Form 36

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Date: xx/xx/20xx	Document: ISO/DIS xxxx

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex **(e.g. 3.1)**	Paragraph/ Figure/Table/Note	**Type of comment**	**Commend (justification for change) by the MB**	**Proposed change by the MB**	**Secretariat observations on each comment submitted**
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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DRAFT International Standard

ISO/DIS 20421-1

Cryogenic vessels — Large transportable vacuum-insulated vessels —

Part 1: Design, fabrication, inspection and testing

Récipients cryogéniques — Récipients transportables isolés sous vide de grande contenance —

Partie 1: Conception, fabrication, inspection et essais

ICS: 23.020.40

ISO/TC **220**

Secretariat: **AFNOR**

Voting begins on:
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2025-04-21

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This third edition cancels and replaces the second edition (ISO 20421-1:2019), which has been technically revised. It also incorporates ISO 20421-1:2006/Cor 1:2007. The main changes compared to the previous edition are as follows:

— Subclause 12.3 has been revised;

— Subclause 10.2.3.1.4 Correction Load factors for normal operation for fatigue analysis in specified transportation modes Table 2 —Load factors for normal operation for fatigue analysis in specified transportation modes;

— Subclause 10.2.3.11 Loads for Piping and valves divided for Road/water and Rail condition;

— Subclause 10.3.2.1 Correction of Table 3;

— Subclause 10.3.2.3.1 Correction of used Material property K for the calculations under consideration of ADR/RID/IMDG-Code/49CFR;

— Subclause D.3.1 Material Table D1 splitting in European Material D.1.1 and Non-European Material D.1.2;

— Subclause D.3 Correction of Requirements for Testing plates under consideration of cold strengthening Table D.2 — Testing of pre-stretched welded test plates;

— Subclause J.3 Correction of Table J.1 Minimum wall thicknesses under consideration of ADR/RID/IMDG-Code/49CFR.

A list of all parts in the ISO 20421 series can be found on the ISO website.

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Introduction

This document has been written so that it is suitable to be referenced in the UN Model Regulations[1].

This document does not include the general vehicle requirements, e.g. running gear, brakes, lighting, etc., for which the relevant standards/regulations apply.

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Cryogenic vessels — Large transportable vacuum-insulated vessels —

Part 1:
Design, fabrication, inspection and testing

1 Scope

This document 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 document 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 document does not include the general vehicle requirements, e.g. running gear, brakes, lighting, etc.

NOTE 1 This document 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.

NOTE 2 This document does not cover specific requirements for refillable liquid hydrogen and LNG tanks that are primarily dedicated as fuel tanks in vehicles. For fuel tanks used in vehicles, see ISO 13985.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3834-2, *Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements*

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

ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

ISO 9606-1, *Qualification 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 NDT personnel*

ISO 10042, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*

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

ISO 10675-1, *Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 1: Steel, nickel, titanium and their alloys*

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

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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 17635, *Non-destructive testing of welds — General rules for metallic materials*

ISO 17637, *Non-destructive testing of welds — Visual testing of fusion-welded joints*

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

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

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

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

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

ASME VIII-2, *Rules for construction of pressure vessels, Division 2, Alternative Rules*

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
cryogenic fluid
refrigerated liquefied gas
gas which is partially liquid because of its low temperature (see Table K.1)

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

Note 2 to entry: In the context of this document, the refrigerated but non-toxic gases and gas mixtures given in Table K.1 are referred to as cryogenic fluids.

3.2
large transportable cryogenic vessel
tank
thermally insulated vessel of more than 450 l intended for the transport of one or more *cryogenic fluids* (3.1), consisting of an *inner vessel* (3.4), an *outer jacket* (3.5), all of the valves and *service equipment* (3.9) together with the structural parts

Note 1 to entry: The large transportable cryogenic vessel comprises a complete assembly that is ready for service.

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3.3
insulation
vacuum interspace between the *inner vessel* (3.4) and the *outer jacket* (3.5)

Note 1 to entry: 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 (3.16) vessel intended to contain the *cryogenic fluid* (3.1) to be transported

3.5
outer jacket
gas-tight enclosure which contains the *inner vessel* (3.4) and enables the vacuum to be established

3.6
normal operation
intended operation of the vessel at a *pressure* (3.16) not greater than the maximum allowable working pressure including the *handling loads* (3.7)

3.7
handling load
load exerted on the transportable cryogenic vessel in all normal conditions of transport including loading, unloading, moving and lifting

3.8
piping system
all pipes, tubes and associated components which can come in contact with *cryogenic fluids* (3.1) including valves, fittings, pressure-relief devices and their supports

3.9
service equipment
measuring instruments and filling, discharge, venting, safety, heating, cooling and insulating devices including any equipment for storing cooling fluids

3.10
manufacturer
<large transportable cryogenic vessel> company that carries out the final assembly, including the final acceptance test, of the *large transportable cryogenic vessel* (3.2)

3.11
gross volume
<of the inner vessel> internal volume of the *inner vessel* (3.4), excluding nozzles, pipes, etc., determined at minimum design temperature and atmospheric *pressure* (3.16)

3.12
tare mass
mass of the empty *large transportable cryogenic vessel* (3.2)

3.13
net volume
volume of the *inner vessel* (3.4), below the inlet to the relief devices, excluding nozzles, pipes, etc., determined at minimum design temperature and atmospheric *pressure* (3.16)

3.14
net mass
maximum allowable mass of the *cryogenic fluid* (3.1) which may be filled

Note 1 to entry: The maximum allowable mass is equal to the mass of the cryogenic liquid occupying 98 % of the *net volume* (3.13)of the *inner vessel* (3.4) 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.

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Note 2 to entry: Cryogenic liquid helium can occupy 100 % of the volume of the inner vessel at any *pressure* (3.16).

3.15
gross mass
sum of *tare mass* (3.12) plus *net mass* (3.14)

3.16
pressure
gauge pressure
pressure relative to atmospheric pressure

3.17
fixed tank
tank vehicle
large transportable vessel permanently attached to a vehicle or to units of running gear

3.18
demountable tank
large transportable vessel non-permanently attached to a vehicle

Note 1 to entry: 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.

3.19
portable tank
a thermally insulated tank having a capacity of more than 450 litres fitted with *service equipment* (3.9) and structural equipment necessary for the transport of refrigerated liquefied gases

Note 1 to entry: It can be lifted full and loaded and discharged without removal of structural element.

Note 2 to entry: The list of the refrigerated liquefied gases is available in Annex K.

3.20
maximum allowable working pressure
ps
maximum gauge *pressure* (3.16) permissible at the top of the vessel in its normal operating position

3.21
relief plate
relief plug
plate or plug retained by atmospheric *pressure* (3.16) which allows relief of excess internal pressure, generally from the vacuum jacket

3.22
bursting disc device
non-reclosing pressure-relief device ruptured by differential *pressure* (3.16)

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

3.23
pressure-strengthened vessel
pressure (3.16) 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 1 to entry: *Pressure* (3.16) vessels made from solution heat-treated material are subject to a controlled plastic deformation during the strengthening operation as its yield point is raised. Pressure vessels made from work-hardened material are subject to little or no plastic deformation.

