INTERNATIONAL STANDARD

**ISO 22734**

First edition
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# Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications

*Générateurs d'hydrogène utilisant le procédé de l'électrolyse de l'eau — Applications industrielles, commerciales et résidentielles*

Reference number
ISO 22734:2019(E)

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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 197, *Hydrogen technologies*.

This first edition cancels and replaces ISO 22734-1:2008 and ISO 22734-2:2011, which have been combined and technically revised. The technical revisions add Alkaline Exchange Membranes to the document scope, update Normative references, clarify pressure terminology definitions, and simplify Risk Management requirements. This document is reorganized into 7 clauses, where all design requirements are now found in Clause 4, and all test methods are now found in Clause 5.

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

In a hydrogen generator electrochemical cell, electricity causes dissociation of water into hydrogen and oxygen molecules. An electric current is passed between two electrodes separated by a conductive electrolyte or “ion transport medium”, producing hydrogen at the negative electrode (cathode) and oxygen at the positive electrode (anode). As water is $H_2O$, twice the volume of hydrogen is produced compared with oxygen.

Hydrogen gas produced using electrolysis technology can be utilized immediately or stored for later use.

The cell(s), and electrical, gas processing, ventilation, cooling, monitoring equipment and controls are contained within an enclosure. Gas compression, feed water conditioning, and auxiliary equipment may also be included.

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# Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications

## 1 Scope

This document defines the construction, safety, and performance requirements of modular or factory-matched hydrogen gas generation appliances, herein referred to as hydrogen generators, using electrochemical reactions to electrolyse water to produce hydrogen.

This document is applicable to hydrogen generators that use the following types of ion transport medium:

— group of aqueous bases;

— group of aqueous acids;

— solid polymeric materials with acidic function group additions, such as acid proton exchange membrane (PEM);

— solid polymeric materials with basic function group additions, such as anion exchange membrane (AEM).

This document is applicable to hydrogen generators intended for industrial and commercial uses, and indoor and outdoor residential use in sheltered areas, such as car-ports, garages, utility rooms and similar areas of a residence.

Hydrogen generators that can also be used to generate electricity, such as reversible fuel cells, are excluded from the scope of this document.

Residential hydrogen generators that also supply oxygen as a product are excluded from the scope of this document.

## 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 1182, *Reaction to fire tests for products — Non-combustibility test*

ISO 3746, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Survey method using an enveloping measurement surface over a reflecting plane*

ISO 3864-2, *Graphical symbols — Safety colours and safety signs — Part 2: Design principles for product safety labels*

ISO 4126-1, *Safety devices for protection against excessive pressure — Part 1: Safety valves*

ISO 4126-2, *Safety devices for protection against excessive pressure — Part 2: Bursting disc safety devices*

ISO 4126-6, *Safety devices for protection against excessive pressure — Part 6: Application, selection and installation of bursting disc safety devices*

ISO 7010, *Graphical symbols — Safety colours and safety signs — Registered safety signs*

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

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ISO 9300, *Measurement of gas flow by means of critical flow Venturi nozzles*

ISO 9951, *Measurement of gas flow in closed conduits — Turbine meters*

ISO 9614-1, *Acoustics — Determination of sound power levels of noise sources using sound intensity — Part 1: Measurement at discrete points*

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 10286, *Gas cylinders — Terminology*

ISO 10790, *Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis flowmeters (mass flow, density and volume flow measurements)*

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 12100, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 12499, *Industrial fans — Mechanical safety of fans — Guarding*

ISO 13709, *Centrifugal pumps for petroleum, petrochemical and natural gas industries*

ISO 13850, *Safety of machinery — Emergency stop function — Principles for design*

ISO 13854, *Safety of machinery — Minimum gaps to avoid crushing of parts of the human body*

ISO 13857, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs*

ISO 14511, *Measurement of fluid flow in closed conduits — Thermal mass flowmeters*

ISO 14847, *Rotary positive displacement pumps — Technical requirements*

ISO 15534-1, *Ergonomic design for the safety of machinery — Part 1: Principles for determining the dimensions required for openings for whole-body access into machinery*

ISO 15534-2, *Ergonomic design for the safety of machinery — Part 2: Principles for determining the dimensions required for access openings*

ISO 15649, *Petroleum and natural gas industries — Piping*

ISO 16111, *Transportable gas storage devices — Hydrogen absorbed in reversible metal hydride*

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

ISO 17398, *Safety colours and safety signs — Classification, performance and durability of safety signs*

ISO 26142, *Hydrogen detection apparatus — Stationary applications*

IEC 31010:2019, *Risk management — Risk assessment techniques*

IEC 60068-2-18:2017, *Environmental testing — Part 2-18: Tests — Test R and guidance: Water*

IEC 60079 (all parts), *Explosive atmospheres*

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IEC 60204-1:2016, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

IEC 60335-1:2010, *Household and similar electrical appliances — Safety — Part 1: General requirements*

IEC 60335-2-41, *Household and similar electrical appliances — Safety — Part 2-41: Particular requirements for pumps*

IEC 60335-2-51, *Household and similar electrical appliances — Safety — Part 2-51: Particular requirements for stationary circulation pumps for heating and service water installations*

IEC 60335-2-80, *Household and similar electrical appliances — Safety — Part 2-80: Particular requirements for fans*

IEC 60364-4-41, *Low voltage electrical installations — Part 4-41: Protection for safety — Protection against electric shock*

IEC 60364-4-43, *Low-voltage electrical installations — Part 4-43: Protection for safety — Protection against overcurrent*

IEC 60445, *Basic and safety principles for man-machine interface, marking and identification — Identification of equipment terminals, conductor terminations and conductors*

IEC 60529, *Degrees of protection provided by enclosures (IP Codes)*

IEC 60534 (all parts), *Industrial-process control valves*

IEC 60695-11-10, *Fire hazard testing — Part 11-10: Test flames — 50 W horizontal and vertical flame test methods*

IEC 60695-11-20, *Fire hazard testing — Part 11-20: Test flames — 500 W Flame test methods*

IEC 60730-1:2013, *Automatic electrical controls for household and similar use — Part 1: General requirements*

IEC 60947-1, *Low-voltage switchgear and controlgear — Part 1: General rules*

IEC 60950-1:2005, *Information technology equipment — Safety — Part 1: General requirements*

IEC 60998-2-2, *Connecting devices for low-voltage circuits for household and similar purposes — Part 2-2: Particular requirements for connecting devices as separate entities with screwless-type clamping units*

IEC 60999-1, *Connecting devices — Electrical copper conductors — Safety requirements for screw-type and screwless-type clamping units — Part 1: General requirements and particular requirements for clamping units for conductors from 0,2 mm2 up to 35 mm2 (included)*

IEC 60999-2, *Connecting devices — Electrical copper conductors — Safety requirements for screw-type and screwless-type clamping units — Part 2: Particular requirements for clamping units for conductors above 35 mm2 up to 300 mm2 (included)*

IEC 61010-1:2010, *Safety requirements for electrical equipment for measurement, control, and laboratory use — Part 1: General requirements*

IEC 61069-7, *Industrial-process measurement and control — Evaluation of system properties for the purpose of system assessment — Part 7: Assessment of system safety*

IEC 61131-1, *Programmable controllers — Part 1: General information*

IEC 61131-2, *Programmable controllers — Part 2: Equipment requirements and tests*

IEC 61508, *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61511-1, *Functional safety: Safety instrumented systems for the process industry sector — Part 1: Framework, definitions, system, hardware and software requirements*

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IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

IEC 61672-2, *Electroacoustics — Sound level meters — Part 2: Pattern evaluation tests*

## 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**
**area classification**
classification of *hazardous areas* (3.2) according to the probability of the existence of an explosive atmosphere, in order to relate the selection of electrical apparatus for use in the area to the degree of *hazard* (3.12)

**3.2**
**hazardous area**
area in which an explosive atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of electrical apparatus

**3.3**
**built-in hydrogen generator appliance**
hydrogen generator intended to be installed in a cabinet, in a prepared recess in a wall, or in a similar location

**3.4**
**commercial use**
use of hydrogen generators by laymen in non-manufacturing business facilities such as stores, hotels, office buildings, educational institutes, filling stations, warehouses, and other non-residential locations

**3.5**
**containment system**
part of the apparatus containing a flammable substance that may constitute a source of release

**3.6**
**dilution**
continuous supply of a *purge gas* (3.27) at such a rate that the concentration of a flammable substance inside an *enclosure* (3.9) is maintained at a value outside the explosive (flammable) limits at any potential ignition source (that is to say, outside the dilution area)

**3.7**
**dilution volume**
location in the vicinity of a source of release where the concentration of flammable substance is not diluted to a level below the lower flammability limit (LFL)

Note 1 to entry: *Dilution* (3.6) of oxygen by inert gas can result in a concentration of flammable gas or vapour above the upper flammability limit (UFL).

Note 2 to entry: Annex B provides information on the flammability limits of hydrogen.

**3.8**
**electrochemical cell**
assembly of electrodes, fluid containment, flow means, and electrical current conduction means that may include product gas separation *membranes* (3.19) and may be arranged as single unipolar cells or in bipolar cell stacks within or without a process containment vessel, for the purpose of producing hydrogen and/or oxygen from water

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**3.9**
**enclosure**
containment and support structure(s) protecting a hydrogen generator from specific environmental and climatic conditions and protecting persons and livestock from incidental contact with the hazardous parts of the hydrogen generator

**3.10**
**enriched oxygen atmosphere**
gas that contains a volume fraction of more than 23,5 % oxygen with the remainder of its components being inert

**3.11**
**factory-matched**
engineered in a factory to correspond with each other and work together, separately packed for storage and transportation, and intended to be assembled together at the point of utilization

[SOURCE: ISO 16110-1:2007, 3.21, modified — The term has been changed from "factory matched unit" to "factory-matched"; the words "system components" have been removed.]

**3.12**
**hazard**
potential source of harm

**3.13**
**hazardous condition**
condition that may adversely affect the safety of the hydrogen generator operation

Note 1 to entry: Examples of hazardous conditions include having an *enriched oxygen atmosphere* (3.10), a hydrogen concentration exceeding the lower flammability limit, an ignition source in a classified area, an overpressure, or an over temperature.

**3.14**
**industrial use**
use of hydrogen generators by qualified and experienced personnel in a controlled manufacturing or processing environment

**3.15**
**ion transport medium**
medium that provides ionic transport within the cell

**3.16**
**maximum allowable working pressure**
**MAWP**
maximum pressure permissible in a vessel or system at the temperature specified for the pressure

Note 1 to entry: The maximum allowable working pressure can also be defined as the design pressure, the maximum allowable operating pressure, the maximum permissible working pressure, or the maximum allowable pressure for the rating of pressure vessels and equipment manufactured in accordance with national pressure vessel codes.

**3.17**
**maximum operating pressure**
**MOP**
maximum pressure that can be expected by the pressure containing components when the hydrogen generator is functioning within its design and control parameters, including anticipated transients

**3.18**
**mechanical ventilation**
replacement of air inside an *enclosure* (3.9) with fresh air accomplished by a mechanical device (such as a fan) to prevent or eliminate hazardous concentrations of hydrogen

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**3.19**
**membrane**
material that provides separation between oxygen and hydrogen product gases while allowing ionic transport within the cell

**3.20**
**natural ventilation**
replacement of air inside an *enclosure* (3.9) with fresh air accomplished exclusively by a natural draft caused, for example, by the effects of wind, temperature gradients or buoyancy effects, to prevent or eliminate hazardous concentrations of hydrogen

**3.21**
**normal condition**
condition in which all means for protection against *hazards* (3.12) are intact

**3.22**
**normal use**
operation, including stand-by, according to the instructions for use or for the obvious intended purpose

Note 1 to entry: In most cases, normal use also implies *normal condition* (3.21), because the instructions for use will warn against using the hydrogen generator when it is not in normal condition.

**3.23**
**pressure relief device**
**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: PRDs are activated by pressure or another parameter, such as temperature, and are either re-closing devices (such as valves) or non-re-closing devices (such as rupture disks and fusible plugs). Common designations for these specific types of PRDs are as follows:

— Pressure safety valve (PSV) — pressure activated valve that opens at a specified set point to protect a system from rupture and re-closes when the pressure falls below the set point.

