

Cryogenic vessels — Large transportable non-vacuum insulated vessels —

Part 2: Design, fabrication, inspection and testing

ICS 23.020.40

National foreword

This British Standard is the UK implementation of EN 14398-2:2003+A2:2008, incorporating corrigendum August 2006. It supersedes BS EN 14398-2:2003 which is withdrawn.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by CEN corrigendum August 2006 is indicated in the text by ⌈AC1⌋ ⌋AC1.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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English Version

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Réceptacles cryogéniques - Grands réceptacles transportables
non isolés sous vide - Partie 2: Conception, fabrication,
inspections et essais

Kryo-Behälter - Große ortsbewegliche, nicht vakuum-
isolierte Behälter - Teil 2: Bemessung, Herstellung und
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Management Centre: rue de Stassart, 36 B-1050 Brussels

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Foreword

This document (EN 14398-2:2003+A2:2008) has been prepared by Technical Committee CEN/TC 268 “Cryogenic vessels”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2008 and conflicting national standards shall be withdrawn at the latest by September 2008.

This document includes Amendment 1, approved by CEN on 2006-10-06, Amendment 2, approved by CEN on 2008-02-07 and Corrigendum 1 issued by CEN on 2006-08-23.

This document supersedes EN 14398-2:2003.

The start and finish of text introduced or altered by amendment is indicated in the text by tags **A1** **A1** and **A2** **A2**.

The modifications of the related CEN Corrigendum have been implemented at the appropriate places in the text and are indicated by the tags **AC** **AC**.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports the objectives of the framework Directives on Transport of Dangerous Goods.

The standard has been submitted for reference into the RID and/or in the technical annexes of the ADR. **A2** *deleted text* **A2**

EN 14398 consists of the following parts under the general title, *Cryogenic vessels – Large transportable non-vacuum insulated vessels*:

- *Part 1: Fundamental requirements*
- *Part 2: Design, fabrication, inspection and testing*
- *Part 3: Operational requirements*

A2 Annexes B, C and E are normative. Annexes A and D are normative. **A2**

This document includes a Bibliography.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This European Standard specifies requirements for the design, fabrication, inspection and testing of large transportable non vacuum insulated cryogenic vessels of more than 1000 l volume, which are permanently (fixed tanks) or not permanently (demountable tanks) attached to a vehicle, for carriage by road. However, it can be used for other mode of transport providing the specific regulations/requirements are complied with.

This European Standard applies to large transportable non vacuum insulated cryogenic vessels for fluids specified in EN 14398-1 and does not apply to vessels designed for toxic fluids.

This European Standard does not include the general vehicle requirements e.g. running gear, brakes, lighting etc. that shall be in accordance with the relevant standards/regulations.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 287-1, *Approval testing of welders - Fusion welding - Part 1: Steels.*

 *deleted text* 

EN 473, *Non destructive testing - Qualification and certification of NDT personnel - General principles.*

EN 875, *Destructive tests on welds in metallic materials - Impact tests - Test specimen location, notch orientation and examination.*

EN 895, *Destructive tests on welds in metallic materials - Transverse tensile test.*

EN 910, *Destructive tests on welds in metallic materials – Bend tests.*

EN 1252-1:1998, *Cryogenic vessels - Materials - Part 1: Toughness requirements for temperatures below - 80 °C.*

EN 1252-2, *Cryogenic vessels - Materials - Part 2: Toughness requirements for temperatures between – 80 °C and –20 °C.*

EN 1418, *Welding personnel – Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanised and automatic welding of metallic materials.*

EN 1435, *Non-destructive examination of welds – Radiographic examination of welded joints.*

EN 1626, *Cryogenic vessels - Valves for cryogenic service.*

EN 1797, *Cryogenic vessels - Gas/material compatibility.*

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

EN 10028-7:2000, *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.*

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

EN 13648-3, *Cryogenic vessels - Safety devices for protection against excessive pressure - Part 3: Determination of required discharge - Capacity and sizing.*

EN 14398-1:2003, *Cryogenic vessels - Large transportable non-vacuum insulated vessels - Part 1: Fundamental requirements.*

EN 14398-3, *Cryogenic vessels – Large Transportable non-vacuum insulated vessels – Part 3: Operational requirements.*

EN ISO 6520-1, *Welding and allied processes - Classification of geometric imperfections in metallic materials - Part 1: Fusion welding*  (ISO 6520-1:2007) .

 EN ISO 9606-2, *Qualification test of welders - Fusion welding - Part 2: Aluminium and aluminium alloys* (ISO 9606-2:2004).

EN ISO 15613, *Specification and qualification of welding procedures for metallic materials - Qualification based on pre-production welding test* (ISO 15613:2004).

EN 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 15614-1:2004).

EN 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 15614-2:2005). 