3.24
residual elongation
original elongation of the steel minus the elongation created by the cold-forming deformation

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3.25
leakproofness test
test using gas subjecting the shell and its *service equipment* (3.9), to an effective internal *pressure* (3.16) not less than 90 % of the MAWP but not greater than the design pressure

4 Symbols

Symbol	Definition	Unit
b	width of pad, ring or shell reinforcement	mm
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
h	thickness of pad reinforcement	mm
l_c	cone length between effective stiffenings (see Figure 5)	mm
l	ligament (web) between two nozzles	mm
l_b, l'_b	buckling length	mm
l_s	length of nozzle reinforcement outstanding	mm
n	number of lobes	—
p	design pressure as defined in 10.3.2.2	—
p_c	calculation pressure as defined in 10.2.3.2.1 a)	bar (or MPa)
p_e	allowable external pressure limited by elastic buckling	bar (or MPa)
p_k	strengthening pressure	bar (or MPa)
p_L	liquid pressure	bar (or MPa)
p_p	allowable external pressure limited by plastic deformation	bar (or MPa)
p_s	maximum allowable gauge pressure	bar (or MPa)
p_T	test pressure (see 6.2)	bar (or MPa)
r	radius, e.g. inside knuckle radius of dished end and cones	mm
s	minimum thickness	mm
s_A	required wall thickness at opening edge	mm
s_e	actual wall thickness	mm
s_g	required wall thickness outside corner area	mm
s_n	thickness of nozzle reinforcement in stand	mm
s_S	wall thickness of nozzle	mm
s_1	required wall thickness within corner area	mm
t	in this context, centre-to-centre distance between two nozzles	mm
x	(decay-length zone) distance over which governing stress is assumed to act	mm
x_i	characteristic lengths (i = 1,2,3) to define corner area [Figure 7 a) and Figure 7 b) and 10.3.6.5.4]	mm
η	factor indicative of the utilization of the permissible design stress in joints or factor allowing for weakenings	—
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_{a1}	outside diameter of connected cylinder (see Figure 7)	mm
D_{a2}	outside diameter at effective stiffening (see Figure 9)	mm
D_i	internal diameter, e.g. of a cylindrical shell	mm

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Symbol	Definition	Unit
D_k	design diameter (see Figure 7)	mm
D_s	shell diameter at nozzle (see Figure 8)	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	—
v	Poisson's ratio	—
u	out of roundness (see 11.5.5.2)	—
φ	cone angle	°

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 Clause 16, and all supporting documentation (including that from his subcontractors, if any), for a required period (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 document.

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 can affect safety and which can lead to leakage. This requirement can be validated by:

— the calculation;

— the calculation and pressure-strengthening method, if allowed;

— the calculation and experimental method.

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6.2 Load during the pressure test

The load exerted during the pressure test shall be calculated with Formula (1):

$$p_T \geq 1{,}3(p_S + 1)\,\text{bar} \quad \text{or} \quad [p_T \geq 1{,}3(p_S + 0{,}1)\ \text{MPa}] \tag{1}$$

where

p_T is the test pressure (in bar);

p_S is the maximum allowable pressure (in bar);

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

+0,1 is the allowance for external vacuum (in MPa).

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 Clause 7):

— a minimum working temperature of –20 °C;

— a maximum working temperature of 50 °C.

NOTE 1 Some locations require lower minimum working temperature e.g. –40 °C and/or higher maximum working temperature, e.g. +65 °C.

NOTE 2 This does not apply if the jacket is designed for a lower temperature to be marked on the nameplate.

9 Materials

9.1 Selection of materials

9.1.1 Materials which are, or can 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.

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9.1.3 The base materials, listed in Annex G, subject to meeting the extra requirements given in Clauses 5 to 16, are suitable for and may be employed in the manufacture of the cryogenic vessels, in conformance with this document.

9.2 Inspection documentation

9.2.1 The material according to ISO 21028-1 and ISO 21028-2 shall be declared by an inspection certificate 3.1 in accordance with ISO 10474:2013, 5.1.

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 3.1 in accordance with ISO 10474:2013, 5.1.

9.2.3 The delivery of material which is not manufactured to a recognized International Standard shall be guaranteed by an inspection certificate 3.2 in accordance with ISO 10474:2013, 5.2 confirming that the material fulfils the requirements in 9.1. 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 clauses 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

The pressure-retaining capability of inner vessels manufactured from austenitic stainless steel, strengthened by pressure, shall be calculated in accordance with Annex D.

10.1.4 Design of components by calculation supplemented with experimental methods

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

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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.

The initial design process shall be repeated also in the event of any change relative to:

— the type of material or grade (e.g. stainless steel to aluminium);

— the fundamental shape;

— the decrease in the minimum mechanical properties of the material being used;

— 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;

— 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 conformance to this document;

— design test programme;

— non-destructive testing requirements;

— pressure test requirements;

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— 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

10.2.3.1.1 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 10.2.3.1.2 and 10.2.3.1.3.

10.2.3.1.2 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 1 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 2.

10.2.3.1.3 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 1 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 2.

10.2.3.1.4 Fatigue life calculation shall be conducted according to EN 13445-3, ASME VIII-2 or equivalent standards/codes under consideration of the imperfections under 11.5, and shall be conducted for the highest number of expected cycles of all relevant loads during the life time with consideration of the following criteria.

The life time 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. The usage factor shall not exceed 0,5 for the inner tank, and 1,00 for the outer tank.

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.

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Table 1 — Design load factors 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 2 — Load factors for normal operation 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	0,5				1,0	
	2		0,5			1,0	
	3			0,3			
	4				0,3	1,0	
	5					1,0	0,5
	5A[a]					1,0	0,5
Rail with cushioning devices[b]	1	0,7				1,0	
	2		0,5			1,0	
	3			0,3			
	4				0,5	1,0	
	5[a]					1,0	0,2
	5A[a]					1,0	0,7
Rail without cushioning	1	1,0				1,0	
	2		0,7			1,0	
	3			0,3			

[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.

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Table 2 *(continued)*

Transportation modes	Load case	Load factors					
		Forward	Backward	Up	Down		Lateral
		cyclic	cyclic	cyclic	cyclic	steady	cyclic
devices[b]	4				0,5	1,0	
	5[a]					1,0	0,4
	5A[a]					1,0	1,0

[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_c, with Formula (2):

$$p_c = p_S + p_L + 1\,bar \text{ or } (p_c = p_S + p_L + 0{,}1\,MPa) \quad (2)$$

where 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 considered for each element of the vessel, e.g. shell courses, head, etc., [see Formula (3)]:

$$p_T \geq 1{,}3(p_S + 1)\,\text{bar} \text{ or } [p_T \geq 1{,}3(p_S + 0{,}1)\,\text{MPa}] \quad (3)$$

where p_S is the maximum allowable pressure.