— Temperature-activated pressure relief device (TPRD) — PRD that opens at a specified temperature to protect a system from rupture and remains open.

**3.24**
**pressure-bearing component**
part subject to a positive internal pressure of 100 kPa or greater

**3.25**
**permanently connected**
electrically connected to a supply by means of a permanent connection, which can be detached only by the use of a *tool* (3.34)

**3.26**
**portable hydrogen generator**
hydrogen generator that is not intended to be permanently fastened in a specific location and can be carried easily by a person

**3.27**
**purge gas**
gas used to maintain protective pressurization or to dilute flammable gas or vapour to a concentration well below the lower flammability limit

**3.28**
**purging**
passage of sufficient volume of a *purge gas* (3.27) through a pressurized *enclosure* (3.9) and its ducts, before the application of voltage to the apparatus, to reduce any ignitable (flammable) gas atmosphere to a concentration well below the lower flammability limit

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**3.29**
**residential use**
use of hydrogen generators by laymen in private households (non-commercial and non-industrial use)

**3.30**
**risk assessment**
overall process of risk identification, risk analysis, risk evaluation, and risk mitigation

**3.31**
**single fault condition**
condition in which one means for protection against *hazards* (3.12) is defective or one fault is present which could cause a hazard

Note 1 to entry: If a single fault condition results unavoidably in another single fault condition, the two failures are considered as one single fault condition.

**3.32**
**standard conditions**
conditions to which the volume or other properties of a gas are referred, and which are represented by a temperature of 273,15 K (0 °C) and an absolute pressure of 100 kPa

**3.33**
**supply cord**
flexible cord, for supply purposes, that is fixed to the hydrogen generator

**3.34**
**tool**
external device, including keys and coins, used to aid a person to perform a mechanical function

# 4 Requirements

## 4.1 Operating conditions

### 4.1.1 Energy consumption

#### 4.1.1.1 Electrical

The manufacturer shall specify, as outlined in IEC 60204-1, the electrical input rating for the hydrogen generator in volt-amperes (VA) or watts (W) and hertz.

#### 4.1.1.2 Other utilities

The manufacturer shall specify any other utilities required.

### 4.1.2 Feed water specifications

The manufacturer shall define the specifications for the feed water to be used in the hydrogen generator.

### 4.1.3 Ambient environment

The manufacturer shall specify the physical environment conditions for which the hydrogen generator is designed. These shall include indoor or outdoor operation, the ambient temperature range, and the barometric and humidity specifications.

### 4.1.4 Purge gas

Where the use of purge gas is required, the manufacturer shall specify the type of purge gas and its specifications.

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#### 4.1.5 Oxygen venting

##### 4.1.5.1 General

The manufacturer shall specify if oxygen is to be vented indoors or outdoors. If oxygen is to be vented indoors, the manufacturer shall specify if oxygen is to be vented directly out of the enclosure or within the enclosure. Oxygen vents shall meet the IP rating of 4.3.9.

##### 4.1.5.2 Oxygen vented outdoors

If oxygen is vented outdoors, it shall be vented out of any enclosure to an outdoor location in a way that will not create a hazardous condition. The installation instructions shall provide full details describing acceptable methods as required by 7.3.1.

##### 4.1.5.3 Oxygen vented within enclosures or indoors

To preclude the formation of a hazardous enriched-oxygen atmosphere within an enclosure, oxygen purposely vented inside the enclosure shall be diluted by a ventilation air stream to a volume fraction of oxygen in air of less than 23,5 % before being exhausted from the enclosure. For electrical equipment that could come in contact with enriched-oxygen mixtures, see 4.4.1.5.

For systems venting oxygen into either the enclosure or indoors, room ventilation guidance to preclude a room oxygen concentration in air above a volume fraction of 23,5 % shall be provided in the installation instructions as required by 7.3.3. A label warning about the presence of oxygen shall be affixed as required by 6.4.

The design of the enclosure ventilation shall dilute the oxygen concentration such that any gas flow exiting the enclosure to the surrounding environment will not create a hazardous condition. Where mechanical ventilation is used to dilute oxygen levels, means of detecting insufficient air ventilation shall be provided and cause the hydrogen generator to shut down.

In residential applications, oxygen shall not be vented indoors directly through tubing or piping in a way that facilitates oxygen product collection (see 4.1.8). The manufacturer shall provide instruction and warnings to exclude oxygen collection per 7.3.1.

Pressure relief devices that vent within enclosures or indoors shall be considered when determining dilution and ventilation requirements.

#### 4.1.6 Hydrogen venting

##### 4.1.6.1 General

Hydrogen shall be vented in a manner that will not create a hazardous condition in accordance with 4.1.6.2 and 4.1.6.3. Hydrogen vents shall meet the IP rating of 4.3.9.

##### 4.1.6.2 Hydrogen vented outdoors

Means shall be provided to connect a hydrogen vent line to the hydrogen generator. When supplied with the hydrogen generator, vent lines should be designed according to ISO/TR 15916, or other similar standards.

NOTE Additional guidance on hydrogen vents can be found in CGA G-5.5 and EIGA Doc 211/17.

##### 4.1.6.3 Hydrogen vented within enclosures or indoors

Hydrogen gas may be vented within enclosures if it is diluted to a volume fraction of hydrogen in air of less than 1 % before exiting the enclosure.

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Room ventilation guidance to preclude a room hydrogen concentration in air above a volume fraction of 1 % shall be provided in the installation instructions as required by 7.3.3 and a label warning about the presence of hydrogen shall be affixed as required by 6.4.

### 4.1.7 Delivery of hydrogen

The manufacturer shall specify the hydrogen production rate, the hydrogen output pressure range, hydrogen temperature range, and the hydrogen quality under standard conditions.

NOTE ISO 14687 includes specifications for hydrogen quality for use in representative applications.

### 4.1.8 Delivery of oxygen

Industrial and commercial equipment may deliver oxygen. Where applicable, the manufacturer shall specify the oxygen production rate, the oxygen output pressure range, hydrogen temperature range, and the quality of the oxygen produced by the hydrogen generator at standard conditions.

Residential hydrogen generators shall not deliver oxygen.

## 4.2 Risk management

The manufacturer shall perform a risk assessment on the hydrogen generator design using one or more structured techniques per IEC 31010:2019, Annex B and/or the requirements of ISO 12100.

It is recommended that the risk assessment be quantitative or semi-quantitative. As a minimum, mitigation measures shall address single faults that present a hazard or risk. (refer to 4.5) The risk assessment shall demonstrate that the mitigation measures are appropriate to achieve the desired reduction of the probability and/or consequences of each risk scenario. The risk assessment shall demonstrate that all mitigation measures employed are appropriate to achieve the desired level of risk for the hydrogen generator.

NOTE 1 It is possible that individual mitigation measures interact to affect the probability and/or impact of multiple aspects of the analysis. For example, use of enclosures can reduce the probability of ignition, but can also potentially increase the consequence of deflagrations.

NOTE 2 It is possible that regulation prescribes the risk assessment methods and the degree of detail of the risk assessment analysis. For example, per national regulations, it is possible the operator must carry out further risk assessment, or layers of protection analysis (LOPA) for the hydrogen generator.

NOTE 3 It is possible that the owner/operator performs a final risk assessment of the hydrogen generator based on the specific location of the hydrogen generator.

Hydrogen generators shall be designed and manufactured such that where a release of flammable gas occurs during normal operation, the formation of a flammable atmosphere is prevented, minimized, detected, and/or controlled. Hydrogen generators shall be manufactured such that unintentional hydrogen releases are minimized (see IEC 60079 and 4.4.1).

## 4.3 Mechanical equipment

### 4.3.1 General requirements

All hydrogen generator parts and all substances used in the hydrogen generator shall be

— suitable for the range of temperatures and pressures to which the hydrogen generator is subjected during expected usage,

— resistant to the reactions, processes, and other conditions to which the hydrogen generator is exposed during expected usage,

— suitable for their intended use, and

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— used within their rating and in accordance with the manufacturer's instructions.

The hydrogen generator as installed per manufacturer's instructions shall be designed to withstand expected shock and vibration loads during use.

Portable equipment or equipment not installed by the manufacturer shall be designed to withstand expected shock and vibration loads, as well as the specified ambient temperature range during transportation to the installation site.

Means shall be provided to facilitate safe handling of the hydrogen generator during lifting, moving, and positioning operations. The hydrogen generator shall be designed to remain stable when subjected to normal operational forces imposed by users or by the environment during the installation or use.

The design of the hydrogen generator shall take into account the requirements specified in ISO 12100.

All parts of hydrogen generators which are set or adjusted at the stage of manufacture and which are not intended to be manipulated by the user or the installer shall be appropriately protected.

Manual controls shall be clearly marked and designed to prevent inadvertent adjustment or activation.

All parts shall be adequately protected from climatic and environmental conditions anticipated by the operating conditions such as seismic-zone rating, snow, rain, and wind loading.

All parts shall be of such construction as to be secure against displacement, distortion, warping, or other damage that could affect their functionality.

All parts that may be contacted during normal usage, adjustment or servicing shall be free from sharp projections or edges.

All parts that require regular or routine maintenance or servicing, such as inspection, lubrication, cleaning, replacement, or similar function, shall be accessible and protected from unauthorized access. All parts that are serviced by the residential user shall be accessible without exposing the user to any hazards.

Moving parts and parts containing liquid shall be designed and mounted in such a way that in all foreseeable modes of operation, the ejection of parts and liquid, and the hazardous injection of liquid are prevented.

Where hazardous fluids are contained in the piping, precautions shall be taken in the design of the sampling and take-off points to ensure safety in accordance with the manufacturer's risk assessment. Where hazardous fluids are contained in the piping, the sampling and take-off points shall be clearly identified with cautionary symbols and protected from unauthorized access.

The manufacturer's risk assessment shall address potential modes of failure and drift values for each safety-critical part shall be conducted (see 4.2).

The hydrogen generator or parts of it where persons are intended to move about or stand shall be designed and constructed to prevent persons slipping, tripping, or falling on or off these parts.

Hydrogen generators shall meet the applicable mechanical strength requirements of IEC 60204-1 or IEC 61010-1.

Portable hydrogen generators shall satisfy the stability requirements given in IEC 61010-1 or IEC 60335-1.

### 4.3.2 General materials requirements

Materials employed in the hydrogen generator shall be suitable for their purpose.

All internal and external parts of the hydrogen generator that are directly exposed to moisture, ion transport medium, process gas streams of hydrogen or oxygen, as well as parts used to seal or

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interconnect the same, shall have the following material attributes during the manufacturer's rated service life:

a) retain mechanical stability with respect to strength (fatigue properties, endurance limit, creep strength) when exposed to the full range of operating conditions specified in Clause 4;

b) resist the chemical and physical action of the fluids that they contain and resist environmental degradation;

c) be compatible with any other material used in conjunction so as to not have a synergistic and undesirable effect.

When selecting materials and manufacturing methods, due consideration shall be given to the following:

— hydrogen embrittlement and hydrogen-assisted corrosion;

— oxygen compatibility;

— corrosion and wear resistance;

— electrical conductivity;

— electrical insulation;

— impact strength;

— aging resistance;

— temperature effects;

— galvanic corrosion;

— erosion, abrasion, corrosion or other chemical attack;

— resistance to ultraviolet (UV) radiation.

NOTE 1 Annex A and ISO/TR 15916 provide useful information on hydrogen embrittlement and hydrogen assisted corrosion.

The auto-ignition temperature of any materials that may contact oxygen during operation shall have ignition temperatures in pure oxygen atmosphere at the maximum operating pressure at least 50 °C greater than the maximum temperature to which they are exposed during operation.

Process piping and vessels carrying oxygen shall be cleaned with due consideration of the oxygen service conditions.

NOTE 2 IEC/TR 60877 and similar standard practices specify procedures for cleaning, assembling, inspecting, handling, and installing industrial equipment and parts used in oxygen service. Factors that can influence oxygen and contaminant ignition reactions include materials, high pressure, high temperature, and flow entrained particle impact energy.

