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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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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (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.	

English Version

Gaseous hydrogen - Cylinders and tubes for stationary storage

Hydrogène gazeux - Bouteilles et tubes pour stockage
stationnaire

Gasförmiger Wasserstoff - Flaschen und Großflaschen
zur ortsfesten Lagerung

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European foreword

This document (prEN 17533:2023) has been prepared by Technical Committee CEN/TC 23 “Transportable gas cylinders”, the secretariat of which is held by BSI.

This document is currently submitted to the CEN Enquiry.

This document will supersede EN 17533:2020.

prEN 17533:2023 includes the following significant technical changes with respect to EN 17533:2020:

- requirements for new design have been revised;
- addition of Figure A.1 Concept of Annex A;
- Annexes B and C have been revised.

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 speciality 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.

1 Scope

This document specifies the requirements for the design, manufacture and testing of 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 1 100 bar, of seamless metallic construction (Type 1) or of composite construction (Types 2, 3 and 4), hereafter referred to as pressure vessels.

NOTE Additional requirements with regard to assemblies (manifolded cylinders and tubes and other pressure vessels) are not covered by this document.

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.

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

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

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

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

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

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

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

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

EN ISO 7225, *Gas cylinders — Precautionary labels (ISO 7225)*

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

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

EN ISO 9809 (all parts), *Gas cylinders — Refillable seamless steel gas cylinders — Design, construction and testing (ISO 9809)*

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

EN ISO 11114-2, *Gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 2: Non-metallic materials (ISO 11114-2)*

EN 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 11114-4)*

ISO 11119-1, *Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — Part 1: Hoop wrapped fibre reinforced composite gas cylinders and tubes up to 450 l*

ISO 11119-2, *Gas cylinders — Design, construction and testing of refillable composite gas cylinders and tubes — 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 — Design, construction and testing of refillable composite gas cylinders and tubes — Part 3: Fully wrapped fibre reinforced composite gas cylinders and tubes up to 450 l with non-load-sharing metallic or non-metallic liners or without liners*

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

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

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

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

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

EN 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 (ISO 16474-3)*

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

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 terminology 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/>

3.1.1**stationary storage****<stationary pressure vessel>**

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

3.1.2**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.

3.1.3**Type 2 pressure vessel**

hoop wrapped cylindrical pressure vessel with a load-sharing metal *liner* (3.1.12) and composite reinforcement on the cylindrical part only

3.1.4**Type 3 pressure vessel**

fully wrapped cylindrical pressure vessel with a load-sharing metal *liner* (3.1.12) and composite reinforcement on both the cylindrical part and dome ends

3.1.5**Type 4 pressure vessel**

fully wrapped cylindrical pressure vessel with a *non-load-sharing liner* (3.1.14) and composite reinforcement on both the cylindrical part and the dome ends

3.1.6**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.

3.1.7**batch of pressure vessels****batch of pressure liners**

set of manufactured *finished pressure vessels* (3.1.6) or *liners* (3.1.12) 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

3.1.8**matrix**

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

3.1.9**composite overwrap**

combination of fibres (including steel wire) and matrix (3.1.8)

3.1.10

thermoplastic material

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

3.1.11

thermosetting material

material capable of being changed into a substantially infusible and insoluble product when cured by heat or by other means, such as radiation and catalysts

Note 1 to entry: These materials are resins and include polymers such as polyesters, epoxides, acrylics, urethanes and phenolics.

Note 2 to entry: The resins may incorporate non-fibrous fillers, flame-retardants, pigments and stabilizers.

