International Standard

ISO 11326

Ships and marine technology — Test procedures for liquid hydrogen storage tank of hydrogen ships

First edition
2024-11

Reference number
ISO 11326:2024(en)

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Foreword

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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 document 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).

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 3, *Piping and machinery*.

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

Hydrogen offers a reliable way to decarbonise a variety of sectors including the maritime industry, where it has been historically difficult to meaningfully reduce CO_2 emissions despite the commitments by governments and the implementation of regulatory measures.

There are technologies available that enable hydrogen to be produced, stored, transported and used as energy in different ways. Various materials can be produced by hydrogen, including renewable energy, natural gas, coal and oil. Hydrogen can be transported as a gas by pipelines or in liquid form by ship, much like liquid natural gas (LNG), and transformed into electric energy to provide homes or industry with power and also into fuels for cars, trucks, ships and planes.

However, the safe and wide use of hydrogen in marine industry faces several challenges, in particular the absence of applicable international standards on the safety testing of hydrogen systems. All system components should be designed and tested for the safety and reliability in handling liquid hydrogen and thereby the facilitation of decarbonisation with the transition into hydrogen-based clean energy.

In this regard, this document sets up a general test requirement for the liquid hydrogen cargo tank of hydrogen carrier ships. It is expected that useful information can be provided to the marine industry stakeholders including ship owners, classification societies and shipyards. Finally, this document aims to contribute to the growth of relevant industries and benefit all related stakeholders.

Ships and marine technology — Test procedures for liquid hydrogen storage tank of hydrogen ships

1 Scope

This document specifies general inspection and test requirements for liquid hydrogen cargo tanks on board hydrogen carrier ships. In the cases of liquefied hydrogen containment systems, the testing activity depends strictly on the type of storage containment technology identified by the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).[1] This document is applicable to Type C independent metallic double wall type tanks with vacuum insulation having a capacity of not more than 1 000 cubic metres (m^3). It is also applicable to liquid hydrogen cargo tanks which are designed to transport pure para-hydrogen (not less than 95 % content).

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 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 17636-1, *Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film*

ISO 17636-2, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors*

ISO 3452-1, *Non-destructive testing — Penetrant testing — Part 1: General principles*

ISO 9934-1, *Non-destructive testing — Magnetic particle testing — Part 1: General principles*

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

3 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
design pressure
pressure used to determine minimum scantlings of the *liquefied hydrogen* (LH_2) (3.3) storage tank

3.2
maximum allowable working pressure
MAWP
maximum pressure of a storage tank determined by the tank design code

Note 1 to entry: MAWP should not be less than the *design pressure* (3.1).

3.3
liquefied hydrogen
LH_2
hydrogen that has been cooled and condensed into liquid form

Note 1 to entry: LH_2 is a cryogenic liquid having a temperature typically around −253 ° Celsius under normal atmospheric pressure.

3.4
para-hydrogen
one of the two isomers of the hydrogen molecule where the nuclear spins of the two atoms are opposed

3.5
independent tank
self-supporting tank that does not form part of the ship's hull and is not essential to the hull strength

Note 1 to entry: The design basis for type C independent tanks is based on pressure vessel criteria modified to include fracture mechanics and crack propagation criteria.

3.6
cold spot
part of the hull or thermal insulation surface where a localized temperature decrease occurs with respect to the allowable minimum temperature of the hull or its adjacent hull structure, or design capabilities of cargo pressure and temperature control systems

4 Abbreviated terms

For the purpose of this document, the following abbreviated terms apply

IMO	International Maritime Organization
MSC	Maritime Safety Committee
IGC Code	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IACS	International Association of Classification Societies
ASME	American Society of Mechanical Engineers

5 Inspection and tests

5.1 General

Tests shall be conducted on new design Type C independent tanks for liquid hydrogen storage on hydrogen carrier ships. All tanks subjected to type tests shall be made unusable after the tests are completed.

The LH_2 storage tank provider shall preserve the type test results for the intended life of the storage tank design. The test result shall also document the tank specification.

Annex B gives an example of general inspection and test procedures. The liquid hydrogen storage tank may be subjected to inspection and tests specified in Annex B, under mutual agreement between owner and the LH_2 storage tank provider.

Annex E provides an example figure of the design and installation arrangements of a vacuum-insulated LH_2 cargo tank, with various piping and instrumentation normally attached to the tank.

Annex A provides information regarding other potential hazards and safety considerations associated with the storage and containment of liquefied hydrogen.

5.2 Design appraisal

Liquid hydrogen storage tank drawings and material specifications shall be submitted to the owner or classification society for written approval before test implementation. The owner or classification society shall approve of the drawings.

An example of the drawings which can be submitted are listed in Annex C.

5.3 Material inspection

Material property testing of liquid hydrogen storage tanks, which are required for the acceptance of use by the classification society or ship owner where the minimum design temperature is less than −196 °C, shall be carried out with the appropriate medium within the range between the maximum design temperature in service (normally taken as 45 °C) and the temperature lower than the minimum design temperature by at least 5 °C.

