$.

For aluminium alloys, $c = 0$.

NOTE *UN Recommendations on the transport of dangerous goods* (6.7.4.2.1) do not allow aluminium alloys for the outer jacket.

For carbon steel, $c = 1,0$ mm.

NOTE c may be reduced to zero if the external surface is adequately protected against corrosion.

10.3.4 Attachments

For those items attached to the inner vessel, other than the inner-vessel supports (see 10.2.3.4), the allowable stress shall not exceed the $0,75 K_{20}$ or $0,75 K_t$ as applicable. Other attachments to the jacket shall be designed for the loads defined in 10.2.3.1 using established design methods and allowable stress not exceeding $0,75 K_{20}$. See also Annex B for an acceptable method.

When the inner vessel is being designed, the temperature and corresponding mechanical properties of the structural attachment attached to the inner vessel may be those of the component in question when the inner vessel is filled to capacity with cryogenic fluid at a temperature not lower than the saturation temperature at pressure p_s . However, it shall be checked whether the stresses are acceptable in warm conditions (vessel empty).

10.3.5 Piping and accessories

Piping shall be designed for the loads defined in 10.2.3.1 using established piping design methods and safety factors. However, the overall safety factor used on the material property K shall not be less than the values given in 10.3.2.4.

10.3.6 Calculation formula

10.3.6.1 Cylindrical shells and spheres subject to internal pressure (pressure on the concave surface)

10.3.6.1.1 Field of application

The field of application for cylindrical shells and spheres is:

$$D_a/D_i \leq 1,2.$$

10.3.6.1.2 Openings

For reinforcement of openings, see 10.3.6.7.

10.3.6.1.3 Calculation

The required minimum wall thickness, s , is:

— for cylindrical shells:

$$s = \frac{D_a p}{20 \frac{K_{20}}{S} v + p} + c \quad (6)$$

— for spherical shells:

$$s = \frac{D_a p}{40 \frac{K_{20}}{S} v + p} + c \quad (7)$$

10.3.6.2 Cylindrical shells subject to external pressure (pressure on the convex surface)

10.3.6.2.1 Field of application

The field of application for cylindrical shells is:

$$D_a/D_i \leq 1,2.$$

10.3.6.2.2 Openings

Openings shall be calculated in accordance with 10.3.6.7 using the external pressure as an internal pressure.

10.3.6.2.3 Calculation

Annex H gives two alternative calculation methods. Both methods give comparable results and shall be equally accepted.

10.3.6.3 Spheres subject to external pressure (pressure on the convex surface)

See Annex H.

10.3.6.4 Dished ends

10.3.6.4.1 Field of application

The following dish ends may be used:

- a) hemispherical ends where $D_a/D_i \leq 1,2$;
- b) torispherical ends where $0,5D_a \leq R \leq D_a$ and $0,5D_a \geq r \geq 0,06D_a$;
- c) 2:1 elliptical ends where $R = 0,9D_a$ and $r = 0,170D_a$.

NOTE In the case of elliptical ends, $0,001 \leq (s - c)/D_a \leq 0,1$.

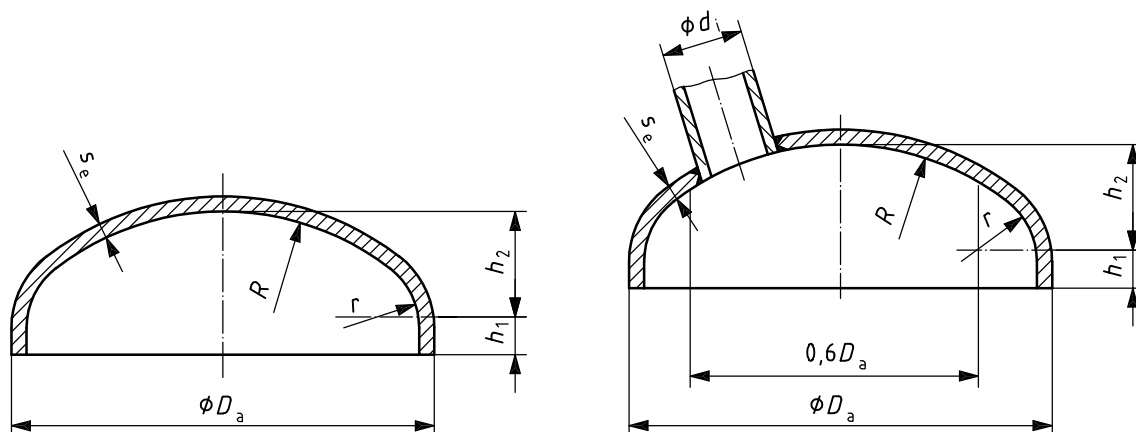
[AC1] Dished ends of vacuum jackets are not required to meet the above restrictions on R and r , when r is greater than or equal to 3 s. **[AC1]**