The 1 bar (0,1 MPa) is added to allow for the external vacuum. The primary membrane stress at test pressure shall not exceed the prescribed value but in no case the yield stress of the material.

The minimum test pressure of the inner vessel shall be 3 bar (0,3 MPa). This requirement does not apply to heating or cooling systems including cooling fluid reservoirs, and related service equipment.

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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 (0,1 MPa);

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 $\frac{2}{3}K_{20}$.

Hardening effects where guarantied can be considered in the allowable stress

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 (0,1 MPa) 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

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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). External stiffening rings shall not be used on vacuum jacket of tanks for flammable fluids.

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.

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 (0,1 MPa) 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 10.2.3.2.1 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 for Road and water is equal to or higher than 20 cycles per second and for Rail 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 a quick-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 inside.

Local regulations shall be considered.

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, as listed in Table 2, including pressure cycles.

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

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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

10.2.7.1 General

Relief systems shall be designed to meet the requirements given in 10.2.7.2 to 10.2.7.4.

10.2.7.2 Inner vessel

10.2.7.2.1 Every shell shall be provided with not less than two independent spring-loaded pressure relief devices set at pressures not exceeding the maximum allowable pressure of the tank. The pressure relief devices shall open automatically at pressures not less than the set pressure of the device and be fully open at a pressure equal to 110 % of the set pressure. These devices shall, after discharge, close at a pressure not lower than 10 % below the pressure at which discharge starts and shall remain closed at all lower pressures. The pressure relief devices shall be of the type that will resist dynamic forces including surge.

10.2.7.2.2 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 document. 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.

10.2.7.2.3 Under the circumstances described in 10.2.7.2.1 and 10.2.7.2.2, 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, providing the piping capacity and effects of back pressures are properly accounted for.

10.2.7.2.4 Relief devices for inner vessels shall be in accordance with ISO 21013-1 and ISO 21013-2.

10.2.7.2.5 The required capacity of the relief devices shall be calculated in accordance with ISO 21013-3.

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

10.2.7.3 Outer jacket

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

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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 (0,05 MPa). The total discharge area of the pressure relief device(s) should not be less than 0,34 mm^2/l capacity of the inner vessel.

10.2.7.4 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 °C at atmospheric pressure, the insulation installed on the tank shall be in accordance with ISO 21010.

Heat shields cooled by non-flammable, non-toxic fluid being transported of a different fluid carried separately or both and is vented to atmosphere may be used in UN portable tanks for refrigerated liquefied gases to reduce the heat flow into the fluid being carried. The vented fluid shall be in gaseous state and the venting shall be done in an environmentally friendly manner with temperature of the venting gas not less than 40 °C below the ambient temperature and pressure of the venting gas not higher than 0,75 bar.

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 on stream, 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.

In some countries, same degree of filling, without taking into account liquid expansion, is allowed when the intended duration of carriage is considerably shorter than the holding time.

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 5 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 3 or 10.3.6.

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Table 3 — Inner-vessel minimum wall thickness

Dimensions in millimetres

Inner vessel diameter D_i	Minimum wall thickness for reference material[a] s_r
$D_i \leq 1\,800$	3
$D_i > 1\,800$	4

[a] Reference material is material having a product R_m [N/mm^2] × A_5 [%] of approximately 10 000, which yields $(R_m \times A_5)^{1/3} = 21{,}4$.

For other materials, the required minimum thickness of the metal used shall be calculated from Annex J.

Minimal wall thickness can be found in applicable national regulations.

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, *p*, shall be the greater of p_C as defined in 10.2.3.2.1 a), or *p*T as defined in 10.2.3.2.2, corrected for operating conditions (i.e. multiplied by $\frac{K_{20}}{K_T}$) 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 inner vessel shall be designed for an 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 for the calculations shall be applied as follows:

— for austenitic stainless steels, $R_{p\,1,0}$ proof strength;

or

— for carbon steels, aluminium and aluminium alloys, R_e = yield strength and, if not available, $R_{p0,2}$ proof strength,

and

— if more stringent, K shall be limited to 2/3 R_m (Rm; 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 10.3.2.2.

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.

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Values of R_e and R_m used for design calculations shall be the minimum specified values of R_e and R_m in the material inspection certificate except that the value of R_e used shall not exceed 0,85 R_m.

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 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 Formula (4) at 20 °C:

$$\frac{10\,000}{S_D} \text{ at } 20\,°C \tag{4}$$

where S_D is the determined tensile strength in N/mm^2.

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_T over the maximum allowable stress.

a) Internal pressure (pressure on the concave surface): S = 1,33.

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

— cylindrical shells: S_p = 1,4;

S_k = 2,6 for out of roundness u ≤ 1,5 %;

S_k = 2,0 + 0,4 × u for out of roundness u ≤ 1,0 % may be used if there is evidence of reduced safety factor for buckling analysis by better manufacturing quality (reduced out of roundness).

— spherical region: S_p = 2,1;

S_k = 2,6 + 0,001 8 R/s_e;

— knuckle region: S_p = 1,6.

10.3.2.5 Weld joint factor, η

η = 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.

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10.3.3 Outer jacket

10.3.3.1 General

The following shall be used to determine the pressure part thickness in conjunction with Formulae (6) and (7).

The reference material equivalent thickness of the outer jacket shall be determined using Annex J.

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. The minimum thickness in reference steel of outer jacket of tanks for flammable fluids shall be 6 mm.

10.3.3.2 Calculation pressure outer jacket, *p*

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

The external calculation pressure shall be 1 bar (0,1 MPa).

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): $S \geq 1{,}33$, for steels having a clearly-defined yield point or guaranteed 0,2 % proof strength for steels with no clearly-defined yield point (1 % for austenitic steels).

   In the outer vessel as part of the fastening under each of the forces, the safety factor to be observed shall be as follows:

   $S \geq 1{,}33$ for fixed tanks;

   $S = 1{,}5$ for tank containers.

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, η

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

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

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10.3.3.7 Corrosion allowances, *c*

For austenitic stainless steel, c = 0.

For aluminium alloys, c = 0.

For carbon steel, c = 1,0 mm.

NOTE c can 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 wall, other than the inner-vessel supports (see 10.2.3.4), the allowable stress shall not exceed the min (0,75 K_{20}, 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 10.2.3.11 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 10.3.2.3.

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 Formula (5):

$$D_a/D_i \leq 1{,}2 \tag{5}$$

10.3.6.1.2 Openings

For reinforcement of openings, see 10.3.6.7.