### 4.3.3 Enclosure requirements

#### 4.3.3.1 Minimum strength

The supporting structure and the enclosure shall have the strength, rigidity, durability, resistance to corrosion and the other physical properties to support and protect all the components and piping, and withstand mechanical stress and shock expected during transport, installation and operation of the hydrogen generator. Electrical enclosures shall meet the requirements of IEC 60204-1.

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#### 4.3.3.2 Environmental tolerance of enclosures

The hydrogen generator enclosure shall be designed and tested for the intended installation environment as classified in IEC 60529.

Where a hazard from ingress of solid foreign objects and/or ingress of water exists, as a minimum the hydrogen generator enclosure shall meet the environmental tolerance requirements of 4.3.9.

No additional enclosure is required where components and equipment are individually protected to levels required by 4.3.9.

#### 4.3.3.3 Fire resistance

The protection against the spread of fire shall comply with the requirements given in IEC 61010-1:2010, Clause 9.

The hydrogen generator enclosure, together with the thermal insulating materials and their internal bonding or adhesive attachment means, as well as the adjacent walls specified in 4.4.1.8, shall have a flammability classification as follows:

a) materials other than plastics shall have a flammability classification that will not support accelerating combustion after electrical and fuel gas sources are removed when tested in accordance with ISO 1182;

b) plastic enclosures that cover sources of combustion or enclose live parts shall comply with the requirements of 5V rated materials when tested in accordance with IEC 60695-11-20. Other plastic enclosures shall comply with the requirements of HB and V rated materials when tested in accordance with IEC 60695-11-10;

c) composite materials shall meet the requirements of either a) or b) above.

#### 4.3.3.4 Thermal insulating materials

Thermal insulating materials on the enclosure of the hydrogen generator shall be mechanically or adhesively retained in place and shall be protected against displacement or damage from anticipated loads and service operation.

Thermal insulating materials and their internal bonding or adhesive attachment means shall withstand all air velocities and temperatures to which they may be subjected in normal operation.

#### 4.3.3.5 Access panels

Access panels shall be designed according to the requirements given in ISO 15534-1 and ISO 15534-2.

Access panels, covers, or insulation that need to be removed for normal servicing and accessibility shall be designed such that repeated removal and replacement will not cause damage or impair the insulating value.

An access panel, cover, or door shall have a means for retaining it in place or opening it and shall require the use of a tool, key, or similar mechanical means to open. If located within classified areas, an access panel, cover, or door shall be designed to not generate sparking in accordance with IEC 60079-0 when being opened or closed.

Removable access panels, covers, and doors shall be designed to prevent them from being attached in an improper position or being interchanged in a manner that may interfere with proper operation of the hydrogen generator.

An enclosure large enough to admit service personnel to the enclosure shall have an access door that opens outwards and, if equipped with a latch, it shall be equipped on the inside with fast-release hardware that can be operated without a key or special tool.


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#### 4.3.3.6 Ventilation openings

Ventilation openings shall be designed so that they shall minimize the likelihood of obstruction during normal operation in accordance with the expected application.

Where personnel can fully enter the enclosure, ventilation openings shall have a minimum total area of 0,003 $m^2$ per $m^3$ of enclosure volume.

#### 4.3.3.7 Containment of hazardous liquid leakage

Where a hydrogen generator contains hazardous liquids that can be harmful to personnel or the environment, the hydrogen generator enclosure shall be designed to safely contain anticipated leaks as follows:

a) the containment means shall have a capacity of 110 % of the maximum volume of the anticipated leak;

b) a leak detection system shall be provided and shall cause the hydrogen generator to alarm and, where possible, change the operating parameters to prevent loss of containment.

#### 4.3.3.8 Prevention of electrostatic accumulation

A terminal connected to earth shall be installed on the enclosure to prevent electrostatic accumulation.

### 4.3.4 Pressure-bearing components

#### 4.3.4.1 General requirements

All pressure-bearing components shall be rated equal to or greater than the pressurized system MAWP defined by the hydrogen generator manufacturer. PRD or equivalent pressure safety systems (see 4.3.4.7) shall protect pressurized components against over-pressure. The pressure setting point for PRD or pressure safety systems shall not exceed the system MAWP and shall be above the system MOP.

Manufacturers shall consider component design margins as well as all credible system operating and upset conditions to determine MAWP, MOP, and over-pressure protection setting points, and to avoid unnecessary activations of PRD or pressure safety systems.

Special consideration shall be given to the following aspects of pressure-bearing components:

a) support, constraint, anchoring, alignment, and pre-tension techniques to mitigate excessive stresses and strains being produced on flanges, connections, bellows, or hoses;

b) effects of sudden movement, high-pressure jets, water hammer, pressure-relieving-device actuations;

c) means for drainage and cleaning of condensation during start-up and/or use occurring inside pressure-bearing components for fluids which could cause damage from water hammer, vacuum collapse, corrosion, and uncontrolled chemical reactions;

d) precautions in design and marking where explosive, flammable, or toxic fluids might be contained.

#### 4.3.4.2 Process vessels

Process vessels for fluids that may exceed 100 kPa in normal operation shall comply with one of the recognized standards conforming to ISO 16528-1 unless the size (diameter or volume) is less than the minimum of the scope of the referenced standards as applicable.

#### 4.3.4.3 Built-in storage of hydrogen and other gases

If there is a need to store hydrogen or any pressurized gases other than oxygen, such as purge gas, calibration gas, etc., inside the hydrogen generator, those gases shall be stored in any of the following

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types of containers that are compatible with the particular gas being stored and the environmental conditions the hydrogen generator is designed for:

a) aluminium cylinders meeting the requirements of ISO 7866;

b) steel cylinders meeting the requirements of ISO 9809-1;

c) hoop wrapped composite cylinders meeting the requirements of ISO 11119-1;

d) fully wrapped fibre reinforced composite gas cylinders with load-sharing metal liners meeting the requirements of ISO 11119-2;

e) fully wrapped fibre reinforced composite gas cylinders with non-load-sharing metallic liners or non-metallic liners meeting the requirements of ISO 11119-3;

f) metal hydride cylinders meeting the requirements of ISO 16111;

g) cylinders and vessels of appropriate construction meeting the requirements of ISO 16528-1.

For containers designed for a) to f), the maximum allowable pressure as defined in ISO 16528-1 shall be the working pressure as defined in ISO 10286.

#### 4.3.4.4 Electrochemical cell stacks

Cell stacks shall be designed to withstand the applicable cell-stack pressure tests of 5.2.5.4 without rupture and permanent deformation.

Cell stacks shall have no rupture, fracture, permanent deformation, or other physical damage when they are subject to the pressure test in 5.2.5.4.2.

If, during normal or abnormal operation, a pressure difference between the oxygen and hydrogen sides of the cell stacks can occur, the maximum allowable differential pressure shall be specified by the manufacturer. The risk assessment required in 4.2 and 4.5 shall determine the need to monitor the pressure differential between the oxygen and hydrogen sides and the conditions that will cause the hydrogen generator to shut down.

NOTE It is possible that national authorities allow safety to be established by calculation, for example according to the Pressure Equipment Directive.

Cell stacks shall have enough tolerance for the differential pressure between oxygen and hydrogen sides which is specified by the manufacturer. The verification test is provided in 5.2.5.4.3.

Cell stacks shall have no leakage according to the leakage tests provided in 5.2.6.

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#### 4.3.4.5 Piping, fittings and joints

Process piping and joints shall conform to the applicable piping standard of ISO 15649 with the following exception:

Polymeric or elastomeric piping, tubing, and joints shall be allowed for flammable fluid service.

The internal surfaces of piping shall be thoroughly cleaned to remove loose particles greater than 10 µm, and the ends of piping shall be carefully finished to remove obstructions and burrs.

To remove oil, the pipe, fittings, and joints in oxygen service shall be cleaned per standard practice.

NOTE IEC/TR 60877 and similar standard practices specify procedures for cleaning, assembling, inspecting, handling, and installing industrial equipment and parts used in oxygen service.

Threaded portions of piping and associated component parts that connect externally to the hydrogen generator shall have threads conforming to ISO 15649.

Polymeric or elastomeric piping, tubing, and joints shall be suitable for the combined maximum operating temperature, pressure, and chemical and material exposure anticipated in service and during maintenance. They shall be made of a material with a low permeation rate and the enclosure shall have adequate ventilation if employed for flammable fluid service. Adequate mechanical strength shall be demonstrated through the pressure tests of 5.2.5.

Polymeric or elastomeric piping, tubing, and joints shall be protected from mechanical damage within the hydrogen generator. Shielding may be used, as appropriate, to protect components against failure of rotating equipment or other mechanical devices housed within the hydrogen generator enclosure. Any compartment enclosing plastic or elastomeric components used to convey flammable fluids shall be protected against the possibility of overheating.

Piping systems conveying dry hydrogen or oxygen shall be constructed of tubing with sufficient conductivity to prevent static build-up. Alternatively, means to collect and drain accumulated static charge to ground from non-conductive dry hydrogen or oxygen pipe or tube shall be provided. Alternatively, gas flow velocities shall be limited to values below which electrostatic charges accumulate.

NOTE Non-conductive piping carrying dry oxygen or hydrogen can accumulate electrostatic charge in the oxygen or hydrogen or on the piping. Discharges from the fuel or from the surface of the tubing when encountering a conductive surface such as a coupling at a different electrical potential can be sufficient to ignite a flammable mixture in the piping or in the fuel compartment.

#### 4.3.4.6 Compressors

If used, compressors shall be suitable for hydrogen or oxygen use and for the pressures and temperatures to which they may be subjected under normal operating conditions.

Compressors shall be provided with the following:

a) pressure relief devices that limit each pressure stage to the maximum operating pressure for the compression cylinder and piping associated with that stage of compression;

b) an automatic shutdown control for high discharge pressure and temperature and low suction pressure;

c) an unloading device that captures blow-down gas for re-use, and/or safe venting where required, to re-start the compressor after shutdown;

d) when necessary, vibration isolation from the inlet and/or discharge pipe to the compressor suction line.

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NOTE Guidance on hydrogen compressors suitable for hydrogen fuelling stations is available in ISO 19880-3.

#### 4.3.4.7 Pressure relief devices or pressure safety systems

All pressurized systems and equipment shall be protected from overpressure by means of one or more PRD or pressure safety systems.

PRDs shall be directly connected to equipment that is the potential source of the overpressure, with no interconnected isolation devices. No automatic or manual valves that can isolate the pressure protection from the components being protected shall be located between the PRD(s) and components being protected.

Hydrogen and oxygen pressure relief devices shall vent outside of the enclosure.

Relieved oxygen shall be addressed as required in 4.1.5. Relieved hydrogen shall be addressed as required in 4.1.6. If hydrogen is vented indoors, the ventilation requirements specified in 4.4.1.4 shall consider the maximum hydrogen released from the PRDs. Installation instructions shall be provided to ensure that relieved gases that are vented outdoors are vented to a safe area.

Pressure safety valves shall meet the requirements of ISO 4126-1 or the standards referenced in ISO 16528-1. Rupture disks shall meet the requirements of ISO 4126-2 and ISO 4126-6 or the standards referenced in ISO 16528-1.

NOTE Examples of pressure relief devices are self-destructive types, such as rupture disks and diaphragms, water column seals, or re-sealable types, such as spring-loaded pressure safety valves (PSVs).

#### 4.3.4.8 Pressure regulators

Pressure regulators shall be suitable for the fluids, pressures, and temperatures that will be encountered.

Pressure regulators shall be of the non-venting type. Alternately, means shall be provided to ensure the pressure regulators vent to a safe location, in accordance with manufacturer's installation instructions (see 7.3).

Pressure regulator actuators controlled by a pneumatic power source shall not have a diaphragm that is facing hydrogen in the opposite side and could leak air into hydrogen.

#### 4.3.4.9 Shut-off valves

Shut-off valves shall be provided for all equipment and systems where containment or blockage of the process fluid flow is necessary during shutdown, testing, maintenance, or emergency conditions.

Shut-off valves shall be rated for the pressures and temperatures encountered and shall be suitable for the fluid media.

Actuators mounted on shut-off valves shall be temperature rated to withstand heat transferred from the valve body.

Automatically operated valves shall conform to the applicable parts of IEC 60534.