10.3.6.4.2 Straight flange

The straight flange length, h_1 [Figure 1a) and b)], shall not be less than:

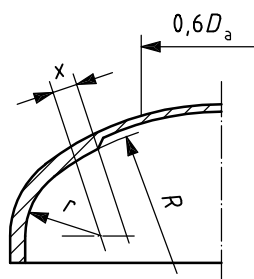
- for 10 % torispherical ends: 3,0 s;
- for 2:1 torispherical ends: 3,0 s;
- for 2:1 elliptical ends: 3,0 s.

The straight flange may be shorter provided that in the case of inner vessels, the circumferential joint between the dished end and the cylinder is non-destructively tested as required for a weld joint factor of 1,0.



a) Unpierced dished end

b) Dished end with nozzle



c) End with knuckle and crown of unequal wall thickness

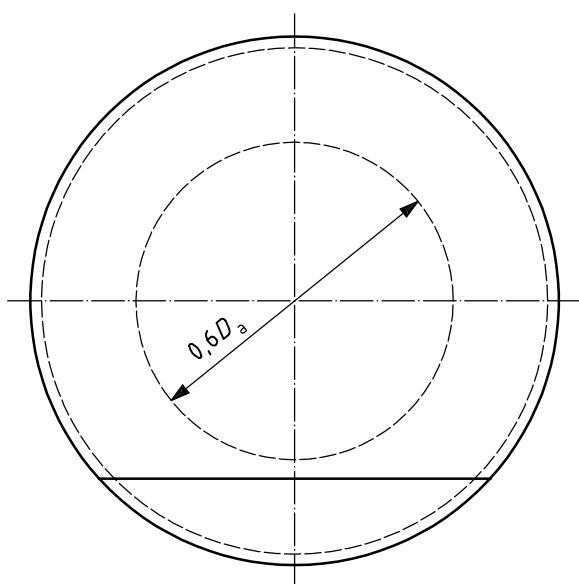
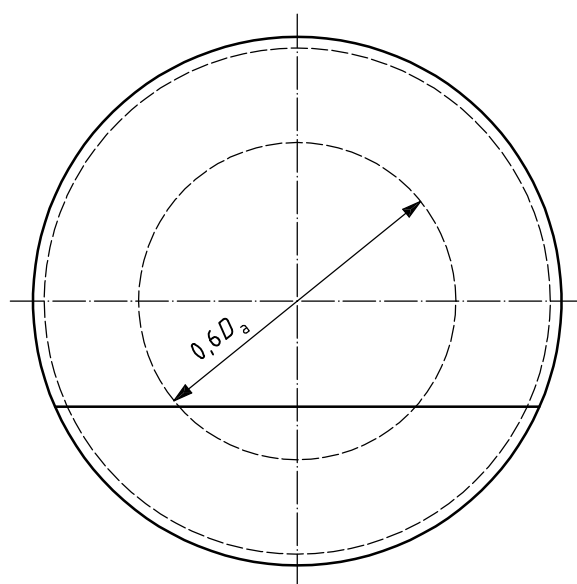
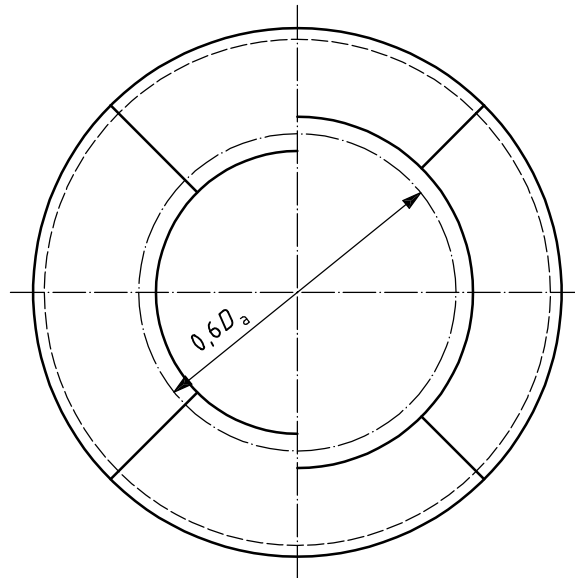
 $v = 0,85$ or $1,0$ d) Weld outside $0,6 D_a$  $v = 1,0$ e) Weld inside $0,6 D_a$