10.3.6.1.3 Calculation

The required minimum thickness, s, for cylindrical shells is Formula (6):

$$s = \frac{D_a p}{20\frac{K_{20}}{S}\eta + p} + c \tag{6}$$

The required minimum thickness, s, for spherical shells is Formula (7):

$$s = \frac{D_a p}{40\frac{K_{20}}{S}\eta + p} + c \tag{7}$$

In case of p in MPa, conversion shall be considered.

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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 Formula (8):

$$D_a/D_i \leq 1{,}2 \tag{8}$$

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 $0{,}5\ D_a \leq R \leq D_a$ and $0{,}5\ D_a \geq r \geq 0{,}06\ D_a$;

c) 2:1 elliptical ends where $R = 0{,}9\ D_a$ and $r = 0{,}170\ D_a$.

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

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.

10.3.6.4.2 Straight flange

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

— for 10 % torispherical ends: 3,0 s;

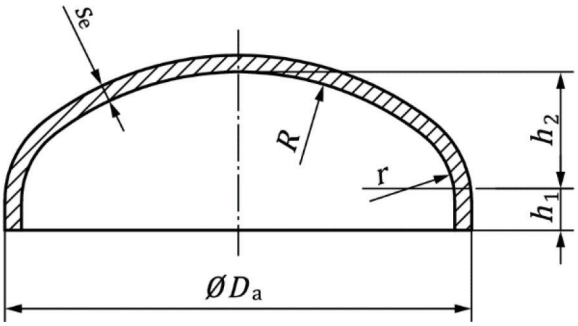
— for 2:1 torispherical ends: 3,0 s;

— for 2:1 elliptical ends: 3,0 s.

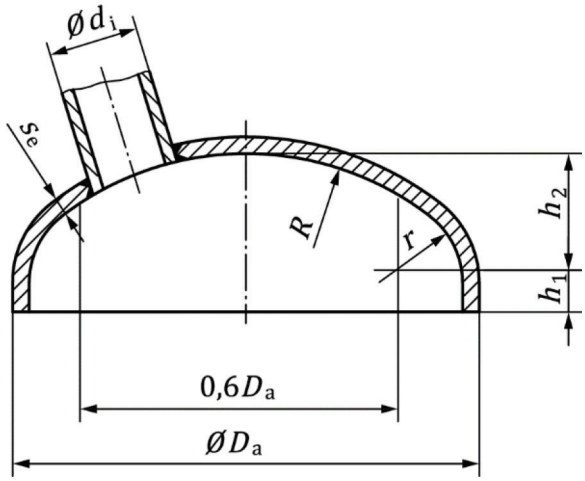
The straight flange may be shorter provided that in the case of inner vessels, the circumferential joint between the dished end and the cylinder is non-destructively tested as required for a weld joint factor of 1,0.

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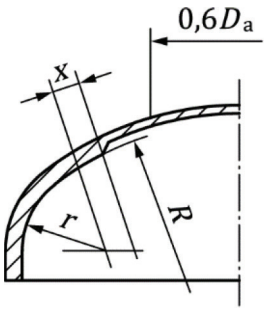
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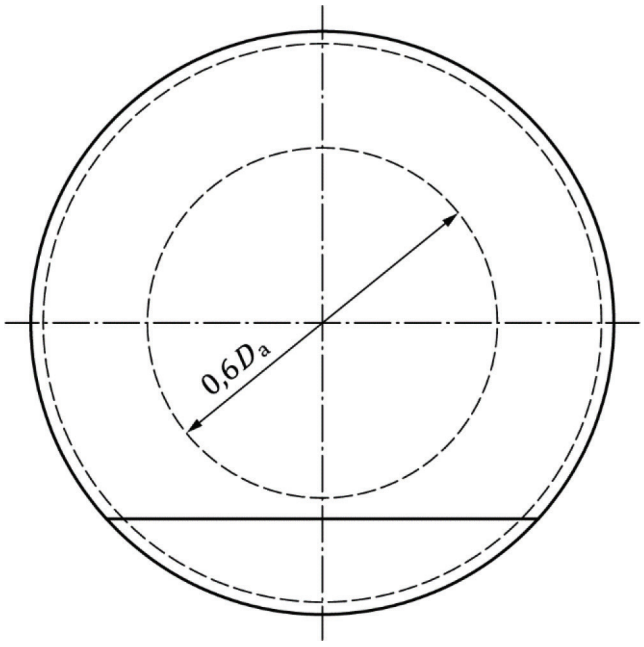
a) Unpierced dished end



b) Dished end with nozzle

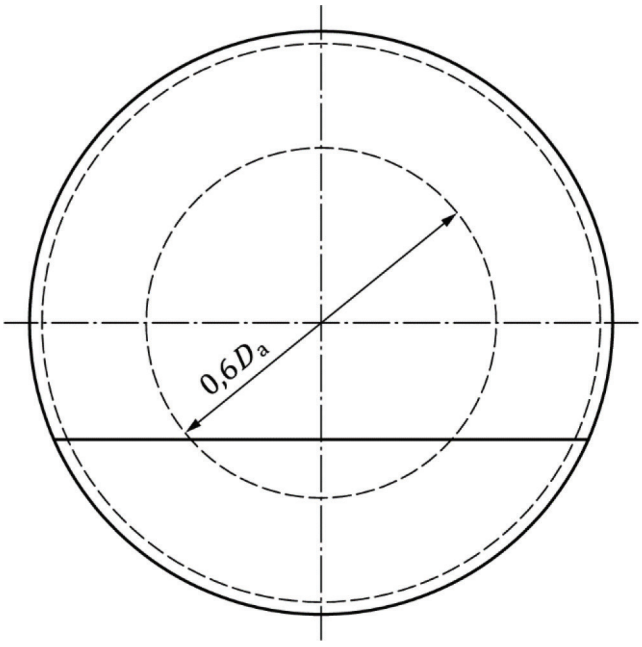


c) End with knuckle and crown of unequal wall thickness



η = 0,85 or 1,0

d) Weld outside 0,6 D_a

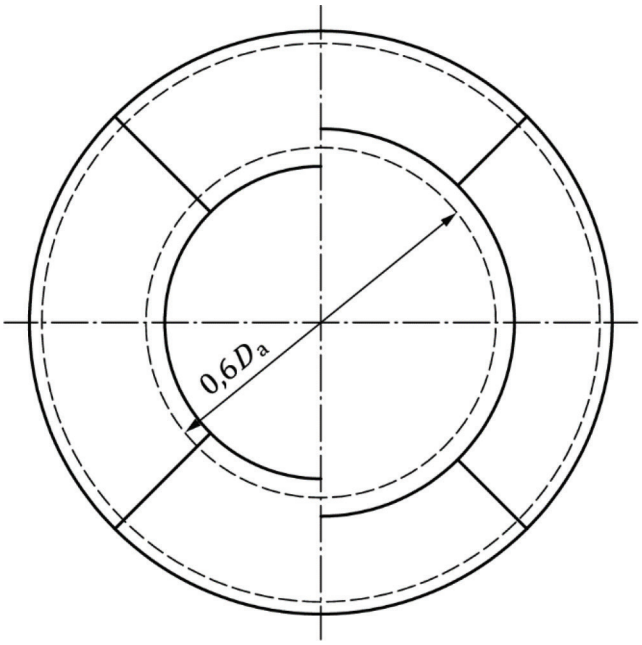


η = 1,0

e) Weld inside 0,6 D_a

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η = 1,0 η= 0,85 or 1,0

f) End welded together from round plate and segments

Figure 1 — Examples of dished ends

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 0,6 D_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 0,8 D_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 Formula (9):

$$s = \frac{pRM}{20\frac{K_{20}\eta}{S} - 0{,}2p} \tag{9}$$

where

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

R is the inside crown radius;

r is the inside knuckle radius.

