INTERNATIONAL STANDARD

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Third edition
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Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes —

Part 2:
Quenched and tempered steel cylinders and tubes with tensile strength greater than or equal to 1 100 MPa

Bouteilles à gaz — Conception, construction et essais des bouteilles à gaz et des tubes rechargeables en acier sans soudure —
Partie 2: Bouteilles et tubes en acier trempé et revenu ayant une résistance à la traction supérieure ou égale à 1 100 MPa

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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 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

This third edition cancels and replaces the second edition (ISO 9809-2:2010), which has been technically revised. The changes compared to the previous edition are as follows:

— water capacity extended from below 0,5 l and up to and including 450 l;

— batch size for tubes now introduced;

— bend test retained only for prototype tests;

— test requirements for check analysis (tolerances modified);

— new test requirements for threads introduced including an informative Annex F;

— original European Annexes now incorporated into the body of this document;

— Annex A "Manufacturing imperfections" now aligned with ISO/TR 16115.

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.

Introduction

This document provides a specification for the design, manufacture, inspection and testing of a seamless steel cylinder and tube. The objective is to balance design and economic efficiency against international acceptance and universal utility.

ISO 9809 (all parts) aims to eliminate existing concern; about climate, duplicate inspections and restrictions because of a lack of definitive International Standards.

This document is intended to be used under a variety of regulatory regimes, and has been written so that it is suitable to be referenced in the UN Model Regulations[11].

Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes —

Part 2:
Quenched and tempered steel cylinders and tubes with tensile strength greater than or equal to 1 100 MPa

1 Scope

This document specifies minimum requirements for the material, design, construction and workmanship, manufacturing processes, examination and testing at time of manufacture for refillable seamless steel gas cylinders and tubes with water capacities up to and including 450 l.

it is applicable to cylinders and tubes for compressed, liquefied and dissolved gases and for quenched and tempered steel cylinders and tubes with an actual tensile strength $R_{ma} \geq 1\ 100$ MPa.

It is not applicable to cylinders and tubes with $R_{ma,\ max} > 1\ 300$ MPa for diameters >140 mm and guaranteed wall thicknesses $a' \geq 12$ mm and for cylinders and tubes with $_{Rma,\ max} > 1\ 400$ MPa for diameters ≤140 mm and guaranteed wall thicknesses $a' \geq 6$ mm because, beyond these limits, additional requirements can apply.

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 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

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

ISO 10286, *Gas cylinders — Terminology*

ISO 11114-1, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 1: Metallic materials*

ISO 11114-4, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting steels resistant to hydrogen embrittlement*

ISO 13341, *Gas cylinders — Fitting of valves to gas cylinders*

ISO 13769, *Gas cylinders — Stamp marking*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10286 and the following 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 http://www.electropedia.org/

3.1
batch
quantity of up to 200 for cylinders and up to 50 for tubes, plus cylinders/tubes for destructive testing of the same nominal diameter, thickness, length and design made successively on the same equipment, from the same cast of steel and subjected to the same heat treatment for the same duration of time

Note 1 to entry: In this document where not specifically mentioned for “cylinder/tube” only the term “cylinder” will be used.

3.2
burst pressure
p_b
highest pressure reached in a cylinder during a burst test

3.3
design stress factor
F
ratio of equivalent wall stress at test pressure, p_h, to guaranteed minimum yield strength, R_{eg}

3.4
quenching
hardening heat treatment in which a cylinder, which has been heated to a uniform temperature above the upper critical point, Ac_3, of the steel, is cooled rapidly in a suitable medium

3.5
reject
cylinder that has been set aside (Level 2 or Level 3) and not allowed to enter into service

3.6
rendered unserviceable
cylinder that has been treated in such a way as to render it impossible for it to enter into service

Note 1 to entry: Examples for acceptable methods to render cylinders unserviceable can be found in ISO 18119. Any actions on cylinders rendered unserviceable are outside the scope of this document.

3.7
repair
action to return a rejected cylinder to a Level 1 condition

3.8
tempering
toughening heat treatment which follows quenching, in which the cylinder is heated to a uniform temperature below the lower critical point, Ac_1, of the steel

3.9
test pressure
p_h
required pressure applied during a pressure test

Note 1 to entry: Test pressure is used for cylinder wall thickness calculation.