Automatically operated shut-off valves shall be of a type that will go to a fail-safe position.

### 4.3.5 Fans and ventilators

Fans and ventilators shall conform to IEC 60335-2-80 or ISO 12499 with the electrical requirements evaluated as in IEC 60204-1. Fans and ventilators shall be of a type suitable for the application.

### 4.3.6 Pumps

Pumps shall conform to ISO 13709, ISO 14847, IEC 60335-2-51, or IEC 60335-2-41, as applicable.

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When used in hazardous locations, if pumps are equipped with a connection band (belt drive) between the motor and pump, it shall be made of antistatic material.

#### 4.3.7 Heat transfer system

Any means of heat transfer, commensurate with the properties of the affected fluids or gases, may be used.

#### 4.3.8 Connection to potable water

The quality and supply characteristics of the water to be used in the hydrogen generator shall be specified by the manufacturer.

If potable water is to be used as the feed-water, the hydrogen generator shall be provided with means to prevent any back-feeding into the potable water supply.

In addition, means shall be provided to prevent any coolant from the heat transfer system from back-feeding into the potable water supply.

#### 4.3.9 Environmental tolerance

The hydrogen generator shall be suitable for the intended installation environment as classified in IEC 60529.

Where a hazard from ingress of solid foreign objects and/or ingress of water exists, as a minimum the hydrogen generator shall:

a) meet the IP22 rating as defined in IEC 60529 for indoor, industrial use

b) meet the IP34 rating as defined in IEC 60529 for indoor, residential use

c) meet the IP44 rating as defined in IEC 60529 for outdoor use

Where a hazard from ingress of solid foreign objects and/or ingress of water exists at hydrogen and oxygen vents, these shall meet the IP22 rating as defined in IEC 60529.

#### 4.3.10 Equipment temperature limits and resistance to heat

Equipment temperature limits and resistance to heat shall comply with the requirements given in IEC 61010-1:2010, Clause 10.

#### 4.3.11 Spillage, overflow, and drain

Hydrogen generators subject to liquid spillage or overflow in normal use, or a failed liquid drain line, shall be constructed so that such spillage, overflow, or drain failure does not introduce electrical hazards.

Hydrogen generators subjected to spillage or overflow of liquid in normal use shall comply with the requirements of IEC 61010-1:2010, 11.3 and 11.4.

Hydrogen generators having liquid disposal system(s) shall, under conditions of a blocked liquid drain line(s), continue to operate within compliance of manufacturer's specifications or stop operation.

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## 4.4 Electrical equipment, wiring and ventilation

### 4.4.1 Fire and explosion hazard protection requirements

#### 4.4.1.1 General requirements

Hydrogen generators shall be manufactured such that unintentional hydrogen releases during normal operation are precluded. Conformity shall be determined by the applicable tests of 5.2.6 or 5.3.5.

NOTE In operation, the potential volume of unintentional hydrogen release of a hydrogen generator without built-in hydrogen storage is limited by the rate of hydrogen production.

#### 4.4.1.2 Area classification for hydrogen generators

The hydrogen generator enclosure shall be classified according to IEC 60079-10-1. Where appropriate, instructions shall be provided to define the classification and extent of classified areas surrounding the hydrogen generator as in IEC 60079-10-1 (see 7.3).

#### 4.4.1.3 Protection requirements for equipment within classified areas

Equipment within classified areas shall comply with the requirements of IEC 60079-0 and the appropriate parts of IEC 60079 for the type(s) of protection used or IEC/IEEE 60079-30-1.

When equipment is intended for operation under conditions not covered in the scope of the appropriate parts of IEC 60079 or in the scope of IEC/IEEE 60079-30-1 (e.g. operation in an enriched-oxygen atmosphere), additional testing related specifically to the intended conditions of use shall be performed.

NOTE This is particularly important when the types of protection flameproof enclosures “d” (IEC 60079-1) and intrinsic safety “i” (IEC 60079-11) are applied.

#### 4.4.1.4 Protection methods to prevent the accumulation of ignitable mixtures

Protection may be provided by passive or active means to ensure that gas mixtures remain below a volume fraction of 1 % hydrogen in air within the enclosure, except in dilution volumes. Computational fluid dynamics analysis, tracer gas, or similar methods such as those given in IEC 60079-10-1, may be used to determine the 1 % volume fraction of hydrogen in air dilution boundary and ventilation requirements.

NOTE Refer to Annex B.

Passive methods include, but are not limited to:

a) pipe orifices and similar methods of flow restriction to restrict the maximum release rate to a predictable value,

b) use of joints that are permanently secured and constructed so that they limit the maximum release rate to a predictable value, and

c) natural ventilation.

Active methods include, but are not limited to:

d) comparison of hydrogen gas flow or pressure measurements relative to control settings to initiate protective measures such as de-energization of non-classified electrical equipment and initiation of ventilation when an out-of-specification condition is detected,

e) constant ventilation sufficient to maintain an average hydrogen gas concentration within the enclosure, except in dilution volumes, below the maximum volume fraction of 1 % hydrogen based on the maximum anticipated hydrogen gas leak rate into the enclosure as determined by the manufacturer,


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f) a hydrogen gas detection system complying with the requirements of 4.4.1.9 that initiates ventilation at an appropriate volume fraction less than 1 % hydrogen.

When ventilation is used as an active protection means, the required minimum ventilation rate shall maintain a volume fraction of hydrogen not exceeding 1 %, based on the maximum anticipated hydrogen gas leak rate into the enclosure as determined by the manufacturer.

Sudden and catastrophic failure of vessels or piping systems typically doesn't need to be considered a leak scenario in the gas leak rate analysis where protection against such failures has already been contemplated in the vessel and piping design, and when instructions are provided to ensure that soundness is verified periodically.

When such active and/or passive protection measures are used, the area classification determined as in 4.4.1.2 and the protection requirements for electrical equipment as in 4.4.1.3 may be adjusted accordingly. Detection of hydrogen/air mixtures exceeding the maximum volume fraction of 1 % hydrogen shall cause hydrogen generation to stop and de-energization of non-classified electrical equipment. Failure of ventilation shall cause a shutdown of gas generation. Equipment that remains energized in the event of failure, such as the hydrogen gas detection system and ventilation equipment shall be suitable for use in hazardous areas as in 4.4.1.3.

#### 4.4.1.5 Additional protection measures where oxygen is purposely vented inside the hydrogen generator enclosure

Electrical equipment that could come in contact with enriched-oxygen mixtures shall be evaluated for their suitability under the possible conditions (see also 4.4.1.3 and 4.4.2.1). When applicable, oxygen dilution shall be provided as per 4.1.5.3.

#### 4.4.1.6 Ventilation

Whenever ventilation is used as in 4.4.1.4 or 4.4.1.5, the manufacturer shall specify the minimum required ventilation rate from the ventilation system.

Failure of ventilation shall cause a shutdown of gas generation.

#### 4.4.1.7 Start-up purge

Hydrogen generator enclosures that rely on ventilation for protection against accumulation of ignitable mixtures as in 4.4.1.4 shall be purged with sufficient air changes at the maximum ventilation rate required for dilution prior to the energization of any devices that are not suitable for the area classification.

All equipment, which shall be energized prior to purging or in order to accomplish purging, shall be suitable for the area classification. Purging doesn't need to be performed at start-up if it can be demonstrated by use of natural ventilation as in 4.4.1.4 that the atmosphere within the enclosure and associated ducts is non-hazardous prior to energization of non-classified electrical equipment.

#### 4.4.1.8 Ventilation of adjacent compartments

Where ventilated electrical or mechanical compartments are adjacent to the hydrogen gas generation compartment, these compartments shall be at a positive pressure relative to the hydrogen gas generation compartment and meet the fire resistance requirements of 4.3.3.3, unless equipment within the adjacent compartment is suitable for the area classification.

#### 4.4.1.9 Hydrogen gas detection system

Where hydrogen gas detectors are required for safety according to the manufacturer's risk assessment, (see 4.2), these shall comply with IEC 60079-29-1 and/or ISO 26142, and be used in accordance with 4.5.1.

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The reliability of a hydrogen gas detection system used for safety-control purposes shall be evaluated as required by 4.5.10.

The electrolyser manufacturer shall ensure that the selection, installation, use, and maintenance of hydrogen gas detectors are in accordance with IEC 60079-29-2.

The hydrogen gas detector(s) shall be installed in optimum location(s) to provide the earliest detection of hydrogen gas, such that their protective function can be proven.

#### 4.4.1.10 Ventilation system testing

The ventilation design and actual flow rates shall be verified by the qualification tests in 5.2.15.

### 4.4.2 Electrical equipment

#### 4.4.2.1 General requirements

Electrical safety shall ensure protection against electrical shock, fire, and burns during operation and routine maintenance activities.

The hydrogen generator shall be designed and constructed in accordance with the relevant requirements of IEC 60204-1 or IEC 61010-1, as appropriate.

Electrical clearance (through air) and creepage distances (over surfaces), as well as solid insulation thickness for electrical circuits, shall be in accordance with IEC 60730-1:2013, Clause 20.

Wiring methods shall comply with the requirements of IEC 60204-1.

Electrical installation and service connection leads or terminals of an individual component shall be identified by number(s), letter(s), symbol(s), or a combination thereof, except when the component

a) incorporates means which physically prevent incorrect wiring, or

b) incorporates only two leads or terminals, the interchange of which does not change the operation of the component.

Wire for power circuits shall be colour coded to allow for consistent identification. Conductors shall be identified as in IEC 60445.

Equipment terminals shall be identified as in IEC 60445.

Electrical components and devices shall be

— suitable for their intended use, and

— installed and used within their ratings and as in the manufacturer's instructions.

#### 4.4.2.2 Grounding and bonding

Equipment shall be bonded and grounded as required by IEC 60204-1 with the following exception:

Parts that shall be isolated from ground to ensure safe and reliable operation of the process by limiting stray currents, such as electrolytic cell metal casings and parts, other electrolyte-carrying vessels and cell ancillary systems, such as feed water and cooling systems, shall be protected as required under IEC 60204-1 to prevent electric shock.

##### 4.4.2.2.1 Touch current and protective conductor current

The touch current and protective conductor current shall comply with the requirements given in IEC 61010-1 or IEC 60950-1:2005, 5.1.1.

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#### 4.4.2.3 Overcurrent protection

Overload and overcurrent protection shall be provided to each electrical device, equipment, and apparatus by means of circuit breakers, overload relays, and/or fuses in accordance with IEC 60364-4-43 or equivalent.

NOTE Guidance is available in IEC/TR 60269-5.

Overcurrent protection shall not be susceptible to nuisance under normal start-up and operating conditions.

#### 4.4.2.4 Electric heaters

Electric heaters shall conform to IEC 60204-1 or the applicable parts of IEC 60335 as appropriate. Suitable insulation material shall be used between the heater coil and its sheath. Airtight bonding shall be provided at both ends of the heater sheath. Insulation resistance between the heater coil and its sheath at the time of shipment shall meet the manufacturer's acceptance value. After the initial start-up, the insulation resistance shall be suitably controlled so as to keep the value greater than the manufacturer's recommendation.

#### 4.4.2.5 Cord anchorage and conductor pull-out

Where applicable, mains supply cord anchorage pull force and torque shall comply with the requirements given in IEC 61010-1:2010, 6.10.2. Conductor connecting devices shall comply with the requirements for pull-out given in IEC 60947-1, IEC 60998-2-2, IEC 60999-1, or IEC 60999-2 as applicable.

#### 4.4.2.6 Terminals for external conductors

The terminals for external conductors shall comply with the requirements given in IEC 61010-1:2010, 6.6.2.

## 4.5 Control systems

### 4.5.1 General

The hydrogen generator shall be equipped with a control system that provides required safe and reliable hydrogen generator performance and limits hazardous conditions from occurring.

With the risk assessment per 4.2 the manufacturer shall identify and analyse failures and faults that can degrade system performance and/or safety. This safety analysis shall provide the basis to set the protection parameters required for the functionality of the safety circuit described in 4.5.2. The response time and accuracy of the instruments used for the detection and the actuation of a control shall be accounted for in the safety analysis.