The hydrogen embrittlement test shall be carried out and materials shall be selected to ensure the safety of liquid hydrogen cargo tanks. Reference should also be made to the “Guide to Safety of Hydrogen and Hydrogen systems” published by the American Institute of Aeronautics and Astronautics (AIAA),[3] as referenced in IMO Resolution MSC. 420(97).[22]

The hydrogen embrittlement test shall be carried out to provide evidence that the metallic double wall type hydrogen storage tank is not susceptible to hydrogen embrittlement. In hydrogen storage tanks that are subject to frequent evaporated gaseous form, conditions can lead to local fatigue, and the initiation and propagation of fatigue cracks induced by ship motion in the liquid hydrogen cargo tanks. The hydrogen compatibility shall be tested in accordance with ISO 11114-4.

Test results should show that the selected materials for liquid hydrogen storage tanks are suitable for their specific operating conditions and environment, taking into account factors such as design temperature, pressure, working stress and other environmental conditions.

5.4 Welding inspection

All welded joints of the shells and domes to shell of liquid hydrogen storage tanks shall be of the butt weld full penetration type to prevent leakage of hydrogen. For nozzle or other penetration connections, either fillet welds or the full penetration type may be used depending on the results of the tests carried out, after getting approval of the welding procedure. Otherwise, if the nozzle or other penetration is made of forgings with an integral forged ring to match the contour of the dome or shell, the joint shall use full penetration butt welds.

All welded points of the liquid hydrogen storage tank between the inner tank and outer tank shall be subjected to non-destructive test inspection. All butt welds of liquid hydrogen storage tanks shall be subjected to radiographic testing in accordance with ISO 17636-1 and ISO 17636-2. Where welding points of the liquid hydrogen storage tank cannot be radiographed, these welds shall be subjected to penetrant testing in accordance with ISO 3452-1, magnetic particle testing in accordance with ISO 9934-1, and approved ultrasonic testing.

5.5 Hydrostatic test

A hydrostatic test shall be carried out at a pressure measured at the top of tank.

The test pressure shall be at least 1,5 times the design pressure. At no point during the pressure test shall the calculated primary membrane stress exceed 90 % of the yield stress of the material. To ensure that this condition is satisfied where calculations indicate that this stress will exceed 0,75 times the yield strength, the type test shall be monitored using strain gauges or other suitable equipment in pressure vessels, other than simple cylindrical and spherical pressure vessels.

The temperature of the water used for the test shall be at least 30 °C above the nil-ductility transition temperature of the material, as fabricated. The pressure shall be held for 2 h per 25 mm of thickness, but in no case less than 2 h.

Where necessary, a pneumatic test may be carried out in cases where the liquid hydrogen storage tank is produced or supported such that it cannot be safely filled with water. The pneumatic test procedures may be specially considered by the relevant testing authority, and the test pressure for a pneumatic test shall be 1,25 times the maximum allowable working pressure (MAWP). Special considerations shall be given to the stored energy involved with a pneumatic test, and it shall be carried out where adequate facilities and procedures are employed to ensure the safety of inspectors and the public.

Upon completion of the hydrostatic test, the inner tank shall be cleaned and dried in accordance with ISO 23208.

5.6 Tightness test

For the liquid hydrogen cargo tank tightness test, helium or a mixture of 5 % hydrogen and 95 % nitrogen should be used as the test medium instead of air, with dedicated detectors employed since the permeability of hydrogen is high.

The tightness check for the inner vessel can be completed after the hydrostatic test by reducing the pressure to the design pressure with an appropriate tracer gas. The helium leak test can be completed by a sniffer method with appropriate calibration at every 10 m of weld. When the LH_2 tank design includes wear plates or support plates covering the inner vessel weld, then appropriate leak testing to test these welds shall be done before the completion of the inner vessel.

The outer vessel vacuum integrity should be confirmed by injecting helium into the space between the inner and annular outer vessel weld/sealing surfaces and placing a detector appropriately on the vacuum port. The standard leak calibrator shall be connected to the vacuum port to establish the delay time and set the speed of the helium spray on the outer vessel welds. During the operation of this test, the inner vessel can be maintained at design pressure with helium tracer gas and nitrogen mixture to complete the test.

The helium leak testing procedure should be confirmed according to ISO 20485 and ISO 20486, ASME Section VIII Div 2, JIS Z 2331 or other suitable standards. Tests shall confirm that there are no leaks larger than the limit acceptable criteria.

Consideration should be given to using oxygen-free nitrogen with a small molecule tracer gas, such as helium, as the test medium and an electronic leak detector for identifying leaks.

If the above test medium is not practical, test mediums other than helium or a mixture of 5 % hydrogen and 95 % nitrogen can be used to conduct the test, upon mutual agreement between the owner and the LH_2 storage tank provider.

5.7 Insulation and testing

The insulation performance testing should be conducted in accordance with ISO 21014. The test can be confirmed in the fully loaded condition at the proper vacuum level.

5.8 Cold spot test

Cold spot tests aim to verify:

— the results of thermal calculation for the adjacent structures of storage tanks such as fixed supports, saddle, nozzle, gauge points or tank holding space bulkheads;

— the possible failure of vacuum insulation system of storage tank.

A cold spot test failure occurs if icing is detected at the cold spot test area. The loading of LH_2 generally improves the vacuum, thereby enhancing the insulation performance. However, there can be cold spots from support structures between the outer and inner walls of the tank.