In case of p in MPa, conversion shall be considered.

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Dished ends designed for normal operation under internal pressure (pressure on concave side) shall have $R \leq D_a$ and $r \geq 0{,}06\ D_a$, 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 Formula (10):

$$s = \frac{pD_i B}{20\frac{K_{20}\eta}{S} - 0{,}2\,p} \tag{10}$$

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.

In case of p in MPa, conversion shall be considered.

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.

η = 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 0,6 D_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 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 $0{,}001 \leq \frac{s_1 - c}{D_{a1}} \leq 0{,}1$.

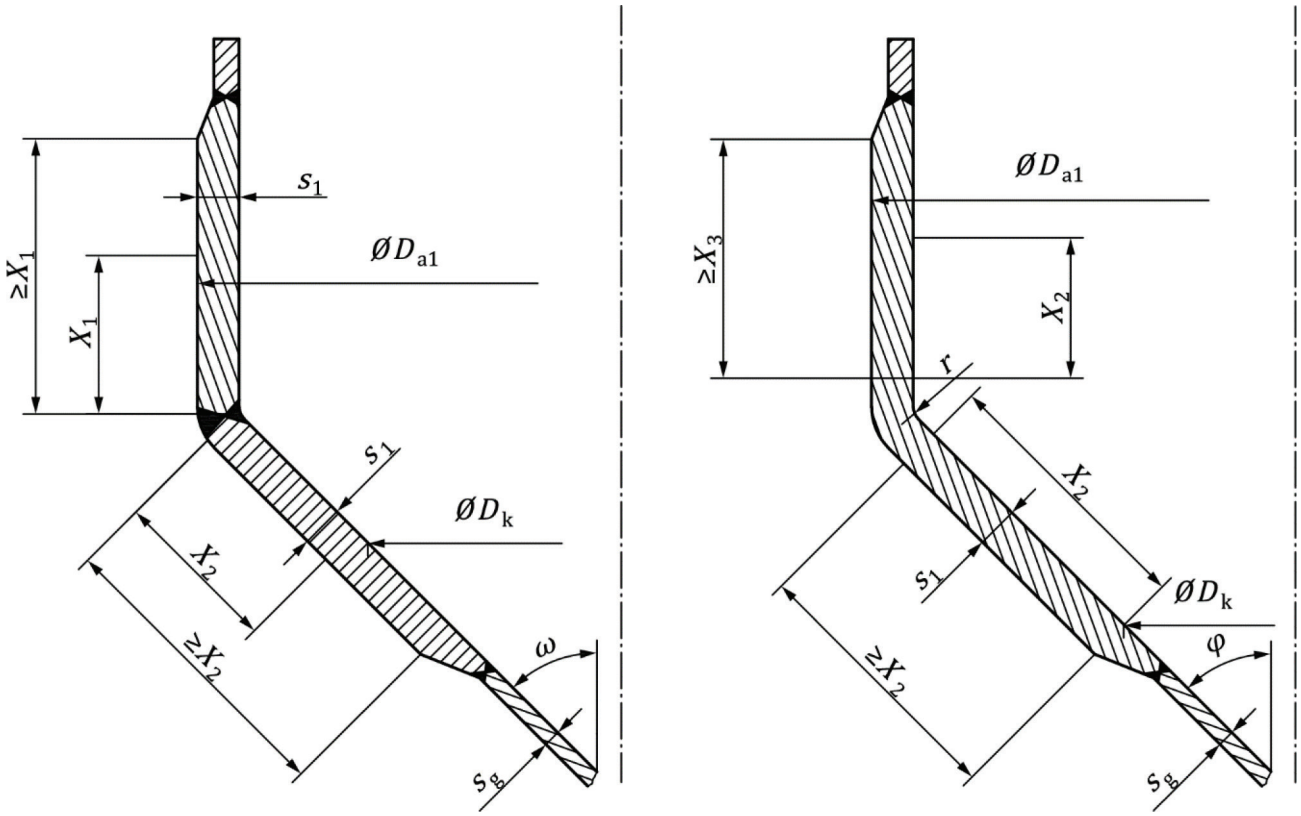
Small ends with a knuckle can be safely assessed and verified as a small end with a corner joint.

For external pressure, $|\varphi| \leq 70°$.

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

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a) Geometry of convergent conical shells **b) Geometry of a divergent conical shell**

Figure 2 — Examples of cones

10.3.6.5.2 Openings

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

— if $|\varphi| < 70°$, design according to 10.3.6.5.5 using an equivalent cylinder diameter as per Formula (11):

$$D_i = \frac{D_s + d_i|\sin\varphi|}{\cos\varphi} \quad (11)$$

— if $|\varphi| \geq 70°$ design according to 10.3.6.5.5.

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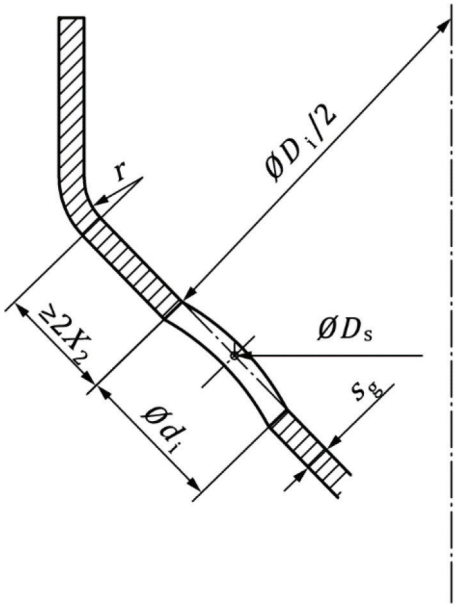


Figure 3 — Geometry of a cone opening

10.3.6.5.3 Non-destructive testing

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

10.3.6.5.4 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 Formulae (12) to (14):

$$X_1 = \sqrt{D_{a1}(s_1 - c)} \tag{12}$$

$$X_2 = 0{,}7\sqrt{\frac{D_{a1}(s_1 - c)}{\cos\varphi}} \tag{13}$$

$$X_3 = 0{,}5X_1 \tag{14}$$

10.3.6.5.5 Internal-pressure calculation (pressure on concave surface) $|\varphi| \leq 70°$

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 Formula (15):

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

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

For intermediate cone angles, linear interpolation shall be used.