[SOURCE: ISO 25762:2009, 3.2.1]

3.1.12

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

3.1.13

load-sharing liner

liner (3.1.12) that has a *burst pressure* (3.1.33) of at least 5 % of the minimum burst pressure of the finished composite cylinder

3.1.14

non-load-sharing liner

liner (3.1.12) that has a *burst pressure* (3.1.33) less than 5 % of the nominal burst pressure of the finished composite cylinder

3.1.15

boss

dome shaped metallic component mounted on one end or on the two ends of a non-metallic *liner* (3.1.12) with a neck providing an opening and/or an external element of mechanical support

3.1.16

autofrettage

pressure application procedure which strains the metal *liner* (3.1.12) 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

3.1.17

autofrettage pressure

pressure within the overwrapped composite pressure vessel at which the required distribution of stresses between the *liner* (3.1.12) and the *composite overwrap* (3.1.9) is established

3.1.18

pre-stress

process of applying *autofrettage* (3.1.16) or *controlled tension winding* (3.1.19)

3.1.19**controlled tension winding**

process used in manufacturing composite pressure vessels with metal *liners* (3.1.12) by which compressive stresses in the liner and tensile stresses in the *composite overwrap* (3.1.9) at zero internal pressure are obtained by winding the reinforcing fibres under controlled tension

3.1.20**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 %.

3.1.21**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**full cycle**

cycle of pressure amplitude between the *maximum allowable working pressure (MAWP)* (3.1.25) and 10 % of the MAWP

3.1.23**minimum allowable temperature**

minimum temperature of any part of the pressure vessel for which it is designed

3.1.24**maximum allowable temperature**

maximum temperature of any part of the pressure vessel for which it is designed

3.1.25**maximum allowable working pressure****MAWP (PS according to PED)****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

Note 1 to entry: In the Pressure Equipment Directive (PED), PS is equal to the MAWP.

3.1.26**shallow pressure cycle**

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

3.1.27**shallow pressure cycle life**

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

3.1.28

pressure cycle life

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

3.1.29

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* (3.1.34).

3.1.30

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 A is used, this is not to be confused with the *test pressure* (3.1.32) P_H used in e.g. the EN ISO 9809 series for design purposes as transportable gas cylinder, see Figure A.1.

3.1.31

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 A Figure A.1.

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

3.1.32

test pressure

required pressure applied during a pressure test

3.1.33

burst pressure

highest pressure reached in a cylinder during a burst test

3.1.34

stress ratio

stress in fibre at specified minimum *burst pressure* (3.1.33) divided by stress at the *MAWP* (3.1.25)

3.1.35

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).

3.1.36**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

3.1.37**design change**

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

3.1.38**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 D.13 is not considered a leakage.

3.1.39**operator**

entity legally responsible for the use and maintenance of the vessel

3.2 Symbols

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

ΔP_i	difference between the minimum and the maximum of pressure during a given actual pressure cycle (in bar)
$\Delta P_{\max}$	maximum difference between the lower and the upper pressure during the cycling pressure tests 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 A.2.2.5), this factor is the multiplication factor to be applied on equivalent cycles n_{eq} calculation to take into account the ageing effect of H_2 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
C_H	constant when fatigue is performed in hydrogen
ΔK	range of the stress intensity factor during the fatigue cycle
R_k	stress intensity factor
K_{Imin}	minimum stress intensity factor during the fatigue cycle

$K_{I\max}$	maximum stress intensity factor during the fatigue cycle
$K_{\max}$	given value, see A.2.2.6

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 exceed 1 100 bar.

NOTE In the PED, PS is equal to the MAWP.

4.2 Maximum allowable energy

The maximum allowable energy (i.e. MAWP x water capacity) content of a single pressure vessel shall not exceed 3 000 000 bar·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. When using Annex A, the maximum allowable temperature shall not exceed 65 °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 (i.e. including full cycles and shallow cycles) in hydrogen service shall be specified, see 6.2.

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

The shallow cycle life shall be calculated according to one of the methods given in 4.5.

4.5 Methods to define the acceptable number of pressure cycles or fatigue behaviour for in service performance

4.5.1 General

One of the following methods shall be used.

4.5.2 Method 1 - Pressure cycling calculation using design standards for transportable applications – Method described in Annex A

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 A and after recalculating MAWP according to A.2.2.1 and after recalculating the stationary test pressure according to A.2.2.4. Different pressure definitions are used in transportable and stationary applications, a sketch is provided to clarify these differences (see Figure A.1).