3.10
working pressure
settled pressure of a compressed gas at a uniform reference temperature of 15 °C in a full gas cylinder

3.11
yield strength
stress value corresponding to the upper yield strength, R_{eH}, or for steels which do not exhibit a defined yield, the 0,2 % proof strength (non-proportional extension), $R_{p0,2}$

Note 1 to entry: See ISO 6892-1.

4 Symbols

A — percentage elongation after fracture

a — calculated minimum thickness, in millimetres, of the cylindrical shell

a' — guaranteed minimum thickness, in millimetres, of the cylindrical shell

a_1 — guaranteed minimum thickness, in millimetres, of a concave base at the knuckle (see Figure 2)

a_2 — guaranteed minimum thickness, in millimetres, at the centre of a concave base (see Figure 2)

b — guaranteed minimum thickness, in millimetres, at the centre of a convex base (see Figure 1)

c — maximum permissible deviation of burst profile, in millimetres (see Figure 13)

d — depth of artificial flaw, in millimetres, in flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)

D — nominal outside diameter of the cylinder, in millimetres (see Figure 1 and Figure 2)

D_c — external diameter, in millimetres, of cutter milling tool for flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)

D_f — diameter, in millimetres, of former (see Figure 6)

F — design stress factor (variable) (see 3.3)

H — outside height, in millimetres, of domed part (convex head or base end) (see Figure 1)

h — outside depth (concave base end), in millimetres (see Figure 2)

l_o — length of artificial flaw, in millimetres, in flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)

L_1 — length of cylindrical part of the cylinder, in millimetres (see Figure 3)

L_o — original gauge length, in millimetres, as defined in ISO 6892-1 (see Figure 8)

p_b — measured burst pressure, in bars, above atmospheric pressure

NOTE 1 bar = 10^5 Pa = 0,1 MPa.

p_f — measured failure pressure, in bars, above atmospheric pressure

p_h — hydraulic test pressure, in bars, above atmospheric pressure

p_y — observed pressure when cylinder starts yielding during hydraulic bursting test, in bars, above atmospheric pressure

r — inside knuckle radius, in millimetres (see Figure 1 and Figure 2)

r_c cutter tip radius of milling tool for artificial flaw, in millimetres, for flawed cylinder burst test and flawed cylinder cycle test (see Figure 5)

R_{eg} minimum guaranteed value of the yield strength (see 7.1.1), in megapascals, for the finished cylinder

R_{ea} actual value of the yield strength, in megapascals, as determined by the tensile test (see 10.2)

R_{mg} minimum guaranteed value of the tensile strength, in megapascals, for the finished cylinder

R_{ma} actual value of tensile strength, in megapascals, as determined by the tensile test (see 10.2)

$R_{ma,\,max}$ maximum actual value of the tensile strength range, in megapascals

$R_{ma,\,min}$ minimum actual value of the tensile strength range, in megapascals

S_o original cross-sectional area of tensile test piece, in square millimetres, in accordance with ISO 6892-1

t actual thickness of the test specimen, in millimetres

t_m average cylinder wall thickness at position of testing during the flattening test, in millimetres

V water capacity of cylinder, in litres

w width, in millimetres, of the tensile test piece (see Figure 8)

5 Inspection and testing

Assessment of conformity to this international standard shall take into account the applicable regulations of the countries of use.

To ensure that cylinders conform to this document, they shall be subject to inspection and testing in accordance with Clauses 9, 10 and 11.

Tests and examinations performed to demonstrate compliance with this document shall be conducted using instruments calibrated before being put into service and thereafter according to an established programme.

6 Materials

6.1 General requirements

6.1.1 Materials for the manufacture of gas cylinders shall fall within one of the following categories:

a) internationally recognized cylinder steels;

b) nationally recognized cylinder steels;

c) new cylinder steels resulting from technical progress.

For all categories, the relevant conditions specified in 6.2 and 6.3 shall be satisfied.

6.1.2 The material used for the manufacture of gas cylinders shall be steel, other than rimming quality, with non-ageing properties and shall be fully killed with aluminium and/or silicon.

In cases where examination of this non-ageing property is required by the customer, the criteria by which it is to be specified should be agreed with the customer and inserted in the order.

6.1.3 The cylinder manufacturer shall establish means to identify the cylinders with the cast of steel from which they are made.

6.1.4 High strength cylinders made in accordance with this document are normally not compatible with corrosive or embrittling gases (see ISO 11114-1). They may nevertheless be used with these gases provided that their compatibility is proven by a recognized test method, e.g. ISO 11114-4.