Figure 1 — Examples of dished ends


 $\nu = 1,0$
 $\nu = 0,85 \text{ or } 1,0$

f) End welded together from round plate and segments

Figure 1 (continued)

10.3.6.4.3 Internal-pressure calculation (pressure on concave surface)

10.3.6.4.3.1 Crown and hemisphere thickness

The wall thickness of the crown region of dished ends and of hemispherical ends shall be determined using 10.3.6.1.3 for spherical shells with $D_a = 2(R + s)$.

The opening within the crown area of $0,6D_a$ of torispherical ends and in hemispherical ends shall be reinforced in accordance with 10.3.6.7. When pad-type reinforcement is used, the edge of the pad shall not extend beyond the area of $0,8D_a$.

10.3.6.4.3.2 Torispherical end knuckle thickness and hemispherical end to shell junction thickness

The required thickness of the knuckle region or hemispherical end junction shall be:

$$s = \frac{pRM}{20 \frac{K_{20\nu}}{S} - 0,2p}$$

where

$$M = 0,25 \left(3 + \sqrt{\frac{R}{r}} \right)$$

and R = inside crown radius and r = inside knuckle radius.

Dished ends designed for normal operation under internal pressure (pressure on concave side) shall have $R \leq D_a$ and $r \geq 0,06D_a$, but in no case less than 3 s. Dished ends of vacuum jackets are not required to meet the above restrictions on R and r except $r \geq 3 s$.

10.3.6.4.3.3 Elliptical ends

The required thickness at the thinnest point after forming of elliptical ends under pressure on the concave side shall be determined by:

$$s = \frac{pD_i B}{20 \frac{K_{20} v}{S} - 0,2p}$$

where

$$B = \frac{1}{6} \left[2 + \left(\frac{D_i}{2h} \right)^2 \right];$$

h is one-half of the length of the minor axis of the ellipsoidal end, or the inside depth of the ellipsoidal end measured from the tangent line (end-bend line), in mm.

10.3.6.4.3.4 If a dished end is welded together from crown and knuckle components, the joint shall be at a sufficient distance x from the knuckle.

x shall be the larger of the following:

- 100 mm;
- $0,78\sqrt{R(s)}$ if the crown and knuckle are of different thickness, where s is the thickness of the knuckle component;
- 3,5 s .

$v = 1,0$ may be used if the scope of testing corresponds to that specified for a design stress level equal to the permissible design stress level or in the case of one-piece ends.

10.3.6.4.3.5 If the ligament on the connecting line between adjacent openings is not entirely within the $0,6D_a$ region, the ligament shall not be less than half the sum of the opening diameters.

