INTERNATIONAL STANDARD

ISO 16111

Second edition
2018-08

Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride

Appareils de stockage de gaz transportables — Hydrogène absorbé dans un hydrure métallique réversible

Reference number
ISO 16111:2018(E)

© ISO 2018



COPYRIGHT PROTECTED DOCUMENT

© ISO 2018

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

 © ISO 2018 – All rights reserved

Contents

Page

Foreword ..... **v**

Introduction ..... **vi**

1 Scope **1**

2 Normative references **1**

3 Terms and definitions **2**

4 Service conditions **4**
4.1 Pressures 4
4.1.1 Maximum developed pressure (MDP) 4
4.1.2 Rated charging pressure (RCP) 4
4.1.3 Stress level at MDP 4
4.2 Rated capacity 4
4.3 Temperature ranges 5
4.3.1 Operating temperature range 5
4.3.2 Service temperature range 5
4.4 Environmental conditions 5
4.5 Service life 5
4.6 Hydrogen quality 5
4.7 Special service conditions 5

5 Design considerations **5**
5.1 General 5
5.2 Material selection 5
5.2.1 General 5
5.2.2 External surfaces 6
5.2.3 Compatibility 6
5.2.4 Temperature 6
5.3 Shell design 6
5.3.1 Shells with internal volume greater than 120 ml 6
5.3.2 Shells with internal volume of 120 ml or less 7
5.4 Design strength 7
5.5 Overpressure and fire protection 7
5.5.1 General 7
5.5.2 PRD activation pressure 8
5.5.3 PRD activation temperature 8
5.6 Loading of hydrogen absorbing alloy 8
5.7 Shut-off valves 8
5.7.1 General 8
5.7.2 MH assemblies with internal volume greater than 120 ml 8
5.7.3 MH assemblies with internal volume of 120 ml or less 9
5.7.4 Integral shut-off valve protection 10
5.7.5 Removable shut-off valve protection 10
5.8 Actively cooled MH assemblies 10
5.9 Particulate containment 10

6 Inspection and testing **10**
6.1 General 10
6.2 Type/qualification tests 10
6.2.1 General 10
6.2.2 Fire test 11
6.2.3 Initial burst tests for MH assemblies with an internal volume of 120 ml or less 13
6.2.4 Drop or impact test 13
6.2.5 Leak test 17
6.2.6 Hydrogen cycling and strain measurement test 17
6.2.7 Shut-off valve impact test 21

© ISO 2018 – All rights reserved

6.2.8 Thermal cycling test 22
6.2.9 Type test reports 23
6.3 Batch tests 23
6.3.1 General requirements 23
6.3.2 Burst test for shell-batch 24
6.3.3 MDP Test for hydride-batch 24
6.4 Routine tests and inspections 24
6.4.1 Routine tests 24
6.4.2 Certificates of manufacture 24
7 Marking, labelling, and documentation 25
7.1 Marking 25
7.2 Labelling 25
7.2.1 General 25
7.2.2 Hazards associated with the solid materials 25
7.2.3 Labelling concerning removable valve protection 25
7.2.4 Temperature warning labelling 25
8 Documentation accompanying the product 26
8.1 Safety data sheets 26
8.2 User's or operating manual 26
8.2.1 General 26
8.2.2 Initial fill and refill procedures 26
Annex A (informative) **Material compatibility for hydrogen service 28**
Annex B (normative) **Environmental tests 31**
Annex C (informative) **Type approval certificate 37**
Annex D (informative) **Acceptance certificate 39**
Bibliography 42

 © ISO 2018 – All rights reserved

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 on 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 ISO/TC 197, *Hydrogen technologies.*

This second edition cancels and replaces the first edition (ISO 16111:2008), which has been technically revised.

The following clauses have been modified with respect to the previous edition: 2; 3.4; 3.5; 3.9; 3.10; 3.11; 3.12; 3.13; 3.14; 3.15; 3.16; 3.17; 3.18; 3.19; 3.20; 3.21; 3.22; 4.1; 4.3; 5.2.1; 5.3; 5.5; 5.8; 6.2; 6.3; 7.2; 8.1 and Annex D.

The main changes compared to the previous edition concern the following:

— service temperature conditions have been described in further detail (4.3.2);

— shell design has been extended to ISO 11119-3 standard reference (5.3);

— drop test conditions have been modified (6.2.4);

— acceptance criteria have been modified for leak testing (6.2.5);

— hydrogen cycling conditions have been modified (6.2.6);

— new warning labelling has been proposed (7.2);

— information in safety data sheets has been updated (8.1).

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.

© ISO 2018 – All rights reserved

Introduction

As the utilization of gaseous hydrogen evolves from the chemical industry into various emerging applications, such as fuel for fuel cells and internal combustion engines and other specialty hydrogen applications, the importance of new and improved storage techniques has become essential. One of these techniques employs the absorption of hydrogen into specially formulated alloys. The material can be stored and transported in a solid form, and the hydrogen later released and used under specific thermodynamic conditions. This document describes the service conditions, design criteria, type tests, batch tests and routine tests for transportable hydride-based hydrogen storage systems, referred to as "metal hydride assemblies" (MH assemblies). Types of MH assemblies may serve as: fuel cell cartridges; hydrogen fuel storage containers; high-purity hydrogen supplies as well as other uses.

© ISO 2018 – All rights reserved

Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride

1 Scope

This document defines the requirements applicable to the material, design, construction, and testing of transportable hydrogen gas storage systems, referred to as "metal hydride assemblies" (MH assemblies) which utilize shells not exceeding 150 l internal volume and having a maximum developed pressure (MDP) not exceeding 25 MPa.