ISO 1106-1, *Recommended practice for radiographic examination of fusion welded joints - Part 1: Fusion welded butt joints in steel plates up to 50 mm thick.*

3 Terms, definitions and symbols

For the purposes of this European Standard, the following terms, definitions and symbols apply.

3.1 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 14398-1:2003 and the following apply.

3.1.1

large transportable non vacuum insulated vessel

vessel of more than 1000 l volume intended for one or more cryogenic fluids, consisting of an inner vessel, an insulation, all of the valves and accessories and additional framework

3.1.2

fixed tank (tank vehicle)

large transportable vessel permanently attached to a vehicle or to units of running gear used in its stead

3.1.3

demountable tank

large transportable vessel non permanently attached to a vehicle. 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

3.1.4

inner vessel

pressure vessel proper intended to contain the cryogenic fluid

3.1.5

insulation

to protect the vessel against heat transfer from the outside atmospheric temperature

3.1.6

automatic welding

welding in which the parameters are automatically controlled. Some of these parameters can be adjusted to a limited extent, either manually or automatically, during welding to maintain the specified welding conditions

3.1.7

maximum allowable pressure, p_s

maximum pressure for which the equipment is designed, as specified by the manufacturer, defined at a location specified by the manufacturer, being the location of connection of protecting or limited devices or the top of the equipment

3.1.8

relief plate/plug

plate or plug retained by atmospheric pressure only which allows relief of excess internal pressure

3.1.9

bursting disc device

non-reclosing pressure relief device ruptured by differential pressure. It is the complete assembly of installed components including where appropriate the bursting disc holder

3.2 Symbols

For the purposes of this European Standard, the following symbols apply.

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 4.3.2.2	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_T	pressure test (see 4.2.3.2)	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 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

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	apparent yield stress or 0,2 % proof stress (1 % proof stress for austenitic steel)	N/mm ²
R_m	minimum tensile strength (actual or guaranteed)	N/mm ²
K	material property used for design	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	-

4 Design

4.1 Design options

4.1.1 General

The design shall be carried out in accordance with one of the options given in 4.1.2, 4.1.3 or 4.1.4.

Metallic materials used at cryogenic temperatures shall meet the requirements of the relevant sections of EN 1252-1 or EN 1252-2.

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

For carbon and low alloy steels the requirements of EN 1252-2 shall be satisfied.

4.1.2 Design by calculation

Calculation of all pressure and load bearing components shall be carried out. The pressure part thicknesses of the vessel shall not be less than required by 4.3. Additional calculations may be required to ensure the design is satisfactory for the operating conditions including an allowance for dynamic loads.

4.1.3 Design by calculation and pressure strengthening

The pressure retaining capability of vessels manufactured from austenitic stainless steel, strengthened by pressure, shall be calculated in accordance with annex C.

4.1.4 Design by calculation supplemented with experimental methods

Where it is not possible to design by calculation alone planned and controlled experimental means may be used providing that the results confirm the safety factors required in 4.3. An example would be the application of strain gauges to assess stress levels.

4.2 Common design requirements

4.2.1 General

The requirements of 4.2.2 to 4.2.7 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 :

- 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 insulation or the vessel itself or the protective frame, if any, are concerned ;

the initial design programme shall be repeated to take account of these modifications.

4.2.2 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 used ;
- liquid capacity ;
- dimensions and allowable weight, taking characteristics of the vehicle into account ;
- location of fastening points and loads allowable on these points ;
- filling and emptying rate ;
- range of ambient temperature, if differing from 7.2 of EN 14398-1:2003.

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 ;
- type of 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 standard ;
- 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.

4.2.3 Design loads

4.2.3.1 General

The large transportable cryogenic vessel shall be able to withstand safely the mechanical and thermal loads encountered during pressure test and normal operation.

In considering design loads during transport, static loads shall be substituted for static plus dynamic loads. The static loads used shall be as follows :

- in the direction of travel : twice the total mass ;
- at right angles to the direction of travel : the total mass ;
- vertically upwards: the total mass ;
- vertically downwards: twice the total mass.

Each of these loads is considered to act in isolation and includes the mass of the component under consideration.

4.2.3.2 Vessel

With the exception of a) the following loads shall be considered to act in combination where relevant :

- a) test pressure : the value used for validation purposes shall be :

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

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

p_s is the maximum allowable pressure, in bar.

The vessel shall be capable of holding the pressure test fluid without plastic deformation.

- b) pressure during operation, p_C , where :

$$p_C = p_s + p_L$$

p_L is the pressure, in bars, exerted by the mass of the liquid contents when the vessel is filled to capacity and subject to each load defined in 4.2.3.1, with either :

- 1) boiling liquid at minimum allowable temperature
- 2) cryogenic fluid at its equilibrium triple point or melting point temperature;
- c) reaction at the support points of the vessel due to the mass of the vessel and its contents when subject to each of the loads defined in 4.2.3.1 ;
- d) load imposed by the piping due to the differential thermal movement of the vessel, the piping and the insulation.