6.1.5 Wherever continuously cast billet material is used, the manufacturer shall ensure that there are no deleterious imperfections (porosity) in the material to be used for making cylinders (see 9.2.6).

6.2 Controls on chemical composition

6.2.1 The chemical composition of all steels shall be defined at least by:

— the carbon, manganese and silicon contents in all cases;

— the chromium, nickel and molybdenum contents or other alloying elements intentionally added to the steel;

— the maximum sulfur and phosphorus contents in all cases.

The carbon, manganese and silicon contents and, where appropriate, the chromium, nickel and molybdenum contents shall be given, with tolerances, such that the differences between the maximum and minimum values of the cast do not exceed the values shown in Table 1.

Table 1 — Chemical composition tolerances

Element	Maximum content (mass fraction) %	Permissible range (mass fraction) %	Check analysis Deviation from the limits specified for the cast analyses (mass fraction) %
Carbon	<0,30	0,03	±0,02
	≥0,30	0,04	
Manganese	All values	0,20	≤1,00 ± 0,04 >1,00 ≤ 1,70 ± 0,05
Silicon	All values	0,15	±0,03
Chromium	<1,20	0,20	≤2,00 ± 0,05
	≥1,20	0,30	>2,00 ≤ 2,20 ± 0,10
Nickel	All values	0,30	≤2,00 ± 0,05 >2,00 ≤ 4,30 ± 0,07
Molybdenum	<0,50	0,10	≤0,30 ± 0,03
	≥0,50	0,15	>0,30 ≤ 0,60 ± 0,04

The combined content of the following elements: vanadium, niobium, titanium, boron and zirconium, shall not exceed 0,15 %.

The actual content of any element deliberately added shall be reported and their maximum content shall be representative of good steel making practice.

6.2.2 Sulfur and phosphorus in the cast analysis of material used for the manufacture of gas cylinders shall not exceed the values shown in Table 2.

Table 2 — Maximum sulfur and phosphorus limits in % (mass fraction)

Sulfur	0,005
Phosphorus	0,015

6.2.3 The cylinder manufacturer shall obtain and provide certificates of cast (heat) analyses of the steels supplied for the construction of gas cylinders.

Should check analyses be required, they shall be carried out either on specimens taken during manufacture from the material in the form as supplied by the steel maker to the cylinder manufacturer or from finished cylinders. In any check analysis, the maximum permissible deviation from the limits specified for the cast analyses shall conform to the values specified in Table 1.

6.3 Heat treatment

6.3.1 The cylinder manufacturer shall certify the heat treatment process applied to the finished cylinders.

6.3.2 Quenching in media other than mineral oil is permissible, provided that:

— the method produces cylinders free of cracks;

— the manufacturer ensures that the rate of cooling does not produce any cracks in the cylinder;

— every production cylinder is subjected to a method of non-destructive testing to prove freedom from cracks, if the average rate of cooling in the medium is greater than 80 % of that in water at 20 °C without additives;

— during the production of cylinders, the concentration of the quenchant is checked and recorded during every shift to ensure that the limits are maintained. Further documented checks shall be carried out to ensure that the chemical properties of the quenchant are not degraded.

6.3.3 The tempering process shall achieve the required mechanical properties.

The actual temperature to which a type of steel is subjected for a given tensile strength shall not deviate by more than+/− 30 °C from the temperature specified by the cylinder manufacturer.

6.4 Failure to meet test requirements

In the event of failure to meet the test requirements, retesting or reheat treatment and retesting shall be carried out as follows to the satisfaction of the inspector.

a) If there is evidence of a fault in carrying out a test, or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored.

b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.

  1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to only one further heat treatment, e.g. if the failure is in a test representing the prototype or batch cylinders. Test failure shall require reheat treatment of all the represented cylinders prior to retesting.

  This reheat treatment shall consist of re-tempering or re-quenching and tempering.

  Whenever cylinders are reheat treated, the minimum guaranteed wall thickness shall be maintained.

Only the relevant prototype or batch tests needed to prove the acceptability of the new batch shall be performed again. If one or more tests prove even partially unsatisfactory, all cylinders of the batch shall be rejected.

2) If the failure is due to a cause other than the heat treatment applied, all cylinders with imperfections shall be either rejected or repaired such that the repaired cylinders pass the test(s) required for the repair. They shall then be re-instated as part of the original batch.

