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Gaseous hydrogen — Cylinders and tubes for stationary storage

Hydrogène gazeux — Bouteilles et tubes pour stockage stationnaire

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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This document was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

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

As the use of gaseous hydrogen evolves from the chemical industry into various emerging applications, such as fuel for fuel cells, internal combustion engines and other specialty hydrogen applications, new requirements are foreseen for seamless and composite pressure vessels, including higher number of pressure cycles.

Requirements covering pressure vessels for stationary storage of compressed gaseous hydrogen are listed in this document and are mainly intended to maintain or improve the level of safety for this application.

Gaseous hydrogen — Cylinders and tubes for stationary storage

1 Scope

This document specifies the requirements for the design, manufacture and testing of standalone or manifolded (for some specific tests such as bonfire) cylinders, tubes and other pressure vessels of steel, stainless steel, aluminium alloys or of non-metallic construction material. These are intended for the stationary storage of gaseous hydrogen of up to a maximum water capacity of 10 000 l and a maximum allowable working pressure not exceeding 110 MPa, of seamless metallic construction (Type 1) or of composite construction (Types 2, 3 and 4), hereafter referred to as pressure vessels.

This document is not applicable to Type 2 and 3 vessels with welded liners.

This document is not applicable to pressure vessels used for solid, liquid hydrogen or hybrid cryogenic-high pressure hydrogen storage applications.

This document is not applicable to external piping which can be designed according to recognized standards.

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 306, *Plastics — Thermoplastic materials — Determination of Vicat softening temperature (VST)*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 1519, *Paints and varnishes — Bend test (cylindrical mandrel)*

ISO 2808, *Paints and varnishes — Determination of film thickness*

ISO 2812-1, *Paints and varnishes — Determination of resistance to liquids — Part 1: Immersion in liquids other than water*

ISO 4624, *Paints and varnishes — Pull-off test for adhesion*

ISO 6272-2, *Paints and varnishes — Rapid-deformation (impact resistance) tests — Part 2: Falling-weight test, small-area indenter*

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

ISO 7225, *Gas cylinders — Precautionary labels*

ISO 7866, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing*

ISO 9227, *Corrosion tests in artificial atmospheres — Salt spray tests*

ISO 9809-1, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 1: Quenched and tempered steel cylinders with tensile strength less than 1 100 MPa*

ISO 9809-2, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 2: Quenched and tempered steel cylinders with tensile strength greater than or equal to 1 100 MPa*

ISO 9809-3, *Gas cylinders —Refillable seamless steel gas cylinders — Design, construction and testing — Part 3: Normalized steel cylinders*

ISO 9809-4, *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing — Part 4: Stainless steel cylinders with an Rm value of less than 1 100 MPa*

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

ISO 11114-2, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 2: Non-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 11119-1, *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 1: Hoop wrapped fibre reinforced composite gas cylinders and tubes up to 450 l*

ISO 11119-2, *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 2: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with load-sharing metal liners*

ISO 11119-3, *Gas cylinders — Refillable composite gas cylinders and tubes — Design, construction and testing — Part 3: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450L with non-load-sharing metallic or non-metallic liners*

ISO 11120, *Gas cylinders — Refillable seamless steel tubes of water capacity between 150 l and 3000 l — Design, construction and testing*

ISO 11357-2, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature*

ISO 11439, *Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles*

ISO 12108, *Metallic materials — Fatigue testing — Fatigue crack growth method*

ISO 14130, *Fibre-reinforced plastic composites — Determination of apparent interlaminar shear strength by short-beam method*

ISO 16474-1, *Paints and varnishes — Methods of exposure to laboratory light sources — Part 1: General guidance*

ISO 16474-3, *Paints and varnishes — Methods of exposure to laboratory light sources — Part 3: Fluorescent UV lamps*

EN 13322-2, *Transportable gas cylinders — Refillable welded steel gas cylinders — Design and construction — Part 2: Stainless steel*

ASTM D3170/D3170M - 14, *Standard Test Method for Chipping Resistance of Coatings*

ASTM E647, *Standard Test Method for Measurement of Fatigue Crack Growth Rates*

3 Terms, definitions and symbols

3.1 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 http://www.electropedia.org/

3.1.1
autofrettage
pressure application procedure which strains the metal *liner* (3.1.13) past its yield point sufficiently to cause permanent plastic deformation, resulting in the liner having compressive stresses and the fibres having tensile stresses when at zero internal gauge pressure