The following cases shall be considered :

- cooldown (vessel warm - piping cold) ;
- filling and withdrawal (vessel cold - piping cold) ; and
- transport and storage (vessel cold - piping warm) ;
- e) load imposed on the vessel at its support points when cooling from ambient to operating temperature and during operation.

4.2.3.3 Self supporting vessels

In the case of vehicles in which the vessel 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 4.2.3.2 c).

4.2.3.4 Vessel supports

The vessel supports shall be suitable for each load defined in 4.2.3.2 c) plus loads due to differential thermal movements.

4.2.3.5 Surge plates

The vessel shall be divided by surge plates to provide stability and limit dynamic loads to the requirements of 4.2.3, 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 that of the vessel.

Current experience with surge plates limiting the capacity to 7 500 l has been shown to meet these requirements.

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 (4.2.3).

4.2.3.6 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 4.2.3.

4.2.3.7 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 strengthening rings, protective canopies or transverse or longitudinal members so shaped that effective protection is given.

4.2.3.8 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 semi-trailer shall not exceed 60 % of the nominal total laden mass of the complete articulated vehicle.

4.2.3.9 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 ;
- b) pressure during operation : not less than the set pressure of the system pressure relief device ;
- c) thermal loads defined in 4.2.3.2 d) ;
- d) dynamic loads ;
- e) set pressure of thermal relief devices where applicable ;
- f) loads generated during pressure relief discharge.

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

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 EN 1797.

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 provided with protection against mechanical damage.

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.

4.2.4 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.

When considering the case of fatigue, the common requirement of dimensioning with loads according to 4.2.3 will be such as to accommodate the effects of fatigue. Particular attention may be necessary to specific details in the supports and piping systems to avoid stress raisers.

4.2.5 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.

4.2.6 Inspection openings

Inspection openings are not required in the vessel, providing the requirements of EN 14398-3 are followed.

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

4.2.7 Pressure relief

Relief systems shall be designed to meet the requirements given in 4.2.7.1 and 4.2.7.2.

4.2.7.1 Vessel

The vessel shall be provided with not less than two independent pressure relief devices at least one of which shall be a relief valve, and shall open at no more than p_s . The devices may be mounted on a common line.

A device shall protect the vessel against excess pressure due to :

a) normal heat leak,

and the devices acting together shall protect the vessel against excess pressure due to ;

b) heat leak with loss of insulation

c) heat leak, without loss of insulation, and the pressure build up system being in the open position.

d) recycling of any possible combination of pumps

Excess pressure means a pressure in excess of 110 % of the maximum allowable pressure for condition a) + d) and in excess of the test pressure for condition b) and in excess of the test pressure for condition c).

Relief devices for the vessel shall be in accordance with EN 13648-3 for calculation of sizing.

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

4.2.7.2 Piping

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

4.2.8 Valves

Valves shall conform to EN 1626.

4.2.9 Insulation

To protect the vessel against heat transfer from the outside atmospheric temperature. The insulation consists of a material with low heat transfer values of a certain thickness, which protects the cold liquid content of the vessel from quick increase of the pressure.

The insulation shall be covered by an outside cladding, to protect the insulation against collection of humidity or water and against damage.

The insulation material can be polyurethane foam (injected or moulded as formed plates), etc.

4.2.10 Degree of filling

The degree of filling of large transportable non vacuum insulated vessels intended for the carriage of flammable gases shall remain below the level at which, if the contents were raised to the temperature at which the vapour pressure equalled the opening pressure of the safety valve, the volume of the liquid would reach 95 % of the vessel's capacity at that temperature. Large transportable non vacuum insulated vessels may be filled with non-flammable gases to 98 % of its total volume at the loading temperature and the loading pressure.

Means shall be provided to ensure that the above limits are not exceeded.

4.2.11 Electrical continuity

All metallic components of large transportable non vacuum insulated vessels intended for the carriage of flammable gases shall be electrically continuous. The large transportable non vacuum insulated vessels shall be provided with the means of attachment to earthing devices so that the resistance to the earthing connection is less than 5 ohms. Any metal contact capable of causing electrochemical corrosion shall be avoided.

4.3 Design by calculation

4.3.1 General

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

4.3.2 Vessel

4.3.2.1 General

The information in 4.3.2.2 to 4.3.2.6 shall be used to determine the pressure part thicknesses in conjunction with the calculation formulae of 4.3.5. ^[A1] The minimum thickness shall however not be less than the minimum wall thickness calculated according to the formulae and the provisions of chapter 6.8 of the technical annexes of the ADR/RID. ^[A2] *deleted text* ^[A2] ^[A1]

^[A1] *deleted text* ^[A1]

4.3.2.2 Design pressure p

The internal design pressure p shall be the greater of p_T as defined in 4.2.3.2 a) or p_C as defined in 4.2.3.2 b) corrected for operating conditions (i.e. times $\frac{K_{20}}{K_T}$) to take into account the cold properties of the material used. It follows that K_{20} shall be used in the subsequent formulae where p is shown as the design pressure.