Where applicable, the following faults and conditions shall be considered:

— a cell-stack voltage under/over the maximum/minimum voltage specified by the manufacturer;

— a cell-stack unbalanced voltage as specified by the manufacturer;

— a cell-stack temperature higher than the maximum temperature specified by the manufacturer;

— a cell-stack current over the maximum current specified by the manufacturer;

— a cell differential pressure higher than the maximum differential pressure specified by the manufacturer;

— a cell differential pressure lower than the minimum differential pressure specified by the manufacturer;

— an electrolyte level higher than the maximum level specified by the manufacturer;

— an electrolyte level lower than the minimum level specified by the manufacturer;

— an electrolyte flow rate lower than the lowest flow rate specified by the manufacturer;

— a volume fraction of hydrogen in air that exceeds the limits defined in 4.4.1.4 or 4.5.1;

— a volume fraction of hydrogen in oxygen that exceeds the limits defined in 4.5.1;

— a volume fraction of oxygen in hydrogen that exceeds the limits defined in 4.5.1;

— a pressure that is not compliant with the operating pressure limits specified by the manufacturer;

— an oxygen pressure higher than the maximum pressure specified by the manufacturer;

— a hydrogen compressor inlet pressure lower than the atmospheric pressure;

— loss of protective ventilation per 4.4.1;

— an ambient or process temperature higher than the maximum temperature specified by the manufacturer;

— an ambient or process temperature lower than the minimum temperature specified by the manufacturer;

— a hazardous liquid leak;

— feed-water purity below the minimum level specified by the manufacturer;

— operation of pressure relief devices;

— limit switch failure;

— shutoff valve failure detected by the limit switch on the valve;

— emergency-stop.

The hydrogen generator shall be designed such that the single failure of a safety-control circuit component does not cascade into a hazardous situation. As indicated in IEC 60204-1, means to prevent cascade failure include but are not limited to:

a) protective devices in the machine (e.g. interlocking guards, trip devices);

b) protective interlocking of the electrical circuit;

c) use of proven techniques and components;

d) provision of partial or complete redundancy or diversity;

e) provision for functional tests.

The control system shall incorporate safety devices and, where appropriate, monitoring devices such as indicators and/or alarms which enable and provide information for appropriate action to be taken, either automatically or manually, to keep the hydrogen generator operating within allowable limits.

The manufacturer's risk assessment shall determine if hydrogen in air, hydrogen in oxygen, or oxygen in hydrogen combustible gas mixture hazards can exist, require detection, and require emergency stop as per 4.5.6. Such emergency stop shall be initiated when the maximum volume fraction of 2 % hydrogen in air, 2 % hydrogen in oxygen, or 3 % oxygen in hydrogen, is exceeded. Gas mixture detection control response time and accuracy shall be accounted for in the risk assessment.

Each operational mode of the hydrogen generator shall be indicated.


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Where the application provides hydrogen to PEM fuel cell applications, the oxygen limit may need to be much lower, for instance the thresholds defined in ISO 14687. However, this may not need to be an emergency stop, and a controlled stop as per 4.5.7 may be appropriate. Similarly, where hydrogen quality for safety reasons is also analysed continuously, for example water, this may also require the electrolyser to be shut down in accordance with either 4.5.7 or 4.5.6.

NOTE Guidance on quality control can be found in ISO 19880-8.

### 4.5.2 Safety control circuit

A risk assessment per 4.2 pertaining to potential modes of failure and drift values for each safety-critical component of the hydrogen generator shall be conducted by the manufacturer, where the manufacturer's risk assessment requires a response to abnormal states (faults).

All the electrical components that have been identified as critical functional components based on the results of the risk assessment shall be provided with a safety-control circuit. The design of the safety-control circuits shall be in accordance with IEC 61069-7 and IEC 61511-1.

The design of a safety-control circuit shall be such that failure of critical functional components will cause the hydrogen generator to go to a safe condition, as follows:

a) the safety control shall act to safely interrupt the intended function under its control, or

b) the control system may allow to complete an operational cycle if safe to do so, but shall fail to start or will lock out on the subsequent cycle.

The safety-control circuit shall ensure that the interchange of the electrical installation and service connection leads or terminals of the critical functional component that failed, when physically interchangeable without alteration, do not activate the component nor result in normal operation of the component.

Requirements for emergency stop are given in 4.5.6.

### 4.5.3 Control function in the event of failure

In case of a fault in the control circuit logic, or failure of or damage to the control circuit:

a) the hydrogen generator shall not start unexpectedly;

b) the hydrogen generator shall not be prevented from stopping if the stop command has been given;

c) automatic or manual stopping of the moving parts shall be possible;

d) the protective safety devices shall remain fully effective.

### 4.5.4 Programmable electronic equipment

When provided, programmable electronic equipment for monitoring, testing, and non-safety-critical functions shall meet the requirements of IEC 60204-1 and shall comply with IEC 61131-1 and IEC 61131-2. Programmable controllers used for safety-critical circuit control shall also comply with IEC 61508. For programmable controllers whose safety functions are fail-safe and of low complexity, IEC 60730-1:2013, Annex H shall apply.

### 4.5.5 Start

The hydrogen generator shall have a start control that initiates operation of the hydrogen generator only when all safeguards prescribed in the manufacturer's safety analysis are in place and functional. Suitable interlocks shall be provided to secure correct sequential starting.

The hydrogen generator may be started only by intentional actuation of a control provided for this purpose.

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Intentional actuation of a control is not required for restarting from a standby mode that is the result of a normal sequence of an automatic cycle.

### 4.5.6 Emergency-stop

The hydrogen generator shall have an emergency-stop function that immediately removes power from systems that produce an actual or impending hazard that cannot be corrected by controls.

A separate emergency stop function is not required when emergency switching off is provided as described in IEC 60204-1.

When provided, the emergency-stop safety circuit shall be designed according to the requirements of IEC 60204-1.

When provided, emergency-stop push buttons shall be designed in accordance with ISO 13850, marked clearly, and shall be easily accessible.

The emergency-stop function shall:

a) stop hydrogen production and de-energize equipment that produced the un-correctable hazardous condition as quickly as possible without creating additional hazards;

b) initiate or permit the initiation of certain safeguard actions as determined by risk assessment; which may include but not be limited to

   1) hydrogen equipment depressurization to a safe location;

   2) de-energization of electrical equipment not intended for use in flammable atmospheres;

c) override all other functions and operations in all modes;

d) be fitted with restart lockouts that require intentional reset before the hydrogen generator start is permitted;

e) not initiate a hazardous condition upon reset.

Control and monitoring systems that can operate safely in the hazardous situation may be left energized to provide system information.

The hydrogen generator may be provided with connection means for an optional remote emergency-stop device (ESD) or emergency switching-off.

### 4.5.7 Stop

The hydrogen generator shall have a stop function separate from the emergency-stop function that initiates a controlled cessation of hydrogen generator operation.

The hydrogen generator may be stopped immediately or in a controlled mode with power remaining available to designated systems as indicated by the manufacturer's safety analysis and the functional requirements of the hydrogen generator.

### 4.5.8 Self-correctable conditions

The hydrogen generator shall be controlled to operate within design limits of pressure, temperature, current, and voltage, as established by the manufacturer's risk assessment. The hydrogen generator may correct operating parameters to operate at a partial rated capacity to stay within safe design limits. The manufacturer's documented technical specifications in Clause 7 shall describe these features.

NOTE For example, a high ambient temperature can limit the heat rejection capacity of the hydrogen generator; the hydrogen generator control can respond by reducing the water electrolysis rate to operate within safe process limits.

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#### 4.5.9 Interconnected installations

When the hydrogen generator is designed to work together with other equipment, the hydrogen generator shall provide effective means to communicate safety-related conditions between the hydrogen generator and such other equipment (see the functional tests of 5.2.4.3).

#### 4.5.10 Safety components

Safety components shall comply with the safety requirements specified in the relevant ISO or IEC standards as far as they reasonably apply.

Safety devices shall:

a) be so designed and constructed as to be reliable and suitable for their intended use;

b) be independent of other functions, unless their safety functions cannot be affected by such other functions;

c) comply with design principles in order to obtain suitable and reliable protection. These principles include, in particular, fail-safe modes, redundancy, diversity, and self-diagnosis.

#### 4.5.11 Remote control systems

Remote monitoring and control systems shall:

a) be allowed only on hydrogen generators where remote start-up will not lead to an unsafe condition;

b) not override locally set manual controls;

c) not override protective safety controls.

Hydrogen generators that can be operated remotely shall have a local, labelled switch or other device that will prevent remote operation when service personnel perform inspection or maintenance.

#### 4.5.12 Alarms

When alarms (audio, visual, etc.) are provided, they shall be unambiguous and easily perceived. Additionally, they shall not draw the users into a hazardous situation and not encourage the users to access the equipment and/or attempt repairs themselves.

The alarm may be provided locally, remotely, or both. The alarm signal shall include sufficient information for a service person to diagnose the fault.

#### 4.5.13 Purge gas quantity

When the purge gas is supplied in compressed gas containers, there shall be a readily apparent indication of the remaining gas supply. If the quantity of purge gas is insufficient for a proper purge, the hydrogen generator shall not be allowed to start or shall shut down.

#### 4.5.14 Reset

Reset shall return the hydrogen generator from a faulted state to a ready-to-start state.

Reset shall only be possible when all the safeguards prescribed in the manufacturer's safety analysis are in place and are functional. Resetting a hydrogen generator shall not initiate a hazardous condition.

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#### 4.5.15 Suspension of safeguards

Where it is necessary to suspend safeguarding (e.g. for performing maintenance), a mode-selection device or means capable of being secured in the desired mode shall be provided so as to prevent unintended operation.

## 4.6 Ion transport medium

### 4.6.1 Electrolyte

The electrolyte shall, over the defined operating lifetime or service interval:

a) be chemically stable with respect to environmental degradation over the full range of operating conditions;

b) not introduce any undesirable attribute in any other material used in conjunction, so as to have a synergistic and undesirable effect that neither materials would possess if used in isolation;

c) not catalyse or serve to promote in any fashion parasitic side reactions, either of a chemical or an electrochemical form, that contaminates the product gases of hydrogen or oxygen;

d) provide sufficient ionic conductivity and prevent degradation of the oxygen/hydrogen separator.

The manufacturer shall provide a mechanism for the safe containment and environmental disposal of the electrolyte upon either a planned released or unplanned event leading to the release of the electrolyte as in 4.3.3.7.

### 4.6.2 Membrane

When oxygen and hydrogen are produced simultaneously, the hydrogen generator shall be provided with a membrane to separate the product gas streams of oxygen and hydrogen. The membrane shall:

a) be chemically stable with respect to environmental degradation over the full range of operating conditions;

b) be selected from the group of natural fibres, synthetic polymers, ceramics, or combinations of the above and shall not contain asbestos;

c) provide sufficient ionic conductivity for the safe operation of the hydrogen generator;

d) provide sufficient electrical resistivity for the safe operation of the hydrogen generator;

e) provide sufficient mechanical strength for the designed differential pressure between anode and cathode cells when assembled;

f) not leach out harmful impurities upon electrolysis operation;

g) provide sufficiently low levels of cross-membrane hydrogen and oxygen gas permeability under hydrated operating condition so as to prevent a flammable gas mixture.

The manufacturer shall provide a mechanism for the safe environmental disposal of the membrane upon hydrogen generator disassembly and replacement. If the membrane material will become unstable over the defined operating lifetime of the hydrogen generator, the manufacturer shall:

a) ensure that the material instability will not affect the safety of the hydrogen generator;

b) incorporate monitoring devices that will monitor the effects of the membrane material instability.

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### 4.7 Protection of service personnel

The exterior and interior of the hydrogen generator enclosure and the interior components shall be designed with due consideration to ISO 13857 and ISO 13854.

All live parts shall be protected from access by unauthorized personnel. Entrances to exposed live parts inside the hydrogen generator shall have warning signs prohibiting access by unqualified personnel.

Guarding shall be provided to protect the service personnel from any contact shock of exposed live parts, as well as from any rotating device.

All non-insulated live parts in a high-voltage circuit within the hydrogen generator compartments shall be located, guarded, or enclosed so as to minimize the possibility of accidental contact by service personnel performing mechanical service functions which may have to be performed with the equipment energized.