3.1.2
autofrettage pressure
pressure within the overwrapped composite pressure vessel at which the required distribution of stresses between the *liner* (3.1.13) and the *composite overwrap* (3.1.6) is established

3.1.3
batch of pressure vessels
batch of pressure liners
set of manufactured *finished pressure vessels* (3.1.10) or *liners* (3.1.13) subject to a manufacturing quality pass/fail criterion based on the results of specified tests performed on a specified number of units from that set

3.1.4
boss
dome shaped metallic component mounted on one end or on the two ends of a non-metallic *liner* (3.1.13) with a neck providing an opening and/or an external element of mechanical support

3.1.5
burst pressure
highest pressure reached in a cylinder during a burst test

3.1.6
composite overwrap
combination of fibres (including steel wire) and *matrix* (3.1.15)

3.1.7
controlled tension winding
process used in manufacturing composite pressure vessels with metal *liners* (3.1.13) by which compressive stresses in the liner and tensile stresses in the *composite overwrap* (3.1.6) at zero internal pressure are obtained by winding the reinforcing fibres under controlled tension

3.1.8
cycle amplitude
ratio of pressure increase to maximum pressure in a *pressure cycle* (3.1.21)

Note 1 to entry: Cycle amplitude is expressed in %.

3.1.9
design change
change in the selection of structural materials or dimensional change exceeding the tolerances as on the design drawings

3.1.10
finished pressure vessel
pressure vessel, which is ready for use, typical of normal production, complete with identification marks and external coating including integral insulation specified by the manufacturer, but free from non-integral insulation or protection

Note 1 to entry: In the framework of this document, a tube or a cylinder is a finished pressure vessel.

3.1.11
full cycle
cycle of pressure amplitude between the *maximum allowable working pressure (MAWP)* (3.1.17) and 10 % of the MAWP

3.1.12
leakage
release of hydrogen through a crack, pore, or similar defect

Note 1 to entry: Permeation through the wall of a Type 4 pressure vessel that is less than the rates described in A.13 is not considered a leakage.

3.1.13
liner
inner portion of the composite cylinder, comprising a metallic or non-metallic vessel, whose purpose is both to contain the gas and transmit the gas pressure to the fibres

3.1.14
load-sharing liner
liner (3.1.13) that has a *burst pressure* (3.1.5) of at least 5 % of the minimum burst pressure of the finished composite cylinder

3.1.15
matrix
material that is used to bind and hold the fibres in place

3.1.16
maximum allowable temperature
maximum temperature of any part of the pressure vessel for which it is designed (or intended to be used if Annex B is followed)

3.1.17
maximum allowable working pressure
MAWP
design pressure
maximum pressure to which the component is designed to be subjected to and which is the basis for determining the strength of the component under consideration

3.1.18
minimum allowable temperature
minimum temperature of any part of the pressure vessel for which it is designed (or intended to be used if Annex B is followed)

3.1.19
operator
entity legally responsible for the use and maintenance of the vessel

3.1.20
pressure-activated pressure relief device
pressure-activated PRD
device designed to release pressure in order to prevent a rise in pressure above a specified value due to emergency or abnormal conditions

Note 1 to entry: Pressure-activated PRDs may be either re-closing devices (such as valves) or non-re-closing devices (such as rupture disks).

3.1.21
pressure cycle
pressure variation composed of one period of monotonic pressure increase up to a peak pressure followed by one period of monotonic pressure decrease

Note 1 to entry: Pressure variations exclusively due to variations of ambient temperature are not counted as pressure cycles.

3.1.22
pressure cycle life
maximum number of *pressure cycles* (3.1.21) in hydrogen service that the pressure vessel is designed to withstand in service

3.1.23
pre-stress
process of applying *autofrettage* (3.1.1) or *controlled tension winding* (3.1.7)

3.1.24
service life
maximum period for which the pressure vessel is designed to be in service based on fatigue life and stress rupture characteristics of composite cylinders

Note 1 to entry: Service life is expressed in years.

Note 2 to entry: Service life usually depends on the *pressure cycle* (3.1.21) or other service conditions and requirements from applicable standards. For composite cylinders, life in years is a requirement to address reliability under stress rupture conditions, which is also an underlying basis for the required *stress ratios* (3.1.29).