The vessel shall be able to withstand, without permanent deformation, an external pressure of not less than 40 kPa (0,4 bar) above the internal pressure.

4.3.2.3 Material properties K

4.3.2.3.1 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 carbon steels the upper yield strength may be used.

For calculation purposes the material property K of the inner vessel shall be limited to 2/3 of R_m the minimum guaranteed tensile strength.

4.3.2.3.2 K_{20}

R_e and R_m shall be the minimum guaranteed values at 20 °C taken from the material standard (see annex E).

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.

4.3.2.3.3 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 10028-7:2000 annex F for austenitic stainless steels) or shall be guaranteed by the material manufacturer.

4.3.2.3.4 Brittleness

The material shall not be subject to brittle fracture at its minimum operating temperature, see EN 1252-1 and EN 1252-2.

4.3.2.3.5 Elongation

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

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

but 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.

4.3.2.4 Safety factors S , S_p and S_k

Safety factors are the ratio of material property K over the maximum allowable stress.

$$S = 1,33$$

4.3.2.5 Weld joint factor v

In all cases $v = 1$ shall be used including circumferential seams with permanent backing strip and circumferential joggle joint.

4.3.2.6 Corrosion allowances c

$$c = 0$$

No corrosion allowance is required.

4.3.3 Attachments

For those items attached to the vessel, the allowable stress shall not exceed the lower of $0,75 R_e$ or $0,5 R_m$.

When designing the vessel systems, the temperature and corresponding mechanical properties to be used may be those of the component in question when the vessel is filled to capacity with cryogenic fluid at a temperature not lower than the saturation temperature at pressure p_s .

4.3.4 Piping and accessories

Piping shall be designed for the loads defined in 4.2.3.9 using established piping design methods and safety factors.

4.3.5 Calculation formulae

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

4.3.5.1.1 Field of application

Cylindrical shells and spheres where :

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

4.3.5.1.2 Openings

For reinforcement of openings, see 4.3.5.5.

4.3.5.1.3 Calculation

The required minimum wall thickness s is :

— for cylindrical shells :

$$s = \frac{D_a p}{20 \frac{K_{20}}{S} v + p} + c \quad (5)$$

— for spherical shells :

$$s = \frac{D_a p}{40 \frac{K_{20}}{S} v + p} + c \quad (6)$$

4.3.5.2 Dished ends subject to internal pressure

4.3.5.2.1 Field of application

Following calculations the thickness of the dished ends shall not be less than the thickness of the cylindrical shell.

Hemispherical ends where $D_a/D_i \leq 1,2$

10 % torispherical ends where $R = D_a$ and $r = 0,1 D_a$

and

2:1 torispherical ends where $R = 0,8 D_a$ and $r = 0,154 D_a$

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

NOTE Other end shapes can be used provided suitable calculations are carried out.

4.3.5.2.2 Internal pressure calculation (pressure on concave surface)

4.3.5.2.2.1 Crown and hemisphere thickness

The wall thickness of the crown region of dished ends and of hemispherical ends shall be determined using 4.3.5.1.3 for spherical shells with $D_a = 2 (R + s)$.

Opening within the crown area of $0,6 D_a$ of torispherical ends and in hemispherical ends shall be reinforced in accordance with 4.3.5.5. When pad type reinforcement is used the edge of the pad shall not extend beyond the area of $0,8 D_a$ for 10 % torispherical ends or $0,7 D_a$ for 2:1 torispherical ends.

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

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

— for the vessel :

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

β is taken from Figure 5 for 10 % torispherical ends and from Figure 6 for 2:1 torispherical ends as a function of $(s-c)/D_a$. Iteration is necessary.

For hemispherical ends a β value of 1,1, shall be applied within the distance x from the tangent line joining the end to the cylinder, regardless of the ratio, $(s-c)/D_a$ where $x = 0,5\sqrt{R(s-c)}$

D_a is the diameter of the end as shown in Figure 4 a) and 4 b).

When there are openings outside the area $0,6 D_a$ the required thickness is found from Figures 5 and 6 using the appropriate curve for the relevant value of d_1/D_a .

The lower curves of Figures 5 and 6 apply when there are no openings outside the area $0,6 D_a$.

4.3.5.2.2.3 If a dished end is welded together from crown and knuckle components, the joint shall be at a sufficient distance x from the knuckle. The distance regarded as sufficient is as follows, but with a minimum, however, of at least 100 mm (see Figure 4 c)) :

— crown and knuckle are of different wall thickness :

$$x = 0,5 \sqrt{R(s-c)} \quad (8)$$

where s is the required wall thickness of the knuckle :

— the crown and knuckle are of equal wall thickness :

— for 10 % torispherical ends $x = 3,5 s$;

— for 2:1 torispherical ends $x = 3,0 s$.