10.3.6.5 Cones subject to internal or external pressure

10.3.6.5.1 Symbols and units

For the purposes of 10.3.6.5, the following symbols apply in addition to those given in Clause 4:

A	area of reinforcing ring	mm ²
D_{a1}	outside diameter of connected cylinder (see Figure 7)	mm
D_{a2}	outside diameter at effective stiffening (see Figure 9)	mm
D_k	design diameter (see Figure 7)	mm
D_s	shell diameter at nozzle (see Figure 8)	mm
I	moment of inertia about the axis parallel to the shell	mm ⁴
l	cone length between effective stiffenings (see Figure 9)	mm

s_g	required wall thickness outside corner area	mm
s_l	required wall thickness within corner area	mm
x_i	characteristic lengths ($i = 1,2,3$) to define corner area [Figures 7 a) and 7 b) and 10.3.6.5.5]	mm
φ	cone angle	°
r	inside radius of knuckle	mm

10.3.6.5.2 Field of application

The field of application for cones is according to Figure 2 where:

$$0,001 \leq \frac{s_g - c}{D_{a1}} \leq 0,1$$

and

$$0,001 \leq \frac{s_1 - c}{D_{a1}} \leq 0,1$$

Small ends with a knuckle can be safely assessed and verified as a small end with a corner joint.

For external pressure $|\varphi| \leq 70^\circ$.

Other cone angles may be used providing suitable calculations are carried out.

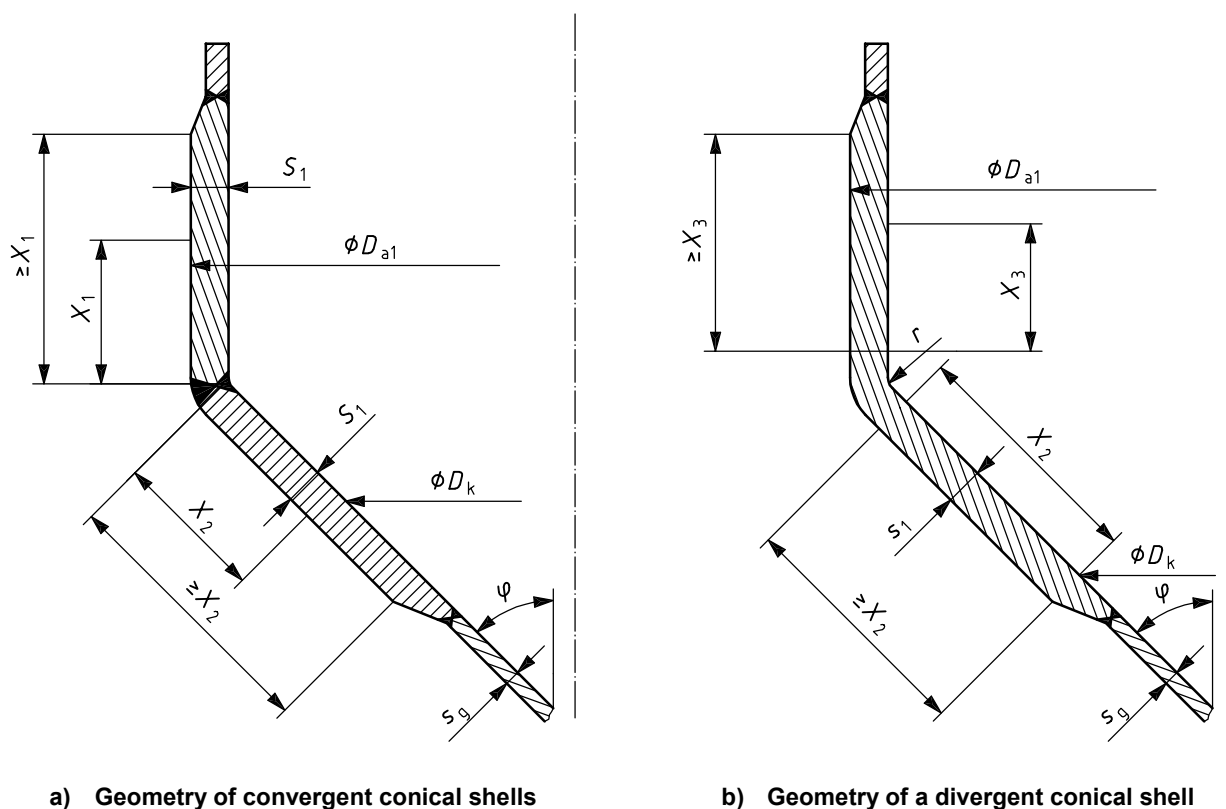


Figure 2 — Examples of cones

10.3.6.5.3 Openings

Openings outside of the corner area (Figure 3) shall be designed as follows:

— if $|\varphi| < 70^\circ$ design according to 10.3.6.5.6 using an equivalent cylinder diameter of:

$$D_i = \frac{D_s + d_i |\sin \varphi|}{\cos \varphi} \quad (8)$$

— if $|\varphi| \geq 70^\circ$ design according to 10.3.6.5.6.

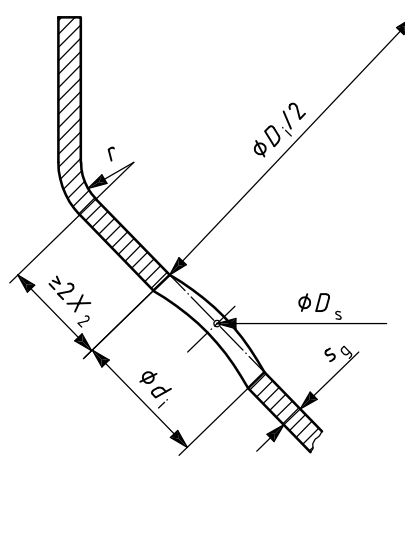


Figure 3 — Geometry of a cone opening

10.3.6.5.4 Non-destructive testing

All corner joints shall be subject to the examination required for a weld joint factor of 1,0.

10.3.6.5.5 Corner area

The corner area is that part of the cone where the dominant stresses are bending stresses in the longitudinal direction.

The corner area is defined in Figures 2 a) and 2 b) by x_1 , x_2 , x_3 calculated from the following equations:

$$x_1 = \sqrt{D_{a1}(s_1 - c)} \quad (9)$$

$$x_2 = 0,7 \sqrt{\frac{D_{a1}(s_1 - c)}{\cos \varphi}} \quad (10)$$

$$x_3 = 0,5 x_1 \quad (11)$$

10.3.6.5.6 Internal-pressure calculation (pressure on concave surface) $|\varphi| \leq 70^\circ$ **a) Within corner area:**

The required wall thickness (s_1) within the corner area is calculated from Figures 4 a) to 4 g) for the large end and Figure 4 h) for the small end of a cone using the following variables:

$$\varphi, \quad \frac{p S}{15 K v} \quad \text{and} \quad \frac{r}{D_{a1}}$$

For a corner joint, the curve for $\frac{r}{D_{a1}} = 0$ shall be used.

For intermediate cone angles, linear interpolation shall be used.

b) Outside corner area:

The wall thickness s_1 in the corner area shall not be less than the required thickness s_g outside the corner area as follows:

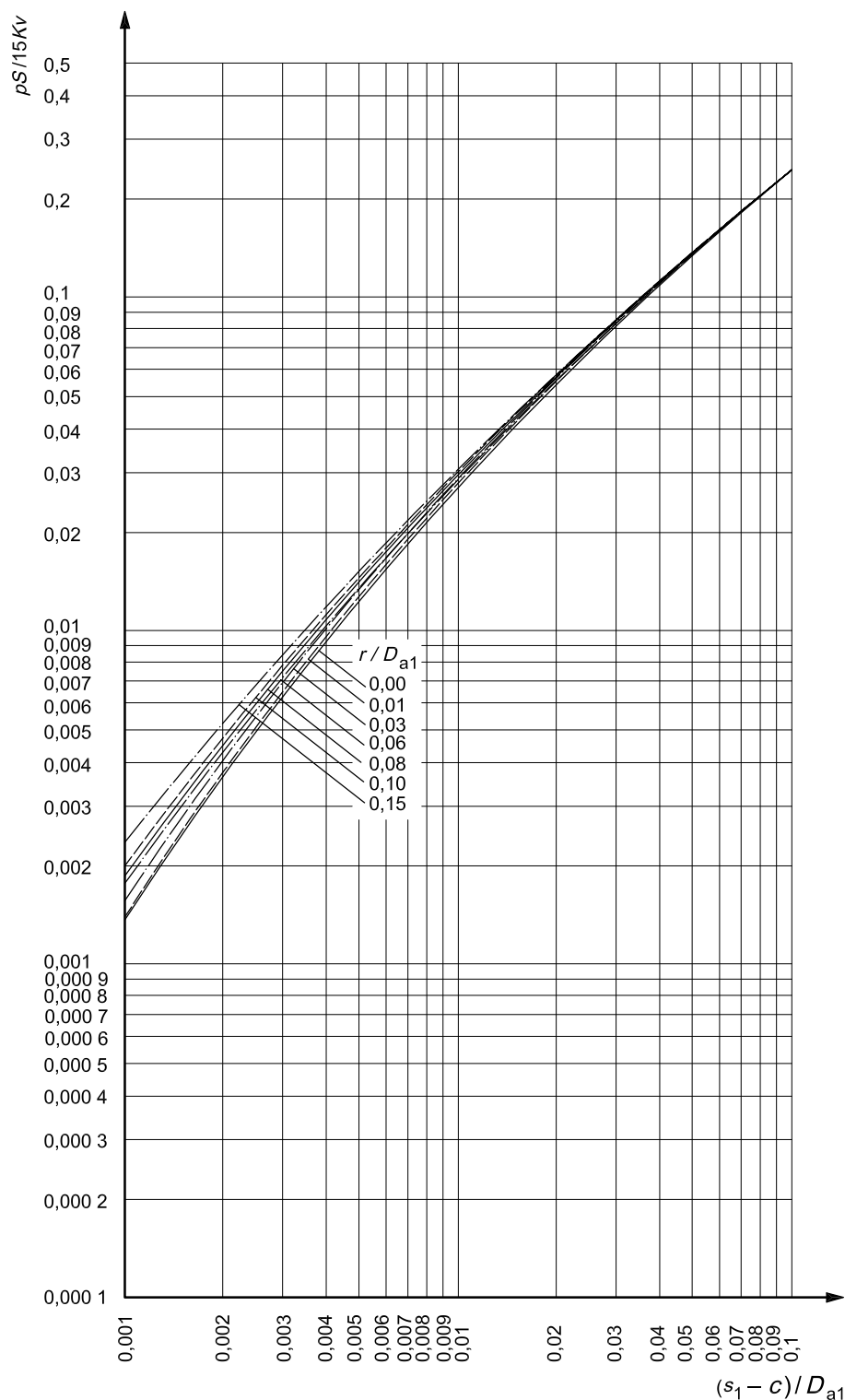
The required wall thickness, s_g , outside the corner area, is calculated from:

$$s_g = \frac{D_k p}{20 \frac{K}{S} v - p} \times \frac{1}{\cos \varphi} + c \quad (12)$$

where

for the large end, $D_k = D_{a1} - 2 [s_1 + r(1 - \cos \varphi) + x_2 \sin \varphi]$;

for the small end, D_k is the maximum diameter of the cone, where the wall thickness is s_g .