3.1.25
shallow pressure cycle
pressure cycle (3.1.21) from the *MAWP* (3.1.17) to not less than 70 % of the MAWP

3.1.26
shallow pressure cycle life
maximum number of *shallow pressure cycles* (3.1.25) that the pressure vessel is designed to withstand in hydrogen service

3.1.27
stationary storage
pressurized storage in a fixed location for a fixed purpose that is not transported while pressurized

3.1.28
stationary test pressure
TP
required pressure applied during a pressure test for the pressure vessel used in stationary service

Note 1 to entry: If Annex B is used, this is not to be confused with the *test pressure* (3.1.30) P_h used in e.g. the ISO 9809 series for design purposes as transportable gas cylinder.

3.1.29
stress ratio
stress in fibre at specified minimum *burst pressure* (3.1.5) divided by stress at the *MAWP* (3.1.17)

3.1.30
test pressure
required pressure applied during a pressure test

3.1.31
thermally activated pressure relief device
thermally activated PRD
device that activates by temperature to release pressure and prevent a pressure vessel from bursting due to fire effects and which will activate regardless of the vessel pressure

3.1.32
thermoplastic material
plastic capable of being repeatedly softened by an increase of temperature and hardened by a decrease of temperature

3.1.33
Type 1 pressure vessel
metal seamless cylindrical pressure vessel

Note 1 to entry: All metal multi-layered non-seamless vessels are not covered in this document. For reference, several types of multi-layered pressure vessels are addressed by ASME BPVC Section VII and Chinese standards GB 150 and GB/T 26466.

3.1.34
Type 2 pressure vessel
hoop wrapped cylindrical pressure vessel with a load-sharing metal *liner* (3.1.13) and composite reinforcement on the cylindrical part only

3.1.35
Type 3 pressure vessel
fully wrapped cylindrical pressure vessel with a load-sharing metal *liner* (3.1.13) and composite reinforcement on both the cylindrical part and dome ends

3.1.36
Type 4 pressure vessel
fully wrapped cylindrical pressure vessel with a *non-load-sharing liner* (3.1.37) and composite reinforcement on both the cylindrical part and the dome ends

3.1.37
non-load-sharing liner
liner (3.1.13) that has a *burst pressure* (3.1.5) less than 5 % of the nominal burst pressure of the finished composite cylinder

3.1.38
working pressure
settled pressure of a fully filled cylinder at a uniform temperature of 15 °C

Note 1 to entry: This term is normally used for transportable cylinders, see Annex B.

[SOURCE: ISO 11439:2013, 3.23, modified — Note 1 to entry has been added.]

3.2 Symbols

ΔP_i	variation of pressure during a given actual pressure cycle (in bar)
ΔP_{max}	variation of pressure during the pressure test specified in the reference standard (in bar)
F	design stress factor (ratio of equivalent wall stress at test pressure P_h to guarantee minimum yield strength)
F_a	hydrogen accelerating factor (see B.2.2.6), this factor is the multiplication factor to be applied on equivalent cycles n_{eq} calculation to take into account the ageing effect of H2 on cycling.
n_{eq}	number of cycles equivalent to full cycles (guaranteed in a given standard)
n_i	number of pressure cycle corresponding to ΔP_i
P_h	test pressure (in bar)

P_w	working pressure (in bar)
a	flaw size
N	number of pressure cycles
da/dN	crack growth rate, da/dN_{low} and da/dN_{high} are given in Table 5
C	constant, see Table 5
m	constant, see Table 5
C_H	constant when fatigue is performed in hydrogen
ΔK	range of the stress intensity factor during the fatigue cycle
ΔK_c	range of the stress intensity factor at which transition in the da/dN from low to high occurs
R_k	stress intensity factor
K_{Imin}	minimum stress intensity factor during the fatigue cycle
K_{Imax}	maximum stress intensity factor during the fatigue cycle
K_{max}	given value, see 8.3.5.6

4 Specified service conditions

4.1 Maximum allowable working pressure

The maximum allowable working pressure shall be specified by the pressure vessel manufacturer, shall not be less than 15 MPa and shall not exceed 110 MPa.

4.2 Maximum allowable energy content

The maximum allowable energy content of a single pressure vessel shall not exceed 300 000 MPa·l.

4.3 Maximum and minimum allowable temperature

The maximum allowable temperature and the minimum allowable temperature shall be specified by the pressure vessel manufacturer and noted on the name plate.

The specified value for the maximum allowable temperature shall not be less than 50 °C and shall not exceed 85 °C.