$v = 1,0$ may be applied, 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.

$v = 1,0$ may also be applied in the case of welded domed ends - except hemispherical ends - regardless of the scope of testing provided the weld intersects the crown area of $0,6 D_a$, see Figures 4 e) and 4 f) (left-hand side).

4.3.5.2.2.4 If the ligament on the connecting line between adjacent openings is not entirely within the $0,6 D_a$ region the ligament shall not be less than half the sum of the opening diameters. See also 4.3.5.5.9.

4.3.5.3 Cones subject to internal pressure

4.3.5.3.1 Symbols and units

For the purposes of 4.3.5.3, the following symbols apply in addition to those given in 3.2 :

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_1	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 4.3.5.3.5)	mm
φ	cone angle	°
r	inside radius of knuckle	mm

4.3.5.3.2 Field of application

Cones according to Figure 7 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.

4.3.5.3.3 Openings

Openings outside of the corner area (Figure 8) shall be designed as follows :

— if $|\varphi| < 70^\circ$ design according to 4.3.5.5 using an equivalent cylinder diameter of :

$$D_i = \frac{D_s + d_i |\sin \varphi|}{\cos \varphi} \quad (9)$$

— if $|\varphi| \geq 70^\circ$ design according to 4.3.5.4.

4.3.5.3.4 Non destructive testing

All corner joints shall be subject to the examination required for a weld joint factor of 1,0, see Table 6.

4.3.5.3.5 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 7a) and 7b) by x_1, x_2, x_3 calculated from the following equations :

$$x_1 = \sqrt{D_{a1}(s_1 - c)} \quad (10)$$

$$x_2 = 0,7 \sqrt{\frac{D_{a1}(s_1 - c)}{\cos \varphi}} \quad (11)$$

$$x_3 = 0,5 x_1 \quad (12)$$

4.3.5.3.6 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 10.1 to 10.7 for the large end and Figure 10.8 for the small end of a cone using the following variables :

$$\varphi, \quad \frac{p_s}{15K_v} \quad \text{and} \quad \frac{r}{D_{a1}}$$

For a corner joint use the curve for $\frac{r}{D_{a1}} = 0$.

For intermediate cone angles use linear interpolation.

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

b) outside corner area

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

$$s_g = \frac{D_k p}{20 \frac{K}{S} v - p} \times \frac{1}{\cos \varphi} + c \quad (13)$$

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 .

4.3.5.3.7 Internal pressure calculation (pressure on the concave surface) $|\varphi| > 70^\circ$

If $r \geq 0,01 D_{a1}$ the required wall thickness is :

$$s_1 = s_g = 0,3(D_{a1} - r) \times \frac{|\varphi|}{90} \times \sqrt{\frac{p}{10 \left(\frac{K}{S}\right) v}} + c \quad (14)$$

4.3.5.4 Flat ends

4.3.5.4.1 Symbols and units

For the purposes of 4.3.5.4, the following symbols apply in addition to those given in 3.2 :

d_1, d_2 etc. opening diameters in mm ;

D_1 , flat end diameters in mm. As shown in Figure 12.

4.3.5.4.2 Field of application

Welded or solid flat ends where Poisson's ratio is approximately 0,3, and :

$$\frac{(s_e - c)}{D_1} \geq \sqrt[4]{\frac{0,0087 p}{E}}$$

and

$$3 \frac{(s_e - c)}{D_1} \leq 1$$

4.3.5.4.3 Openings

Openings are calculated in accordance with 4.3.5.4.4 but with the C factor multiplied by C_A , where C_A is given in Figure 11.

4.3.5.4.4 Calculation

The required minimum wall thickness of a circular flat end is :

$$s = CD_1 \sqrt{\frac{0,1 p S}{K}} + c \quad (15)$$

C and D_1 are taken from Figure 12.

The required minimum wall thickness of a rectangular or elliptical flat end is :

$$s = C_e \sqrt{\frac{0,1 p S}{K}} + c \quad (16)$$

where C_E is taken from Figure 13.

4.3.5.5 Openings in cylinders, spheres and cones

4.3.5.5.1 Symbols and units

For the purposes of 4.3.5.5, the following symbols apply in addition to those given in 3.2 :

b	width of pad, ring or shell reinforcement	mm
h	thickness of pad-reinforcement	mm
l	ligament (web) between two nozzles	mm
l_s	length of nozzle reinforcement outstandings	mm
s	length of nozzle reinforcement instand	mm
s_A	required wall thickness at opening edge	mm
s_S	wall thickness of nozzle	mm
t	in this context : centre-to-centre distance between two nozzles	mm

4.3.5.5.2 Field of application

Round openings and the reinforcement of round openings in cylinders, spheres and cones within the following limits :

$$0,002 \leq \frac{(s-c)}{D_a} \leq 0,1$$

$$\frac{(s-c)}{D_a} < 0,002 \text{ is acceptable if } \frac{d_i}{D_a} \leq \frac{1}{3}$$

These rules only apply to cones if the wall thickness is determined by the circumferential stress.