4.5.3 Method 2 - Fatigue evaluation using fracture mechanics – Method described in Annex B (type 1 and type 2)

For type 1 and type 2 vessels, the pressure cycle life can be determined by the use of fracture mechanics as described in Annex B.

4.5.4 Method 3 - Fatigue evaluation based on performance testing – Method described in Annex C

For all types of vessels, the method described in Annex C can be used.

4.6 Service life

The maximum service life shall be specified in years or number of pressure cycles whichever is reached first:

- For Type 2, Type 3, and Type 4 designs incorporating aramid, carbon or glass fibre, the specified service life shall not exceed 30 years.
- The duration of service for all types is 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.

5 Additional service conditions

5.1 General

A risk assessment, in accordance with the applicable regulations, shall be performed to take into account the environmental conditions (see 5.2) and fire conditions (see 5.3).

5.2 Environmental conditions

It 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.

5.3 Fire conditions

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

NOTE For protection of the complete installation, several solutions exist (e.g. extinguishing devices, fire retardants, PRD, intumescent paints, etc.).

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 5.3;
- 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 or estimated in order to ensure that the maximum acceptable number of cycles is not exceeded;
- 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 especially during storage and use;
 - for Type 4 designs, the manufacturer shall:
 - specify the minimum residual pressure (MRP) in normal operation to avoid liner collapse. The specified MRP shall not exceed 15 % of the MAWP;
 - specify the maximum depressurization rate during normal operation, which shall be lower than 200 bar/min;
 - provide a procedure for complete depressurization from MRP without liner collapse.

NOTE Annex D provides further typical information on the manufacturer's instructions for handling, use and inspection of pressure vessels.

6.3 Design, drawings and information

All pressure vessel drawings and/or related technical data shall be kept on file by the pressure vessel manufacturer and shall show the following information:

- a) title, reference number, date of issue, and revision numbers with dates of issue, if applicable;
- b) the MAWP;

- c) the operating process temperature range;
- d) the specified service conditions, in addition to the MAWP, as specified in Clauses 4 and 5;
- e) dimensions complete with tolerances, including details of end closure shapes with minimum thickness and openings;
- f) mass, complete with tolerance;
- g) material specifications, complete with minimum mechanical and chemical properties and tolerance ranges and, for metal pressure vessels, metal liners and bosses, the specified hardness range and maximum allowable defect size;
- h) autofrettage pressure range and duration; if applicable;
- i) test pressure as carried out by the manufacturer;

NOTE Applicable standard/regulation can require a different value.

- j) details on exterior protective coating.

6.4 Material property data

The manufacturer shall keep the following information on file, as applicable, and make it available to regulatory authorities or inspectors on request:

- a) detailed description of the materials and tolerances of the material properties used in the design, including test data characterizing the mechanical properties and the suitability of the materials for service under the conditions specified in Clauses 4 and 5;
- b) published specifications for composite materials, as well as the material manufacturer's recommendations for storage conditions and shelf life;
- c) the fibre manufacturer's certification that each shipment conforms to the manufacturer's specifications for the product.

6.5 Manufacturing data

Details of all fabrication processes, tolerances, non-destructive examinations, batch tests and production tests shall be specified and kept on file by the manufacturer.

The manufacturer shall specify the minimum burst pressure for the design. In no case shall the minimum specified burst pressure be less than the minimum burst pressure specified in this document in relation to the MAWP.

Surface finish, thread details, acceptance criteria for non-destructive examination, and lot sizes for batch tests shall also be specified by the manufacturer and kept on file. Examples of procedures to determine the acceptable defect sizes are given in Annex C.

The manufacturing data specified in 9.2.5, 9.2.6 and 9.2.7, along with the results of non-destructive examinations, batch tests, and production tests shall be kept on file by the manufacturer.

6.6 Retention of records

The design and manufacturing data kept on file, as specified in 6.4, 6.5 and 9.3.1, shall be retained by the manufacturer for a duration of at least the service life of the pressure vessel plus five years from the date of manufacture.