An electrical control component that may require examination, adjustment, servicing, or maintenance while energized shall be located and mounted with respect to other components and grounded metal parts so it is accessible for electrical service functions without subjecting the service personnel to the likelihood of shock hazard from adjacent non-insulated live parts or accident hazard from adjacent hazardous moving parts.

## 5 Test methods

### 5.1 General

Each new hydrogen generator design considered for compliance with this document shall be subjected to the type (qualification) tests of 5.2 to verify that the hydrogen generator is compliant with the design specification. Serial production hydrogen generators built to this compliant type tested design need only be subjected to the routine tests of 5.3.

### 5.2 Type (qualification) tests

#### 5.2.1 General requirements

The hydrogen generator type test article shall be a representative production sample.

#### 5.2.2 Basic test arrangements

Type tests may be conducted at the factory or at the installation site, as applicable. In conducting the type tests, the entire hydrogen generator, including any air filters, start-up devices, venting or exhaust systems, and all field-furnished equipment shall be installed in accordance with the manufacturer’s instructions to replicate the manner in which it is to be installed and operated.

Tests shall be carried out on the hydrogen generator assembled for normal use and under the least favourable combination and configuration, within the manufacturer's stated ratings.

#### 5.2.3 Reference test conditions

##### 5.2.3.1 Environmental conditions

Unless otherwise specified by the manufacturer, the tests shall be carried out in the following environment:

a) a temperature of 15 °C to 35 °C;

b) a relative humidity of not more than 75 %, but not exceeding the limits of 4.1.3;

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c) an atmospheric pressure of 75 kPa to 106 kPa;

d) no hoarfrost, dew, percolating water, rain, solar radiation, etc.

#### 5.2.3.2 State of hydrogen generator

##### 5.2.3.2.1 General

Unless otherwise specified, each test shall be carried out on the hydrogen generator assembled for normal use and under the least favourable combination of the conditions given in 5.2.3.2.2 to 5.2.3.2.13.

If dimensions or mass make it unsuitable to carry out particular tests on a complete hydrogen generator, tests on sub-assemblies are allowed, provided it is verified that the assembled equipment will meet the requirements of this document.

Equipment intended to be built into a wall, recess, cabinet, etc., shall be installed as specified in the manufacturer's instructions.

##### 5.2.3.2.2 Position of the hydrogen generator

The hydrogen generator shall be in any position of normal use and with any ventilation unimpeded.

##### 5.2.3.2.3 Accessories

Accessories and user-interchangeable parts available from, or recommended by, the manufacturer for use with the equipment under test may be either connected or not connected.

##### 5.2.3.2.4 Covers and removable parts

Covers or parts which can be removed without using a tool may be left in place or removed.

##### 5.2.3.2.5 Mains supply voltage

The mains supply voltage shall be between 90 % and 110 % of any rated supply voltage for which the equipment can be set or, if the equipment is rated for a greater fluctuation, at any supply voltage within the fluctuation range.

The frequency shall be any rated frequency.

A hydrogen generator designed for both alternative current (a.c.) and direct current (d.c.) shall be connected to an a.c. or d.c. supply.

A hydrogen generator designed for d.c. or single-phase supply shall be connected both with normal and reverse polarity.

Unless the hydrogen generator is specified for use only on a non-earthed mains supply, one pole of the reference test supply shall be at or near earth potential.

If the means of connection permits reversal, battery-operated hydrogen generators shall be connected with both reverse and normal polarity.

##### 5.2.3.2.6 Input and output voltages

Input and output voltages, including floating voltages but excluding the mains supply voltage, shall be set to any voltage within the rated voltage range.

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#### 5.2.3.2.7 Earth terminals

Protective conductor terminals, if any, shall be connected to earth. Functional earth terminals may be connected or not connected to earth.

#### 5.2.3.2.8 Controls

Controls that can be adjusted by hand shall be set to any position except that:

a) mains-selection devices shall be set to the correct value;

b) combinations of settings shall not be made if they are prohibited by the manufacturer's marking on the equipment.

#### 5.2.3.2.9 Connections

If the hydrogen generator is designed to work with other equipment as specified in 4.5.9, the hydrogen generator may be connected for its intended purpose.

#### 5.2.3.2.10 Load on motors

Load conditions of motor-driven parts of the hydrogen generator shall be in accordance with the intended purpose.

#### 5.2.3.2.11 Output

The following shall be taken into account regarding the hydrogen generator equipment giving an electrical output:

a) the equipment shall be operated in such a way as to provide the rated output power to the rated load;

b) the rated load impedance of any output may be connected or not.

#### 5.2.3.2.12 Duty cycle

Equipment for short-term or intermittent operation shall be operated for the longest period and shall have the shortest recovery period consistent with the manufacturer's instructions.

Equipment for short-term or intermittent operation that develops significant heat during the start-up phase, and that relies on continued operation to dissipate that heat, shall also be operated for the shortest rated period followed by the shortest rated recovery period.

#### 5.2.3.2.13 Loading and filling

Equipment intended to be loaded with a specific material in normal use, such as a desiccant or electrolyte, shall be loaded with the least favourable quantity of the materials specified in the instructions for use, including not loaded (empty) if the instructions for use permit this in normal use.

In case of doubt, tests shall be performed in more than one loading condition.

If the specified material could cause a hazard during the test, another material may be used, provided that it can be demonstrated that the result of the test is not affected.

### 5.2.4 Electrical tests

#### 5.2.4.1 Continuity of the protective bonding circuit test

The continuity of the protective bonding circuit specified in 4.4.2.2 shall be verified by a loop impedance test in accordance with IEC 60364-4-41 or IEC 61010-1.

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The continuity of the protective bonding circuit should be verified before power is applied to the hydrogen generator, as most short-circuit protective devices rely on this continuity for proper operation. Similarly, the continuity of the protective bonding circuit should be verified before the voltage test of 5.2.4.2.

#### 5.2.4.2 Strength of the electrical insulation

The strength of the electrical insulation specified in 4.4.2.1 shall be verified in accordance with IEC 61010-1:2010, 6.8 with the following exceptions:

a) humidity preconditioning is not required for hydrogen generators too large for readily available test chambers; the voltage testing requirements for such large hydrogen generators shall in no case be less than those of IEC 60204-1:2016, 19.4;

b) any of the tests of IEC 61010-1:2010, 6.8.4 may be used.

Alternatively, the test method as described in IEC 60335-1:2010, Clause 16 may be used.

If the hydrogen generator employs a component such as a solid-state device that can be damaged by the voltages specified in this test, and that component complies with the applicable International Standard specified in 4.4.2.1, the conductors of the circuit being tested may be disconnected at the component to eliminate the likelihood of damaging the component.

The voltage test should be performed after the continuity of the protective bonding circuit is verified as in 5.2.4.1 to minimize the possibility of inadvertently energizing accessible conductive surfaces and to ensure proper operation of the test equipment.

The strength of the electrical insulation should be verified before applying power to the hydrogen generator to minimize the potential for short circuits and exposure to hazardous voltages.

#### 5.2.4.3 Functional tests

The functions of electrical equipment shall be tested, according to the manufacturer's test procedures, particularly those related to safety and safeguarding. At a minimum, the functioning of the control system, safety-control circuit, and components identified in 4.5 shall be verified according to the requirements of 4.3.3.7 and applicable subclauses of 4.5.

Functional tests and especially those of the safety circuit should be performed immediately after the continuity of the protective bonding circuit and the strength of the electrical insulation have been verified as in 5.2.4.1 and 5.2.4.2 and before the hydrogen generated is operated at full capacity.

#### 5.2.4.4 Mains supply

The mains supply marking requirements of 6.2 shall be checked in accordance with IEC 61010-1:2010, 5.1.3.

#### 5.2.4.5 Touch current and protective conductor current

The touch current and protective conductor current requirements of 4.4.2.2.1 shall be limited and tested in accordance with IEC 61010-1 or IEC 60950-1:2005, 5.1.2 to 5.1.8.

#### 5.2.4.6 Capacitor discharge

Cord-connected hydrogen generators shall comply with the capacitor discharge requirements outlined in IEC 61010-1:2010, 6.6.2 and 6.10.3 c) and d).


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#### 5.2.4.7 Cord anchorage and conductor connection pull force tests

The requirements for cord-connected hydrogen generators specified in 4.4.2.5 shall be verified in accordance with the test specified in IEC 61010-1:2010, 6.10.2. The requirements for conductor connecting devices specified in 4.4.2.5 shall be verified in accordance with the test specified in IEC 60947-1, IEC 60998-2-2, IEC 60999-1, or IEC 60999-2, as applicable.

#### 5.2.4.8 Terminals for external conductors test

The requirements of terminals for external conductors specified in 4.4.2.6 shall be verified by the test specified in IEC 61010-1:2010, 6.6.2.

#### 5.2.4.9 Starting current test

To verify the proper design of overcurrent protection per 4.4.2.3 the hydrogen generator shall be started and operated three times in succession without actuating an overcurrent protection device and without failure of any component.

### 5.2.5 Pressure test

#### 5.2.5.1 General

All pressures cited in this clause are gauge unless stated otherwise.

#### 5.2.5.2 Pressure test — Liquid-containing parts

The strength and integrity of all pressure-bearing parts of 4.3.4 ,including joints and connections, that convey a liquid shall be tested by the methods of IEC 61010-1:2010, 11.7.

Cell stacks need only be tested according to 5.2.5.4.

Parts subjected to the same internal pressure during normal operation of the hydrogen generator through (inter) connection may be considered as an individual test section, which may be pressurized separately and, when deemed necessary, isolated from the rest of the hydrogen generator by any convenient means.

#### 5.2.5.3 Pressure test — Gas and gas/liquid-mixture-containing parts

The requirements for the strength and integrity of all pressure-bearing parts, including joints and connections, that convey a gas or a gas/liquid mixture shall be tested by the methods of IEC 61010-1:2010, 11.7 with the following modifications:

a) test pressure shall be at least 1,5 times MAWP;

b) the minimum test pressure shall be 70 kPa;

c) the test duration shall be 2 min ± 10 s;

d) Cell stacks need only be tested according to 5.2.5.4.

Parts subjected to the same internal pressure during normal operation of the hydrogen generator through (inter) connection may be considered as an individual test section, which may be pressurized separately and, when deemed necessary, isolated from the rest of the hydrogen generator by any convenient means.

If a pneumatic test is used, a non-reactive test gas, such as nitrogen or helium, is recommended.

NOTE In addition to verifying the ability of the pressure-bearing parts to withstand pressure, this test confirms the integrity of hydrogen containment system including piping, fittings, and vessels in support of the fire and explosion hazard protection requirements of 4.4.1. See IEC 60079-2.

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#### 5.2.5.4 Pressure test — Cell stacks

##### 5.2.5.4.1 Applicability

The cell stacks shall be subjected to the common pressure test of 5.2.5.4.2. If during normal or abnormal operation a pressure difference between the oxygen and hydrogen sides of the cell stacks can occur, the cell stack shall additionally be subjected to the differential pressure test of 5.2.5.4.3.

NOTE A slightly different test is provided for cell stacks because unlike the other pressure-bearing components the cell stacks are the pressure source. If the cell stacks fail, the source of both pressure and hydrogen is removed.

Robust cell stacks can be tested with the other pressure equipment in accordance with 5.2.5.2 and 5.2.5.3.

It is possible that national authorities allow safety to be established by calculation, for example according to the Pressure Equipment Directive.

##### 5.2.5.4.2 Common pressure test

The oxygen and hydrogen sides of each cell stack shall be connected to a common pressure source and tested simultaneously. The pressure test shall be performed as in 5.2.5.3, except that cell stacks with a MAWP ≤ 50 kPa shall be subjected to 1,3 times the MOP for 30 min.

##### 5.2.5.4.3 Differential pressure test

The cell stacks shall be heated or cooled to the maximum or minimum operating temperature, whichever is more severe. The pressure test shall be performed as in 5.2.5.3, except that the pressure will be applied to either the anode or cathode channels but not both and the test pressure shall be 1,3 times the maximum allowable differential pressure determined in 4.3.4.4.