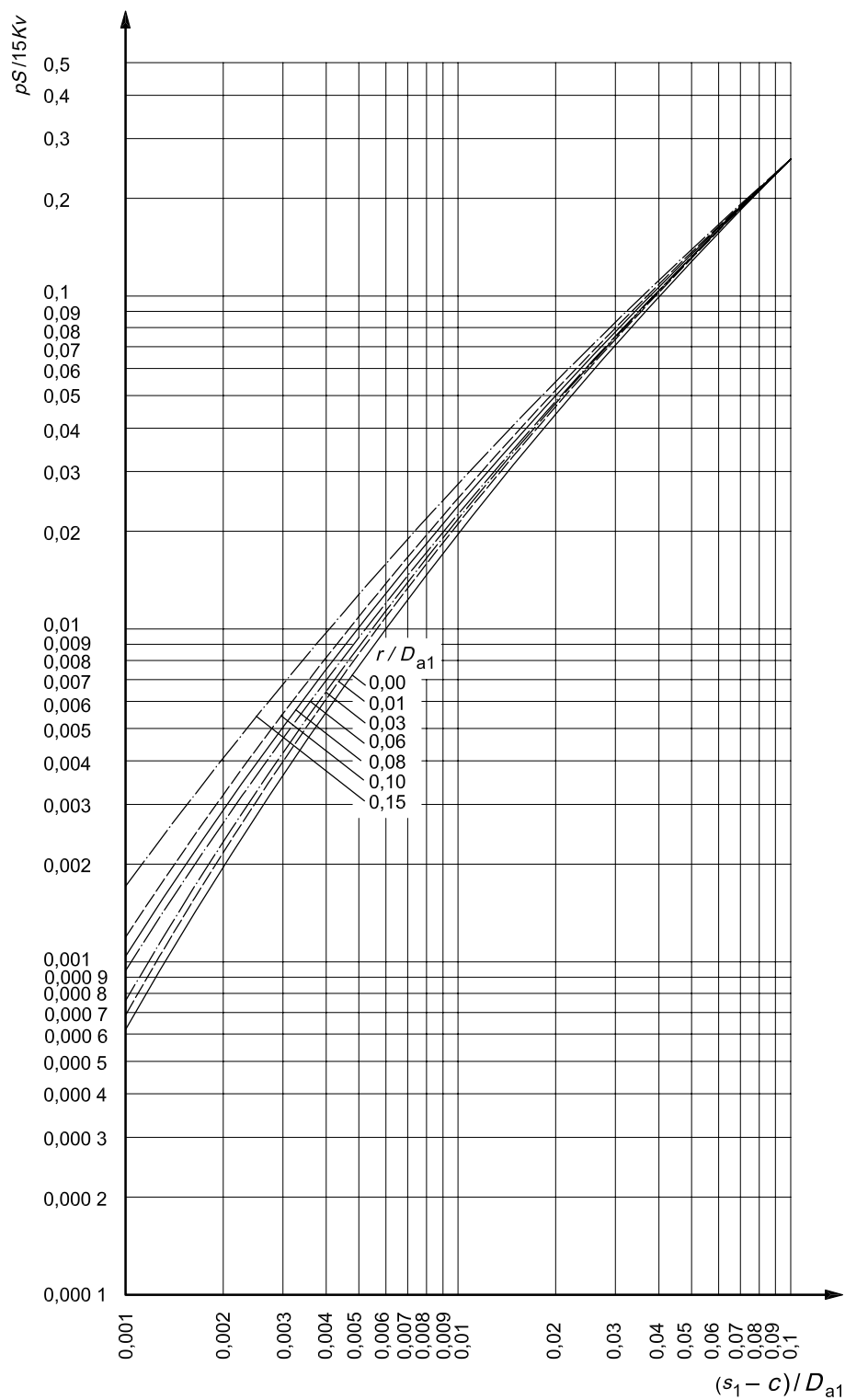
**Key**

$$X = \ln[(s_1 - c)/D_{a1}] \quad Z = \sum_{i=1}^4 \sum_{j=1}^2 A_{ij} \cdot X^{i-1} \cdot Y^{j-1}$$

$$Y = r/D_{a1} \quad \frac{pS}{15Kv} = e^Z$$

a) Permissible value $\frac{pS}{15Kv}$ for convergent cone with an opening angle $\varphi = 10^\circ$

Figure 4

**Key**

$$X = \ln[(s_1 - c)/D_{a1}] \quad Z = \sum_{i=1}^4 \sum_{j=1}^2 A_{ij} \cdot X^{i-1} \cdot Y^{j-1}$$

$$Y = r/D_{a1} \quad \frac{pS}{15Kv} = e^Z$$

b) Permissible value $\frac{pS}{15Kv}$ for convergent cone with an opening angle $\varphi = 20^\circ$

Figure 4 (continued)