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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.

The required wall thickness, s_g, outside the corner area, is calculated from Formula (16):

$$s_g = \frac{D_k p}{\left(20\frac{K}{S}\eta\right) - p} \times \frac{1}{\cos\varphi} + c \qquad (16)$$

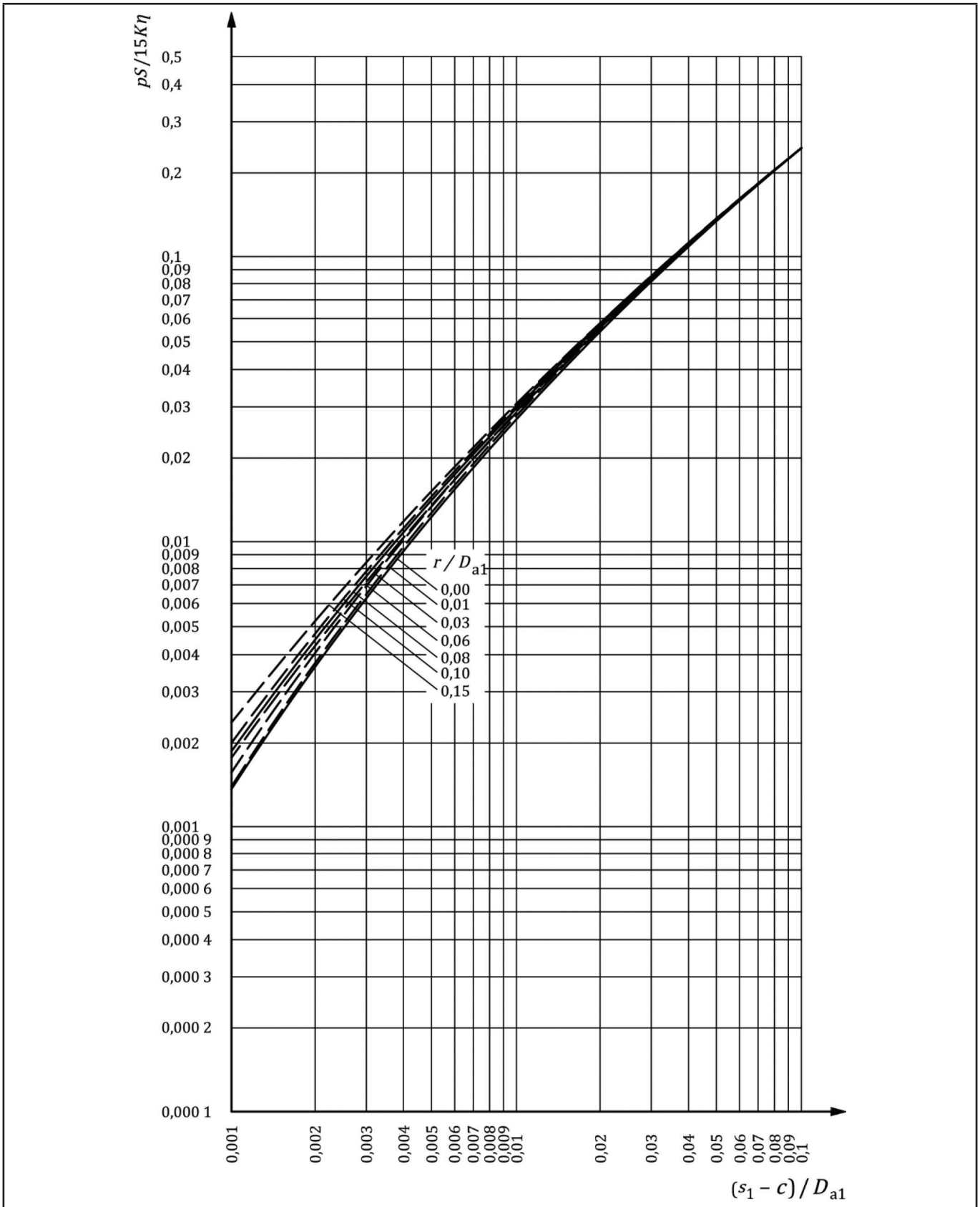
where

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.

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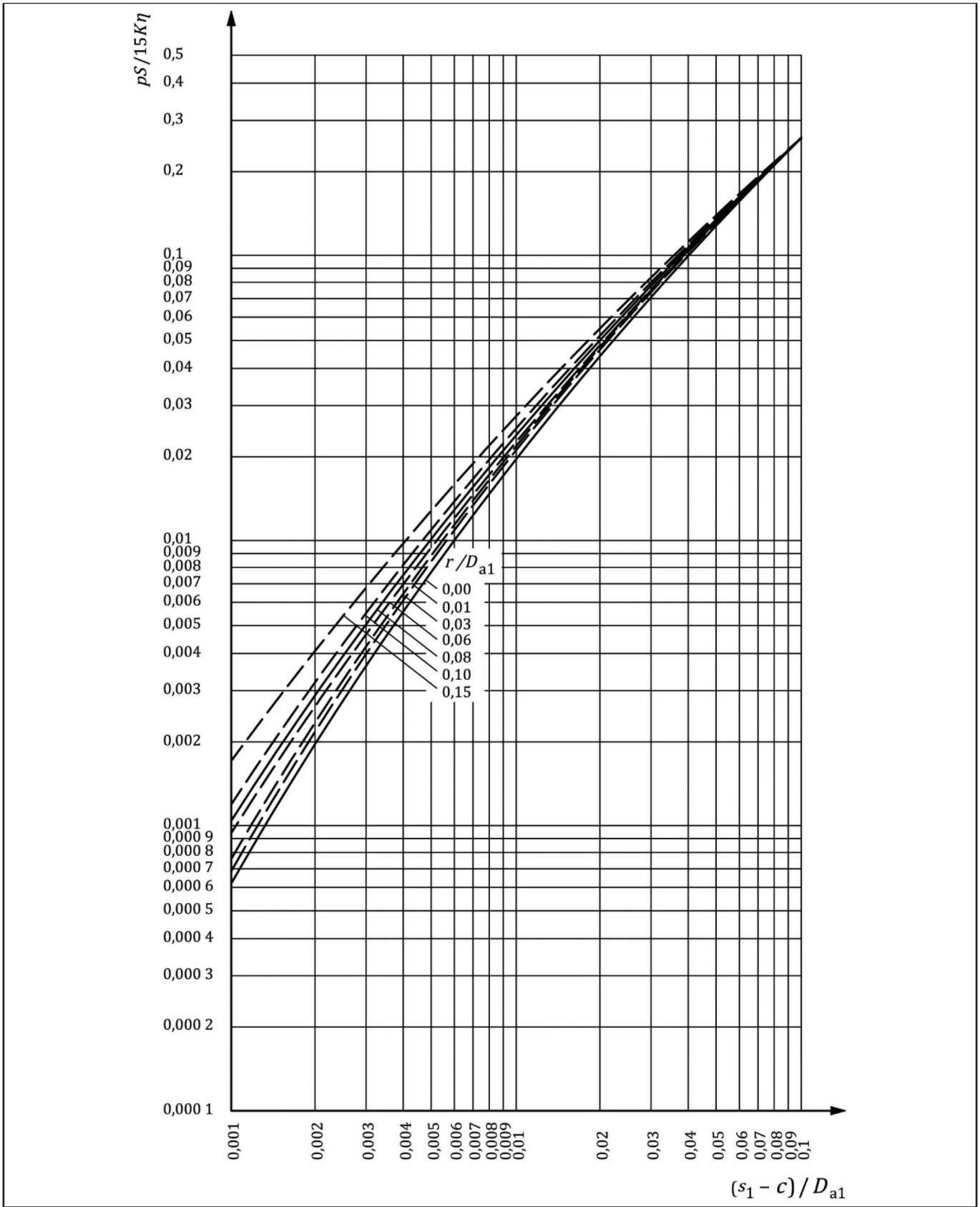
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a) Permissible value $\frac{p_s}{15K_\eta}$ for convergent cone with an opening angle φ = 10°