This document is applicable to refillable storage MH assemblies where hydrogen is the only transferred media. It is not applicable to storage MH assemblies intended to be used as fixed fuel-storage onboard hydrogen fuelled vehicles.

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 7225, *Gas cylinders — Precautionary labels*

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

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 10297:2014, *Gas cylinders — Cylinder valves — Specification and type testing*

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 11119-2:2012, *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 2018 – All rights reserved

ISO 14246, *Gas cylinders — Cylinder valves — Manufacturing tests and examinations*

ISO 14687 (all parts), *Hydrogen fuel — Product specification*

ISO 16528-1, *Boilers and pressure vessels — Part 1: Performance requirements*

UN Recommendations on the Transport of Dangerous Goods: Model Regulations

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 http://www.electropedia.org/

3.1
absorbed, adj.
taken and held through the formation of chemical bonds within the bulk of the material

3.2
burst pressure
highest pressure reached in an MH assembly during a burst test

3.3
design stress limit
total stress loading allowed on the shell wall

Note 1 to entry: In MH assemblies, the shell design takes into account the gas pressure plus other stresses, such as pressure exerted by expansion of the hydrogen absorbing alloy.

3.4
fuel cartridge
MH assembly, which stores hydrogen for use as a fuel in a fuel cell through a valve(s) that controls the discharge of fuel into the fuel cell

3.5
full flow capacity pressure
gas pressure at which the pressure relief device is fully open to have the maximum gas flow

3.6
hydrogen absorbing alloy
material capable of reacting with hydrogen gas to form a reversible metal hydride

3.7
internal component
structure, matrix, material or device contained within the shell (excluding hydrogen gas, hydrogen absorbing alloy and metal hydride)

Note 1 to entry: Internal components may be used for purposes such as heat transfer, preventing movement of the hydrogen absorbing alloy/metal hydride and/or to prevent excessive stress on the shell walls due to hydride expansion.

3.8
internal volume
water capacity of the shell

© ISO 2018 – All rights reserved

3.9
maximum developed pressure
MDP
highest gas gauge pressure developed internally to an MH assembly at rated capacity and equilibrium under normal service conditions or normal operating conditions, whichever is greater

Note 1 to entry: The MDP term was specifically selected for MH assemblies to avoid confusion with the maximum allowable working pressure (MAWP) and the service pressure used in other ISO International Standards.

3.10
metal hydride
solid material formed by reaction between hydrogen and hydrogen absorbing alloy

3.11
metal hydride assembly
MH assembly
single complete hydrogen storage system, including shell, metal hydride, pressure relief device (PRD), shut-off valve, other appurtenances and internal components

Note 1 to entry: The MH assembly extends only to, and including, the first shut-off valve.

Note 2 to entry: A fuel cell cartridge is a type of MH assembly.

3.12
normal operating conditions
range of pressures, MH assembly external shell temperatures, hydrogen flow rates, hydrogen quality, etc., specified for all use and filling operations

3.13
normal service conditions
range of pressures and environmental temperatures, specified for transportation and storage conditions

3.14
pressure relief device
PRD
device intended to prevent the rupture of an MH assembly in the event of overpressure or exposure to fire

Note 1 to entry: A pressure relief device may be “pressure-activated”, set to activate at a certain pressure. Alternatively, a pressure relief device may be “thermally-activated”, set to activate at a certain temperature. A pressure relief device may also be both “pressure-activated” and “thermally-activated”.

3.15
pressure relief valve
PRV
reseatable pressure relief device (PRD)

3.16
rated capacity
maximum quantity of hydrogen deliverable under specified conditions

3.17
rated charging pressure
RCP
maximum pressure to be applied to the MH assembly for refilling

Note 1 to entry: The RCP is not necessarily equal to the equilibrium plateau pressure of the hydrogen absorbing alloy.

© ISO 2018 – All rights reserved

3.18
reversible metal hydride
metal hydride for which there exists an equilibrium condition where the hydrogen absorbing alloy, hydrogen gas and the metal hydride co-exist

Note 1 to entry: Changes in pressure or temperature will shift the equilibrium favouring the formation or decomposition of the metal hydride with respect to the hydrogen absorbing alloy and hydrogen gas.

3.19
rupture
structural failure of a shell resulting in the sudden release of stored energy

3.20
shell
enclosure of any shape (cylindrical, prismatic, cubic, etc.) designed to contain the hydrogen gas, metal hydride and other internal components of the MH assembly

Note 1 to entry: A shell may be a gas cylinder, a pressure vessel or other type of container.

3.21
stress level at MDP
sum of all the stresses on the shell wall caused by the metal hydride at rated capacity, hydrogen gas at MDP and any other applicable mechanical loadings

3.22
test pressure
required pressure applied during a pressure test for qualification

4 Service conditions

4.1 Pressures

4.1.1 Maximum developed pressure (MDP)

The MDP shall be determined by the manufacturer from the metal hydride's temperature–pressure characteristics. In no case shall the MDP exceed 0,8 times the test pressure of the shell. The MDP shall not exceed 25 MPa.

4.1.2 Rated charging pressure (RCP)

The RCP shall be specified by the manufacturer in order to prevent charging at a pressure that could result in the shell wall stress exceeding the design stress limit.

4.1.3 Stress level at MDP

The stress level at MDP shall be determined by the manufacturer from the hydrogen absorbing alloy's packing and expansion properties, the MDP within the MH assembly, and other applicable mechanical loadings.

4.2 Rated capacity

The manufacturer shall state the rated capacity of the MH assembly by units of mass of hydrogen.

© ISO 2018 – All rights reserved