The specified value for the minimum allowable temperature shall not exceed -25 °C and shall not be less than -50 °C.

The manufacturer may specify a distinct maximum temperature not to be exceeded during maintenance (e.g. for painting).

4.4 Pressure cycle life

The pressure cycle life in hydrogen service shall be specified by the pressure vessel manufacturer.

The owner/operator may elect to further restrict to number of cycles allowed.

4.5 Shallow pressure cycle life

A shallow pressure cycle life may optionally be specified by the pressure vessel manufacturer or user. In this case, the shallow pressure cycle life shall be at least three times the pressure cycle life.

The shallow cycle life shall be calculated according to one of the methods given in 4.6.3, 8.3.5 or experimentally determined according to methods described in A.7.

4.6 Effective pressure cycle count and maximum number of pressure cycles allowed in service

4.6.1 General

One of the following methods shall be used to determine the pressure cycles life of the cylinder.

4.6.2 Pressure cycles calculation method — Method described in Annex B

For all types of vessels, the number of cycles equivalent to full cycles (guaranteed in a given standard) can be calculated according to the formula given in Annex B.

4.6.3 Pressure cycles calculation method — Goodman diagrams method described in Annex F

The cycle life may be determined by the use of a Goodman diagram and Miner's Rule. The Goodman diagram shall be based on fatigue testing of similar materials and construction as the vessel to be qualified. An example of this approach is provided in Annex F.

4.7 Service life

The service life shall be specified by the pressure vessel manufacturer.

For Type 2, Type 3, and Type 4 designs incorporating aramid or glass fibre, the specified service life shall not exceed 30 years.

The duration of service is also limited by the specified pressure cycle life. The operator is responsible for monitoring the cycles placed on the pressure vessels and removing them from service when their rated life has been reached. For example, a pressure vessel specified for 150 000 cycles and subjected to a pressure cycle every hour will need to be removed from service after 17 years.

5 Additional service conditions

5.1 Environmental conditions

The manufacturer shall specify the environmental conditions for which the pressure vessel has been designed as well as any protection to be provided at point of use, such as external protection from extreme solar radiation.

Precautions shall be taken against drop or impact (particularly during installation). If drop or impact does occur, an inspection shall be conducted.

This information shall be included in the statement of service provided by the manufacturer as required by 6.2.

Immersion in fluids, additional coating, protecting layer or medium isolating the cylinders or generating retention of fluids of any kind requires written approval from the manufacturer.

5.2 Fire conditions

The owner/operator shall assess the outcome of a risk analysis to demonstrate that in case of a fire, overall safety will be maintained.

For protection, several solutions can be used (e.g. extinguishing devices, fire retardants, PRD, intumescent paints, etc.).

When regulations or risk analysis require the installation of a pressure relief device, see for information suggested design and test procedures in Annex G.

6 Information to be recorded

6.1 General

The pressure vessel manufacturer shall keep on file the information specified herein. This information shall be retained for the intended life of the pressure vessel.

6.2 Statement of service

A statement of service shall be provided by the manufacturer of the pressure vessel to the user. This statement of service shall include the following:

a) the name and address of the pressure vessel manufacturer;

b) the service conditions as specified in Clause 4 and Clause 5, including a warning about the need for measures to prevent specified limitations, such as temperature limits and cycle life, from being exceeded;

c) a statement that the pressure vessel design is suitable for use in the service conditions provided in Clauses 4 and 5;

d) a description of the pressure vessel design, including diameter (mm), length (mm), internal volume (l), empty weight (kg), and port geometry;

e) if applicable, a specification of the pressure relief performance required to prevent violent rupture in case of exposure to fire conditions, as specified in 5.2;

f) a specification for the support methods, external protection, protective coatings and any other items required, but not provided with the pressure vessel;

g) a statement that the number of cycles of operations shall be determined and that the actual number of cycles shall be monitored;

h) any other information and instructions necessary to ensure the safe use and inspection of the pressure vessel, including those specified hereafter, where relevant:

   — for Type 2, Type 3, and Type 4 designs requiring protection against exposure to UV emissions, instructions shall require that this protection be provided by the installation;

   — for Type 4 designs, the manufacturer shall:

      — specify the minimum residual pressure (MRP) in normal operation. The specified MRP shall not exceed 15 % of the MAWP;

      — specify the maximum depressurization rate during normal operation, which shall be lower than 20 MPa/min;

      — provide a procedure for complete depressurization from MRP without liner collapse.