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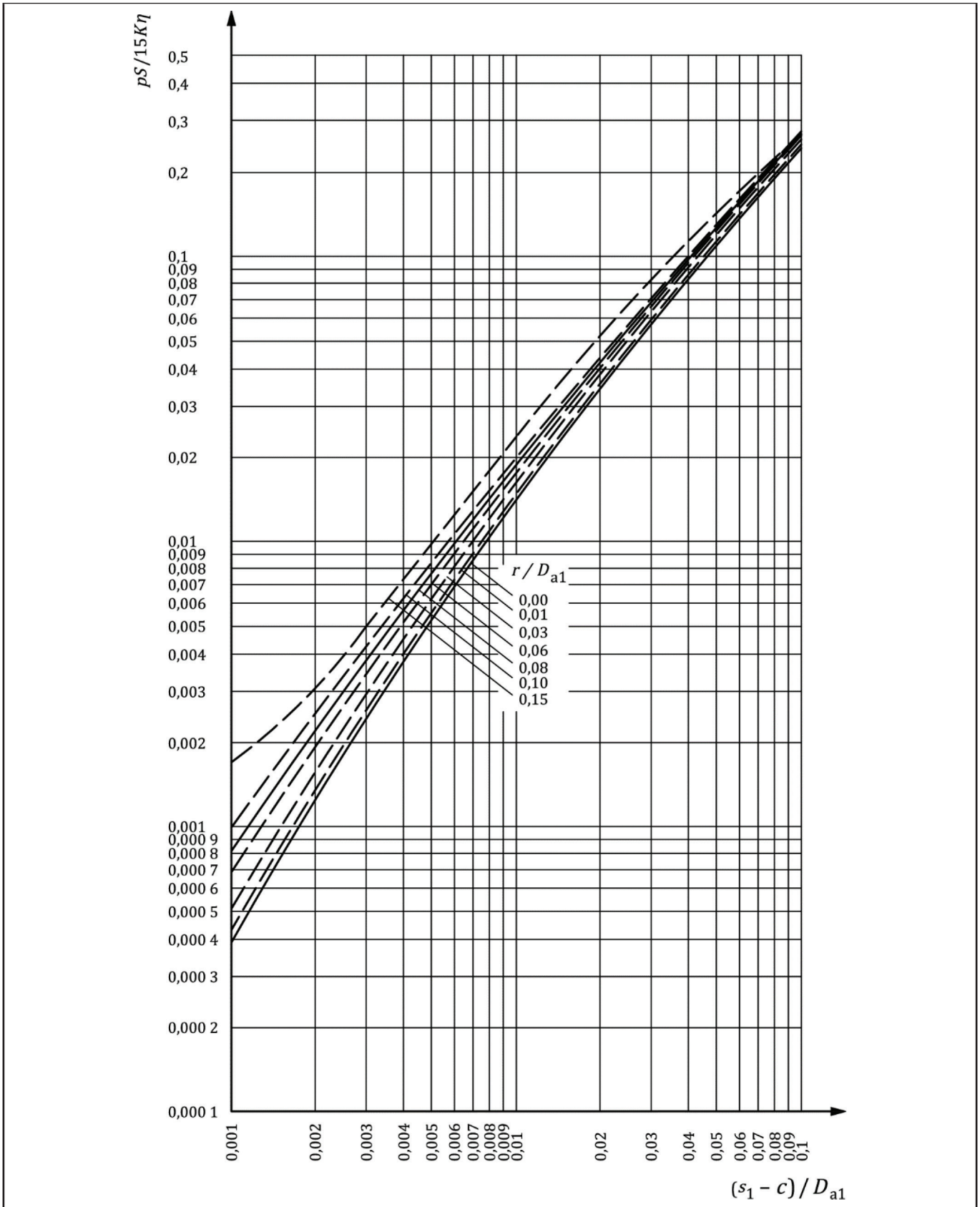
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b) Permissible value $\frac{p_s}{15K_\eta}$ for convergent cone with an opening angle φ = 20°