Additionally, the leakage rate between anode and cathode sides shall be measured either continuously during the test, or before and after the pressurization. The leakage rate between anode and cathode sides shall not increase as a result of this test and shall be within the manufacturer's specification for the temperature of the test. The measurements after the pressurization shall not deviate from the initial results by more than the accuracy and repeatability of both the instrumentation and the test set-up.

#### 5.2.6 Leakage test

##### 5.2.6.1 General

The applicable leakage tests of 5.2.6 shall be performed to supplement the pressure tests of 5.2.5.

Any functional parts shall be caused to assume the open position so the required test pressure is exerted on all parts of the test section.

Parts subjected to the same internal pressure during normal operation through (inter) connection may be tested separately as an individual test section, and, when deemed necessary, isolated from other test sections by any convenient means.

##### 5.2.6.2 Normal leakage tests

The tests of 5.2.5 shall be repeated on the hydrogen generator with the following modifications.

a) The test pressure shall be of no less than the MOP or, in the case of differential pressure cell stacks, maximum operating differential pressure.

b) When the test pressure is reached, the flow of test fluid shall be stopped and the pressure in the hydrogen generator shall be monitored for at least 2 min. There shall be no measurable pressure drop. Temperature compensation shall be taken into account when determining pressure drops.

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In the case of differential pressure cell stacks that have to be additionally subjected to the test of 5.2.5.4.3, the same requirements apply for the leakage rate between anode and cathode sides. The leakage rate between anode and cathode sides shall be within the manufacturer's specification for the temperature of the test. The measurements after the pressurization shall not deviate from the initial results by more than the accuracy and repeatability of both the instrumentation and the test set-up.

The manufacturer shall select test fluids that are compatible with the hydrogen generator test section and do not introduce hazardous test conditions.

NOTE 1 Typical pneumatic gases used are hydrogen or helium or $H_2$ in $N_2$ tracer gas for hydrogen-bearing test sections; nitrogen or helium for oxygen bearing test sections gas.

NOTE 2 Potential hazards include unplanned hydrogen/air and hydrogen oxygen mixtures above flammable limit.

#### 5.2.6.3 Additional leakage testing of hydrogen gas component connections and piping joints

##### 5.2.6.3.1 General

If 5.2.6.2 is conducted using a hydraulic test fluid, then the tests of 5.2.6.3 are required

In addition to the leakage test of 5.2.6.2, hydrogen gas conveying piping connections shall be leak tested in accordance with 5.2.6.3.2 or 5.2.6.3.3.

##### 5.2.6.3.2 Bubble test

Using an inert test gas such as nitrogen or helium, hydrogen gas component systems shall be leak tested with a test pressure of no less than the MOP. The leak test shall be carried out once the test pressure has been reached and hydrogen conveying piping joints and component connections completely covered with a leak detection liquid suitable for the surface. The leak detection liquid shall be applied in a manner to prevent bubbles as a result of the application process. Each hydrogen gas connection shall be pressurized for a minimum of 10 min. No visible bubbles produced by gas leakage shall be observed.

If the component to be tested has parts made of stainless steel, nickel, or chromium alloys, the leak detection liquid shall have a volumetric fraction of less than 10 $cm^3/m^3$ sulfur and 10 $cm^3/m^3$ halogen. If the component to be tested has parts made of polyethylene or structural plastic, the leak detection liquid shall not promote environmental stress cracking (E.S.C).

Electrochemical cells may be excluded from the bubble test and contact with the leak detection liquid if incompatible per 4.6.1.

##### 5.2.6.3.3 Tracer gas leak detection

As an alternative to the bubble test, a calibrated trace gas detector using a non-flammable tracer gas in accordance with ISO 10156, such as a hydrogen and nitrogen mixture containing a volumetric fraction of hydrogen in nitrogen of less than 5,7 % or a helium mass spectrometer with helium gas, may be used to detect hydrogen conveying connection, cell stack and pipe joint leaks when used in accordance with instructions provided by the tracer gas detector manufacturer and the hydrogen generator manufacturer's requirements.

### 5.2.7 Dilution tests

#### 5.2.7.1 General

Where mechanical ventilation is used to protect equipment and/or dilute hydrogen and/or oxygen as described in 4.4.1, these tests shall be performed.

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The air pressure and airflow measured during the test conditions shall be corrected for temperature and altitude. The corrected airflow and pressure shall meet the design criteria for the specified operating range of the hydrogen generator.

For the dilution tests to be valid, the integrity of the containment system shall have been confirmed by the tests of 5.2.5.

#### 5.2.7.2 Air flow test

The air flow rate shall be measured to confirm that the flow rate meets or exceeds the ventilation rate specified in 4.4.1.6. The ventilation rate shall be determined by measuring air flow into or out of the hydrogen generator enclosure.

#### 5.2.7.3 Air pressure test

The pressure of the ventilated enclosure shall be measured to confirm that the pressure differential meets the flow and pressure requirements specified in 4.4.1.6 and 4.4.1.8, as applicable.

#### 5.2.7.4 Dilution test

The effectiveness of the dilution by ventilation specified in 4.4.1.4, 4.4.1.5, and 4.4.1.6 shall be confirmed using the method of IEC 60079-2.

### 5.2.8 Protection against the spread of fire tests

The requirements to protect against the spread of fire specified in 4.3.3.3 shall be tested by the methods of IEC 61010-1:2010, Clause 9 to verify.

NOTE The standards for fire resistance referenced in 5.3.3 contain additional tests.

### 5.2.9 Temperature tests

Equipment temperature limits and resistance to heat specified in 4.3.10 shall be verified according to the test methods given in IEC 61010-1:2010, Clause 10.

### 5.2.10 Environmental test

#### 5.2.10.1 Ingress protection

The components, electrical enclosures, and process enclosures of the hydrogen generator shall be tested according to IEC 60529 for compliance with the IP classification determined as in 4.3.9 and 4.3.3.2.

NOTE In addition to providing protection from the environment, enclosures can prevent access to hazardous live electrical parts as required by 4.4.2.1. See IEC 61010-1:2010, 6.2 for more information and a preferred means of testing for this particular protection.

#### 5.2.10.2 Water test

The components, electrical enclosures, and process enclosures of hydrogen generators intended for outdoor use or water hose wash shall be tested by the methods of IEC 60068-2-18:2017, 6.3 or by the methods of IEC 60529 to the IP rating as defined according to 4.3.9 and 4.3.3.2.

Where a hazard from ventilation opening water ingress exists, the hydrogen generator ventilation openings provided or specified by the manufacturer shall be tested.

Hydrogen and oxygen vent terminals provided or specified by the manufacturer shall meet the requirements of 4.3.9.

Enclosures not intended to provide water ingress protection are not required to be tested.

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### 5.2.11 Performance tests

#### 5.2.11.1 Hydrogen and oxygen production rate test

The hydrogen production rate, and where applicable, the oxygen production rate shall meet or exceed the specifications in 4.1.7 and 4.1.8.

The hydrogen production rate shall be measured at 100 % capacity for a period of 1 h using the method defined in ISO 9300, ISO 9951, ISO 10790, or ISO 14511.

If applicable for industrial and commercial applications, the oxygen production rate shall be measured at 100 % capacity for a period of 1 h using the method defined in ISO 9300, ISO 9951, ISO 10790, or ISO 14511.

The average production rate shall meet or exceed the rate specified by the manufacturer.

#### 5.2.11.2 Hydrogen and oxygen quality test

The applicable hydrogen quality parameters specified in 4.1.7 shall be verified to meet or exceed the manufacturer's specification.

NOTE Guidance on suitable hydrogen quality analysis methods is provided by ISO 14687.

Where applicable, the oxygen quality parameters specified in 4.1.8 shall be verified to meet or exceed the manufacturer's specification.

### 5.2.12 Spillage, overflow, and drain test

Conformity of hydrogen generators subject to liquid spillage or overflow in normal use shall be verified per the tests of IEC 61010-1:2010, 11.3 and 11.4.

The manufacturer shall verify by performance test that liquid disposal system(s) shall, under conditions of a blocked liquid drain line(s), continue to operate within compliance of manufacturer's specifications or stop operation.

### 5.2.13 Mechanical strength

Hydrogen generators shall be verified to meet the mechanical strength requirements of 4.3.1 with the applicable tests of IEC 60204-1 or IEC 61010-1.

### 5.2.14 Stability test

The hydrogen generator shall be subjected to the stability test of IEC 60335-1:2010, 20.1. Hydrogen generators that are intended to be permanently connected may be exempted from this test.

The stability of portable hydrogen generators specified in 5.1 shall be verified with the test in IEC 61010-1 or IEC 60335-1.

### 5.2.15 Vent tests

#### 5.2.15.1 General

The vent tests specified in 5.2.15 are applicable to hydrogen generators for indoor installation that are provided with a vent system by the manufacturer.

#### 5.2.15.2 Vent leakage

The vent assembly shall comply with the leakage test requirements of 5.2.6.

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The leakage test shall be conducted with the vent system assembled to the hydrogen generator as intended with the longest manufacturer-recommended length of vent piping assembly and most parts attached.

### 5.2.15.3 Vent temperature test (non-metallic vent materials)

Vent systems employing materials affected by temperature shall be assembled and installed in accordance with the manufacturer's instructions for the temperature test of 5.2.9 on the system.

Temperatures shall be monitored in accordance with the temperature test requirements outlined in 5.2.9.

### 5.2.15.4 Mechanical strength of vent systems

#### 5.2.15.4.1 General

The static force and impact tests of 5.2.15.4 shall be conducted with the vent system assembled to the hydrogen generator as intended with the longest recommended length of vent piping assembly and maximum parts installed.

#### 5.2.15.4.2 Static force

In order to perform the test, a vertical suspension load of 70 kg shall be evenly distributed (without impact) over the vent terminal. The load shall then be removed. The vent terminal shall not be distorted or altered in a way that would result in the hydrogen generator not operating satisfactorily or in leakage of vented gases.

Following the static force test, the hydrogen generator shall comply with the leakage test in accordance with 5.2.6.

#### 5.2.15.4.3 Impact

The horizontal vent terminal supplied with the hydrogen generator shall be subjected to an impact test as follows:

The impact shall be produced by a pendulum consisting of a cloth bag, filled with sand, weighing 12 kg suspended from a steel cable or rope. The bag shall be formed from a flat section of burlap, canvas, or other suitable material. A suitable plastic liner may be used to prevent sand loss. All sides and corners of the cloth shall be drawn up as tightly as possible around the sand and the excess material tied as close as possible at the top of the bag. The bag shall have an at-rest position not more than 25 mm from the edge of the bag to the nearest edge of the vent terminal (see Figure 1).

The point of impact shall be at the height of the centre of gravity of the bag. The angle of swing shall be 45° and it shall be measured between the pendulum arm with the bag at its at-rest position and the pendulum arm at its elevated position. The length of the pendulum, measured from the point of rotation to the centre of gravity of the bag as shown in Figure 1, shall be 2 m.

One impact shall be made at each of the following points:

a) at the centre of the vertical front surface of the vent terminal,

b) at the leading edge on the left side of the vent terminal, pendulum rotated left at an angle 45° from the point described in a),

c) at the leading edge on the right side of the vent terminal, pendulum rotated right at an angle 45° from the point described in a).

Following the impacts, the hydrogen generator shall show compliance with the leakage test of 5.2.6.

At the option of the manufacturer the vent terminal may be replaced following each impact.