NOTE 1 Additional external forces and moments are not covered by this subclause and should be considered separately where necessary.

NOTE 2 These design rules permit plastic deformations of up to 1 % at highly stressed local areas during pressure test. Openings should therefore be carefully designed to avoid abrupt changes in geometry.

The design rules for non perpendicular nozzles shall be based on a perpendicular nozzle, using the dimension of the major elliptical axis or shall be calculated in accordance with EN 13445-3.

4.3.5.5.3 Reinforcement methods

Openings may be reinforced by one or more of the following typical but not exclusive methods :

- increase of shell thickness, see Figures 14 and 15 ;
- set in or set on ring reinforcement, see Figures 16 and 17 ;
- pad reinforcement, see Figure 18 ;
- increase of nozzle thickness, see Figures 19 and 20 ;
- pad and nozzle reinforcement, see Figure 21.

Where ring or pad reinforcement is used the space between the two fillet welds shall be vented to the outside of the vessel.

4.3.5.5.4 Design of openings

The fillet weld on a reinforcing pad shall have a minimum throat thickness of half of the pad thickness.

The through thickness of a fillet weld of each nozzle to shell weld shall be not less than the required thickness of the thinner part.

Where the strength of the reinforcing material is lower than the strength of the shell material an allowance in accordance with 4.3.5.5.5 shall be made in the design calculations. If the strength of the reinforcing material is higher than the strength of the shell material no allowance for the increased strength is permitted.

4.3.5.5.5 Calculation

Where the material property K of the reinforcement is lower than that of the shell the cross section of pad reinforcement and the thickness of nozzle reinforcement shall be reduced by the ratio of K values before determining the factor v_A . In the case of a shell subjected only to internal pressure, with a row of nozzles joined to the shell by fully penetrating welds, it is not necessary to calculate the individual reinforcement required for each nozzle. However the thickness of the shell to resist internal pressure shall be calculated using the least value of weakening factor of either v_A obtained from equation (34) or v .

Openings shall also be reinforced according to the following relationship :

$$\frac{p}{10} \left(\frac{A_p}{A\sigma} + \frac{1}{2} \right) \leq \frac{K}{S} \quad (17)$$

which is based on equilibrium between the pressurised area A_p and the load bearing cross sectional area $A\sigma$. The wall thickness obtained from this relationship shall be not less than the thickness of the unpierced shell.

The pressurized area A_p and the load bearing cross sectional area $A\sigma$ which equals $A\sigma_0 + A\sigma_1 + A\sigma_2$ are obtained from Figures 22 to 25.

The maximum extent of the load bearing cross sectional area shall be not more than b as defined in formula (20) for shells and l_s as defined in formulae (22) or (23) for nozzles, as appropriate.

The protrusion of nozzles l_s may be included as load bearing cross sectional area up to a maximum length of

$$l'_s = 0,5 l_s \quad (18)$$

The restrictions of 4.3.5.5.7 and 4.3.5.5.8 shall be observed.

If the material property K_1 , K_2 etc. of the reinforcing material is lower than that of the shell the dimensions shall comply with :

$$\left(\frac{K}{S} - \frac{p}{20}\right) A_{\sigma 0} + \left(\frac{K_1}{S} - \frac{p}{20}\right) A_{\sigma 1} + \left(\frac{K_2}{S} - \frac{p}{20}\right) A_{\sigma 2} \geq \frac{p}{10} A_p \quad (19)$$

4.3.5.5.6 Ring or pad reinforcement or increased shell thickness

If the actual wall thickness of the cylinder or sphere is less than the required thickness s_A at the opening, the opening is adequately reinforced if the wall thickness s_A is available round the opening over a width of :

$$b = \sqrt{(D_i + s_A - c)(s_A - c)} \quad (20)$$

with a minimum of $3 s_A$ (see Figures 16, 17 and 18).

For calculation purposes s_A shall be limited to not more than twice the actual wall thickness.

The thickness of pad reinforcement in accordance to Figure 18 preferably shall be not more than the actual wall thickness to which the pad is attached.

Internal pad reinforcement is not allowed.

The width of the pad reinforcement may be reduced to b_1 provided the pad thickness is increased to h_1 according to :

$$b_1 \times h_1 \geq b \times h \quad (21)$$

and the limits given above are observed.

4.3.5.5.7 Reinforcement by increased nozzle thickness

For calculation purposes s_S shall be not more than twice s_A .

The thickness of the nozzle s_S should be not greater than twice s_A .

The wall thickness s_A at the opening shall extend over a width b in accordance with formula (20) with a minimum of $3 s_A$.