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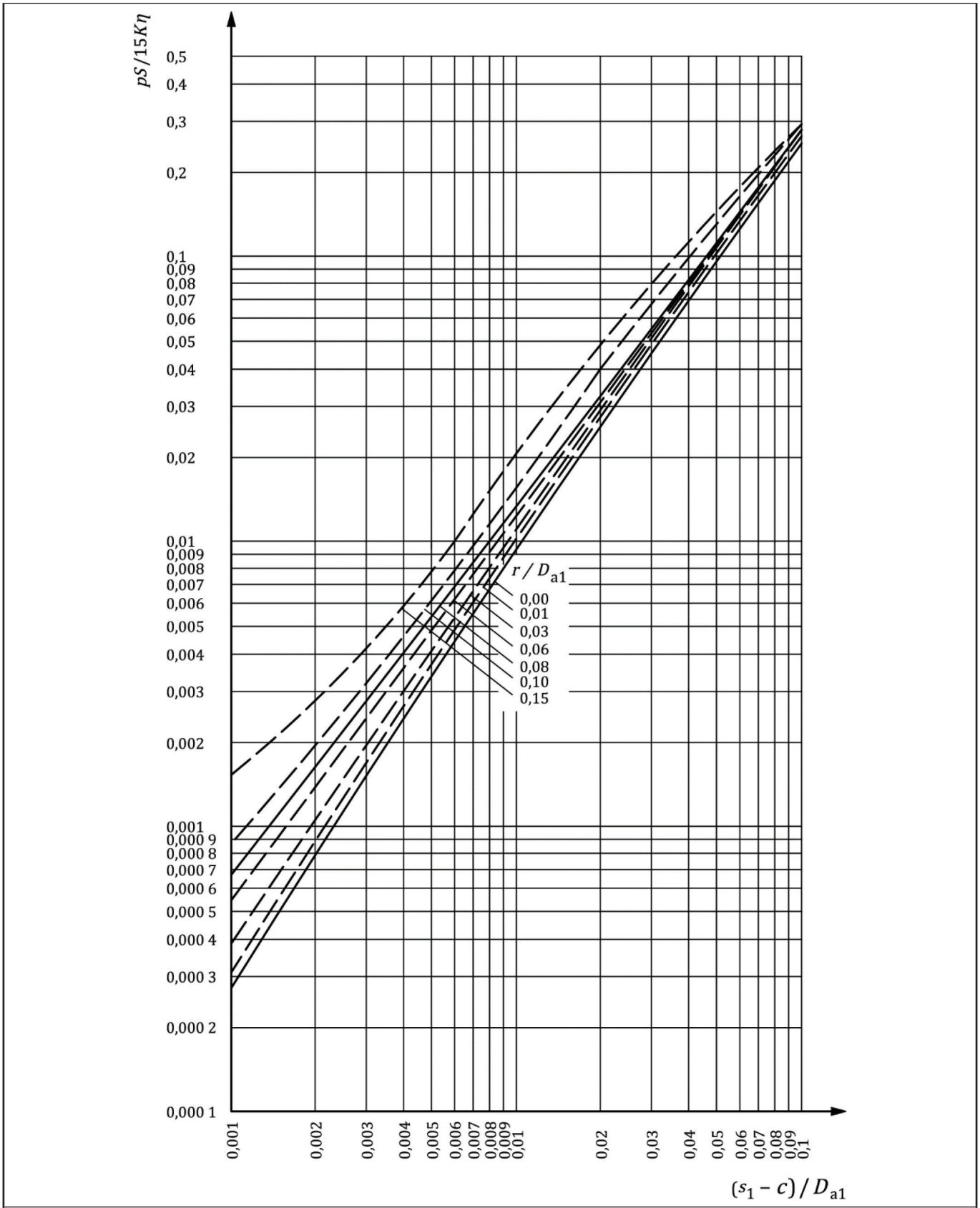
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c) Permissible value $\frac{p_s}{15K_\eta}$ for convergent cone with an opening angle φ = 30°

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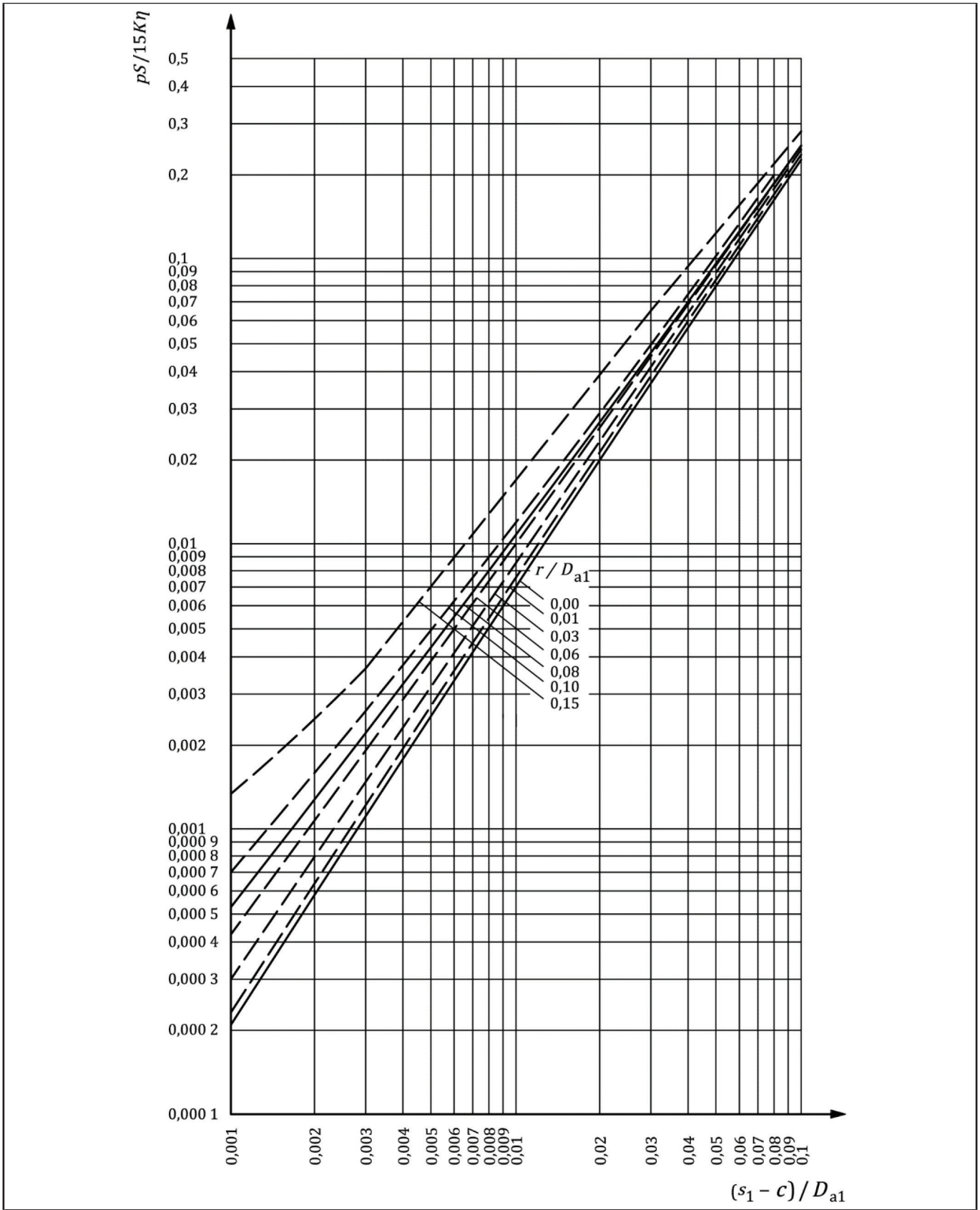
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d) Permissible value $\frac{p_s}{15K_\eta}$ for convergent cone with an opening angle $\varphi = 40°$

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e) Permissible value $\frac{p_S}{15K_\eta}$ for convergent cone with an opening angle $\varphi = 50°$

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