7 Design

7.1 General requirements

7.1.1 The calculation of the wall thickness of the pressure-containing parts shall be related to the guaranteed minimum yield strength, R_{eg}, of the material in the finished cylinder.

7.1.2 Cylinders shall be designed with one or two openings along the central cylinder axis only.

7.1.3 For calculation purposes, the value of R_{eg} shall not exceed 0,90 R_{mg}.

7.1.4 The internal pressure upon which the calculation of wall thickness is based shall be the hydraulic test pressure p_h.

7.2 Limitation on tensile strength

The maximum value of the tensile strength is limited by the ability of the steel to meet the requirements of Clauses 9 and 10. The maximum range of tensile strength shall be 120 MPa (i.e. $R_{ma, max} - R_{ma, min} \leq 120$ MPa).

However, the actual value of the tensile strength as determined in 10.2 shall not exceed 1 300 MPa for cylinders with an outside diameter greater than 140 mm, and 1 400 MPa for cylinders with an outside diameter equal to or less than 140 mm.

7.3 Design of cylindrical shell thickness

The guaranteed minimum thickness of the cylindrical shell, a', shall not be less than the thickness calculated using Formulae (1) and (2), and additionally condition (3) shall be satisfied:

$$a = \frac{D}{2}\left(1 - \sqrt{\frac{10\ FR_{eg} - \sqrt{3}p_h}{10\ FR_{eg}}}\right) \qquad (1)$$

where the value of F is the lesser of $\frac{0,65}{R_{eg}/R_{mg}}$ or 0,77.

R_{eg}/R_{mg} shall not exceed 0,90.

The wall thickness shall also satisfy Formula (2):

$$a \geq \frac{D}{250} + 1 \qquad (2)$$

with an absolute minimum of a = 1,5 mm.

The burst ratio shall be satisfied by test as given in Formula (3):

$$p_b / p_h \geq 1{,}6 \quad (3)$$

NOTE 1 If the result of these requirements is a guaranteed thickness of the cylindrical shell $a' \geq 12$ mm for diameter $D \geq 140$ mm, or a guaranteed thickness of the cylindrical shell, $a' \geq 6$ mm for diameter $D \leq 140$ mm, such a design is outside the scope of this document (see Clause 1).

NOTE 2 It is generally assumed that p_h = 1,5 times working pressure for compressed gases for cylinders designed and manufactured to this document.

NOTE 3 For some applications such as tubes assembled in batteries to equip trailers or skids (ISO modules) or MEGCs for the transportation and distribution of gases, it is important that stresses associated with mounting the tube (e.g. bending stresses, see Annex E, torsional stresses, dynamic loadings) are considered by the assembly manufacturer and the tube manufacturer.

NOTE 4 In addition, during hydraulic pressure testing, tubes could be supported or lifted by their necks; therefore, potential bending stresses are considered. For general guidance, see Annex E.

7.4 Design of convex ends (heads and bases)

7.4.1 When convex base ends (see Figure 1) are used, the thickness, b, at the centre of a convex end shall be not less than that required by the following criteria:

where the inside knuckle radius, r, is not less than 0,075D, then

$b \geq 1{,}5\,a$ for $0{,}40 > H/D \geq 0{,}20$;

$b \geq a$ for $H/D \geq 0{,}40$.

To obtain a satisfactory stress distribution in the region where the end joins the shell, any thickening of the end when required shall be gradual from the point of juncture, particularly at the base. For the application of this rule, the point of juncture between the shell and the end is defined by the horizontal lines indicating dimension H in Figure 1.

7.4.2 The cylinder manufacturer shall prove by the pressure cycling test detailed in 9.2.3 that the design is satisfactory.

The shapes shown in Figure 1 are typical of convex heads and base ends. Shapes a), c) and d) are base ends and shape b) is a head.

7.5 Design of concave base ends

When concave base ends (see Figure 2) are used, the following design values are recommended:

$a_1 \geq 2a$

$a_2 \geq 2a$

$h \geq 0{,}12D$

$r \geq 0{,}075D$

The design drawing shall at least show values for a_1, a_2, h and r.

To obtain a satisfactory stress distribution, the thickness of the cylinder shall increase progressively in the transition region between the cylindrical part and the base.

The cylinder manufacturer shall in any case prove by the pressure cycling test detailed in 9.2.3 that the design is satisfactory.