The limits of reinforcement normal to the vessel well are :

$$\text{— for cylinders and cones, } l_s = 1,25 \sqrt{(d_i + s_s - c)(s_s - c)} \quad (22)$$

$$\text{— for spheres, } l_s = \sqrt{(d_i + s_s - c)(s_s - c)} \quad (23)$$

The length l_s may be reduced to l_{s1} provided that the thickness s_s is increased to s_{s1} according to the following :

$$l_{s1} \times s_{s1} \geq l_s \times s_s \quad (24)$$

and the limits given above are observed.

4.3.5.5.8 Reinforcement by a combination of increased shell and nozzle thicknesses

Shell and nozzle thicknesses may be increased in combination for the reinforcement of openings (Figure 21). For the calculation of reinforcement 4.3.5.5.6 and 4.3.5.5.7 shall be applied together. The increase in shell thickness may be achieved by an actual increase in shell thickness or the addition of a pad.

4.3.5.5.9 Multiple openings

Multiple openings are regarded as single openings provided the distance l between two adjacent openings, Figures 24 and 26, complies with :

$$l \geq 2\sqrt{(D_i + s_A - c)(s_A - c)} \quad (25)$$

If l is less than required by formula (25) a check shall be made to determine whether the cross section between openings is able to withstand the load acting on it. Adequate reinforcement is available if the requirement of formula (17) or (19), as appropriate is met.

Where adjacent openings in a cylinder are arranged intermediately between the longitudinal and circumferential direction the calculation scheme for the longitudinal direction (Figure 24) shall be applied, but the part of the pressure loaded area corresponding to the unpierced cylinder $\left(\frac{tD_i}{2}\right)$ may be reduced with an arrangement factor $-0,5 (1 + \cos^2 \varphi)$.

See Figure 25) for angle φ .

Nozzles joined to the shell in line by full penetration welds with the wall thickness calculated for internal pressure only may be designed with a weakening factor

$$v_A = \frac{(t - d_i)}{2} \quad (26)$$

If the nozzles are not attached by full penetration welds, d_a shall be used in formula (26).

4.3.6 Calculations for operating loads

Unless the design has been validated by experiment, calculations in addition to those in 4.3.5 may be required to ensure that stresses due to operating loads are within acceptable limits. All load conditions expected during service shall be considered (see 4.2.3).

In these calculations static loads shall be substituted for static plus dynamic loads.

The analysis shall take account of gross structural discontinuities, but need not consider local stress concentrations.

Annex A provides terminology and acceptable stress limits when an elastic stress analysis is performed.

Acceptable calculation methods include :

- finite element ;
- finite difference ;
- boundary element ;
- recognised text books, published papers, codes and standards.

Planned and controlled experimental means may be used in order to confirm these calculations, for example, by application of strain gauges to verify stress levels.

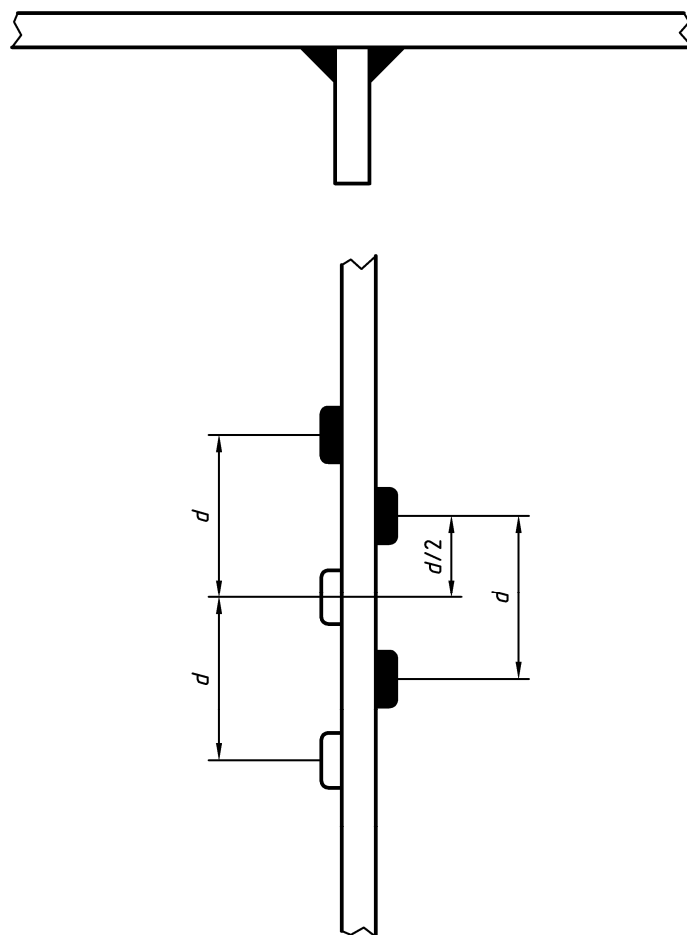
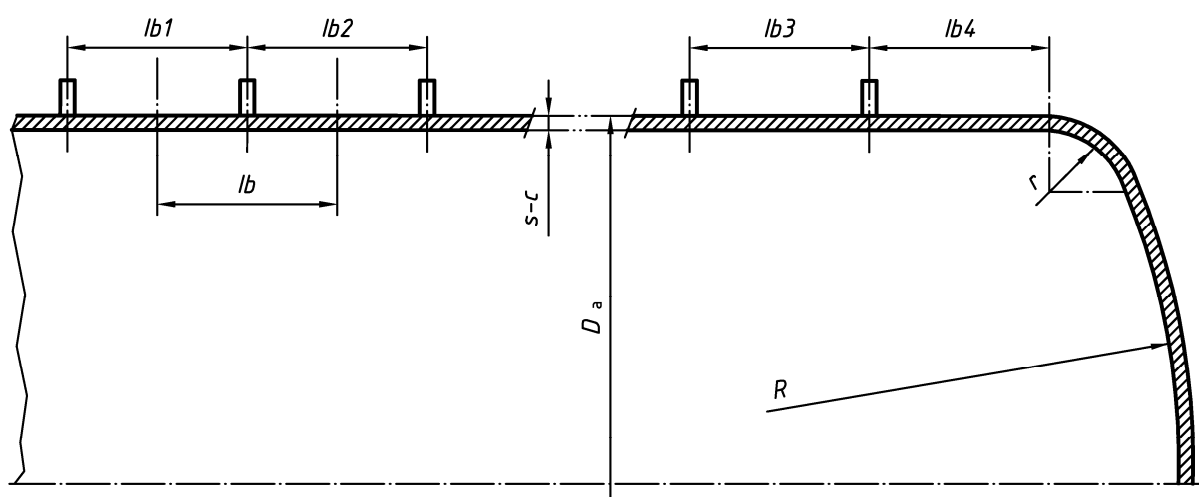


Figure 1 — Example of joining stiffening ring to shell



- For design of cylindrical shell :

$l_b = \text{maximum of } l_{b1}, l_{b2}, l_{b3}, l_{b4}.$

- For design of reinforcing elements :

$$l'_b = \frac{l_{b1} + l_{b2}}{2}$$

Figure 2 — Determination of buckling length



Figure 3b)



$$\begin{aligned} h/ea &\leq 50 \\ b &\leq ea + \\ &1 \cdot 1 \sqrt{Da \cdot es} \\ b &\leq ea + 32 es \end{aligned}$$

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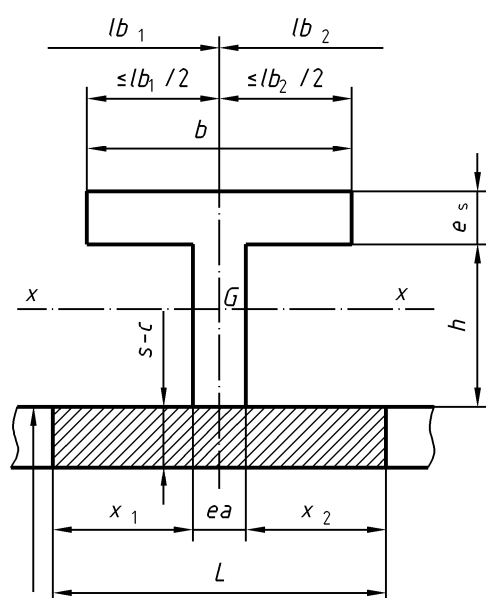


Figure 3c)

$$\begin{aligned} h/ea &\leq 50 \\ b &\leq ea + \\ &1 \cdot 1 \sqrt{Da \cdot es} \\ b &\leq ea + 32 es \end{aligned}$$

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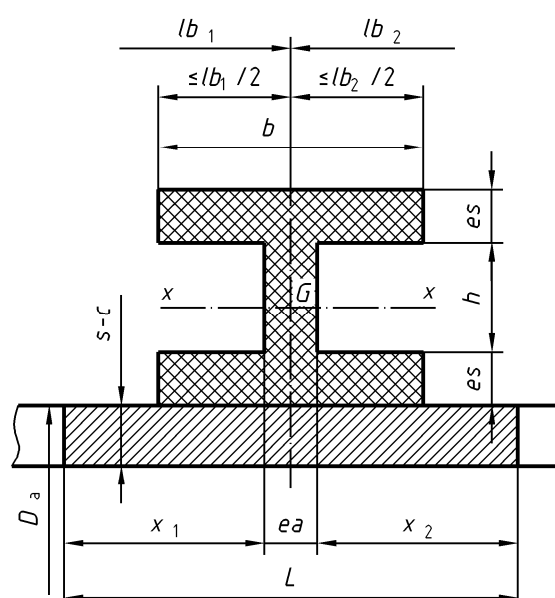


Figure 3d)