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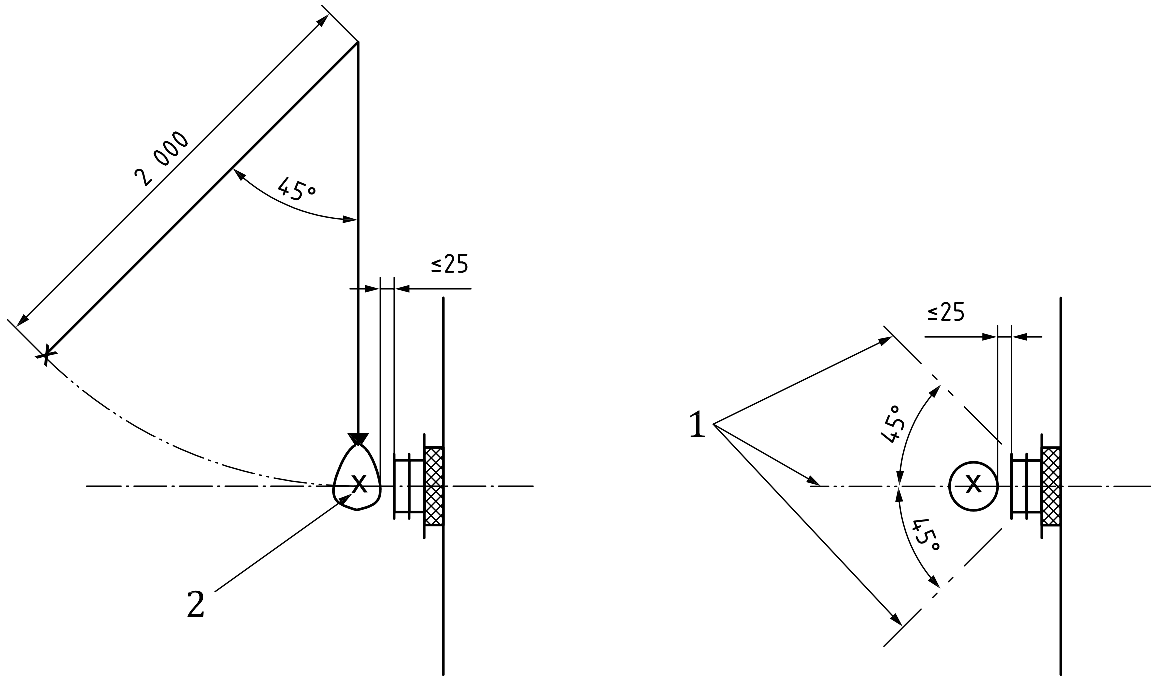
Dimensions in millimetres




**Key**

1 sandbag path

2 centre of gravity of the 12 kg sandbag

**Figure 1 — Impact test set-up**

### 5.2.16 Sound level test

The maximum sound pressure level which the hydrogen generator can produce shall be measured and if necessary, the maximum sound power level calculated. Sound from alarms and parts at remote locations shall not be included in the calculation.

Practicable sound level reducing protective materials or measures as prescribed by the manufacturer's installation instructions which may be used, including the fitting of noise-reducing baffles or hoods, shall be permitted for the test.

NOTE A sound pressure level of 85 dB above a reference sound pressure of 20 μPa is at present regarded by many authorities as the threshold at which a hazard can be caused. Special means, such as the use of protective earpieces, can make a higher level non-hazardous to the user.

The maximum A-weighted sound pressure level shall be measured at the operator position and at whatever point 1 m from the enclosure of the equipment has the highest sound pressure level, and if necessary, the maximum A-weighted sound power level produced by the equipment calculated, in accordance with either ISO 3746 or ISO 9614-1. The following conditions apply:

a) During measurement, any part necessary for the correct operation of the equipment and supplied by the manufacturer as an integral part of such equipment, for example, a pump, shall be fitted and operated as in normal use.

b) Sound level meters used in the measurement shall conform either to type 1 of IEC 61672-1 or, if an integrated sound level meter, to type 1 of IEC 61672-2.

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c) The test room shall be semi-reverberant, with a hard-reflecting floor. The distance between any wall or any other object and the surface of the equipment shall not be less than 3 m.

d) The equipment shall be tested with the combination of load and other operating conditions (for example, pressure, flow, and temperature) which creates the maximum sound pressure level.

## 5.3 Routine tests

### 5.3.1 General requirements

Routine tests shall be performed on every hydrogen generator prior to placement on the market, installation, or commissioning.

The routine tests may comprise part of factory acceptance test.

NOTE It is possible that additional tests are to be performed regularly, according to national regulations or the manufacturer's maintenance recommendations, once the hydrogen generator is in operation.

### 5.3.2 Continuity of the protective bonding circuit test

The continuity of the protective bonding circuit shall be tested as specified in 5.2.4.1 or as in IEC 61010-1:2010, F.1.

NOTE Any of the alternative methods listed in 5.2.4.1 are applicable, regardless of the size or ratings of the hydrogen generator.

### 5.3.3 Voltage test

The electrical insulation shall be tested as specified in 5.2.4.2 or as in IEC 61010-1:2010, F.2 and F.3.

### 5.3.4 Functional tests

At a minimum, the following functions of each hydrogen generator shall be verified when connected to rated electrical mains and utilities:

— function of safety-control circuit and each associated sensor and component;

— normal system start with no system warnings or alarms;

— normal generation of hydrogen at specified output rate and pressure within rated temperature with no system warnings or alarms for a duration sufficient for having the electrolyte reach and stabilize at its nominal temperature;

— normal system stop with no system warnings or alarms.

### 5.3.5 Leakage test

The integrity of each hydrogen generator's piping shall be tested as specified in 5.2.6. The integrity of each hydrogen generator's cell stack shall be tested as specified in 5.2.6.2, except that temperature shall be in accordance with manufacturer's standard routine test protocol.

# 6 Marking and labelling

## 6.1 General requirements

The hydrogen generator shall be marked in compliance with the applicable clauses of ISO 3864-2 and ISO 17398.

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## 6.2 Hydrogen generator marking

Each hydrogen generator shall bear a data plate or combination of adjacent labels located so as to be easily read when the hydrogen generator is in a normally installed position. The data plate/label(s) shall include the following information:

a) manufacturer's name (with trademark), and contact information;

b) the model number or type;

c) serial number of the hydrogen generator;

d) date of construction;

e) electrical input in volts (single value or range);

f) current rating in amperes or the rated power (W or VA);

g) frequency range in hertz and phases;

h) IP rating;

i) maximum hydrogen production rate, in kilograms (kg) or grams (g), or in litres (l) or cubic metres ($m^3$) under standard conditions, per unit of time;

j) maximum hydrogen output pressure, in kilopascals (kPa) or megapascals (MPa);

k) maximum hydrogen output temperature in degrees Celsius (°C);

l) if applicable, maximum oxygen production rate, in kilograms (kg) or grams (g), or litres (l) or cubic metres ($m^3$), under standard conditions, per unit of time;

m) if applicable, the maximum oxygen output pressure in kilopascals (kPa) or megapascals (MPa);

n) if applicable, the temperature range of output oxygen in degrees Celsius (°C);

o) water use rate, in litres or cubic metres ($m^3$) per unit of time;

p) reference to this document (ISO 22734);

q) hydrogen generators containing hazardous areas as determined in 4.4.1.2 shall be marked as required by IEC 60079-0 and the appropriate parts of IEC 60079 for the type(s) of protection.

## 6.3 Marking of components

All types of valves, transmitters, motors, pumps, and fans shall be identified to match the hydrogen generator documentation. Piping and tubing shall be marked to identify contents and flow direction. Inlet and outlet ports and vents shall be marked to identify function, contents, and flow direction. Electrical supply, protective earthing, and external control connections shall be marked. Manual controls shall be marked to identify function. Convenience outlets, if provided, shall be marked with maximum current ratings. Replaceable fuses shall have fuse replacement markings near the fuse.

Markings shall be consistent with documentation accompanying the hydrogen generator (see Clause 7).

## 6.4 Warning signs

Warning signs shall be appropriately placed to identify electrical hazards, potential hazards associated with indoor oxygen or hydrogen venting if applicable (see 4.1.5.3 and 4.1.6.3), contents from drain valves, potential hazards associated with the liquids contained in the hydrogen generator, hot components and mechanical hazards. Signs shall conform to ISO 3864-2.

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# 7 Documentation accompanying the hydrogen generator

## 7.1 General

Hydrogen generators shall be accompanied by documentation for safety purposes as follows:

a) intended use of the hydrogen generator;

b) technical specification;

c) instructions for use;

d) name and address of manufacturer or supplier from whom technical assistance may be obtained;

e) the information specified in 7.2 to 7.5;

f) instructions for storage and transportation.

If applicable, warning statements and a clear explanation of warning symbols marked on the hydrogen generator shall be provided in the documentation or shall be durably and legibly marked on the hydrogen generator. In particular, there shall be a statement that documentation needs to be consulted in all cases where hazard or warning symbols are used, in order to find out the nature of the potential hazard and any actions which have to be taken.

If normal use involves the handling of hazardous substances, instruction shall be provided on correct use and safety provisions. If any hazardous substance is specified or supplied by the equipment manufacturer, the necessary information on its constituents and the correct disposal procedure shall also be provided.

Some examples of hazardous substances that hydrogen generators may contain, produce, or use are hydrogen, oxygen, purge gases, and electrolytes.

Where graphical symbols for hazards and warnings are used, they shall be graphical symbols specified in ISO 7010. Graphical symbols for equipment diagrams should be as specified in ISO 7000. Additional symbols may be used, provided that they do not give rise to misunderstanding. Units of physical quantities used with their symbols shall be those of the International System of Units.

EXAMPLE

— General warning sign (ISO 7010-W001)

— Three-phase alternating current (ISO 7000-5032-1)

## 7.2 Hydrogen generator ratings

Documentation shall include the following:

a) the supply voltage or voltage range, frequency or frequency range, and power or current rating;

b) a description of all input and output connections;

c) the rating of the insulation of external circuits, appropriate for single fault conditions, if such circuits are nowhere accessible (see IEC 61010-1:2010, 6.6.2 or IEC 60335-1:2010, 3.6.3);

d) a statement of the range of environmental conditions for which the equipment is designed (see 4.1.3);

e) a statement of the degree of protection, if the equipment is rated according to IEC 60529;

f) a statement of the sound level when installed per manufacturer's instructions.

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## 7.3 Hydrogen generator installation

### 7.3.1 General

The documentation shall include installation and specific commissioning instructions and, if necessary for safety, warnings against hazards which could arise during installation or commissioning of the hydrogen generator. Examples are:

a) assembly, location, and mounting requirements;

b) instructions for protective earthing;

c) connections to the supply;

d) requirements for special services, for example, air, cooling liquid;

e) the maximum sound power level produced by equipment which emits sound, if measurement is required by 4.1.3;

f) instructions relating to sound pressure level (see 5.2.16);

g) instructions related to lifting hydrogen generators that are not portable (see 7.3.5);

h) oxygen venting requirements (see 4.1.5);

i) hydrogen venting requirements (see 4.1.6);

j) requirements to prevent the formation of hazardous areas (see 4.4.1);

k) connections to other equipment;

l) clearance distance to allow for operation, maintenance, and service;

m) instructions for installation and test of sound level reducing material, as applicable;

n) instructions prohibiting oxygen product collection from residential hydrogen generators.

### 7.3.2 Specific requirements for permanently connected hydrogen generators

The instructions for permanently connected hydrogen generators shall include information with regard to the following:

a) supply wiring requirements;

b) requirements for any external disconnect switch or circuit-breaker and external over current protection devices and a recommendation that the switch or circuit-breaker should be near the equipment.

### 7.3.3 Specific requirements for indoor installations

The instructions for indoor installations of hydrogen generators shall include guidance with the purpose of avoiding, as applicable,

a) accumulation of leaked oxygen,

b) accumulation of leaked hydrogen, or

c) excessive temperature elevation.

This ventilation guidance shall be expressed in form of means, such as size and location of openings to outdoors.

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For the case of oxygen and/or hydrogen vented indoors, ventilation requirements shall be specified with the purpose of avoiding, as applicable,

a) excessive oxygen enrichment of air as specified in 4.1.5.3;

b) excessive hydrogen concentration in air as specified in 4.1.6.3, considering also potential leaks;

c) excessive temperature elevation.

These ventilation requirements shall be expressed as the minimum flow rate of natural and/or mechanical ventilation air.

#### 7.3.4 Specific requirements for built-in hydrogen generator appliances

The instructions for built-in hydrogen generator appliances shall include information with regard to the following:

— dimensions of the space to be provided for the appliance;

— dimensions and position of the means for supporting and fixing the appliance within this space;

— minimum distances between the various parts of the appliance and the surrounding structure;

— minimum dimensions of ventilating openings and their correct arrangement;

— connection of the appliance to the supply mains and the interconnection of any separate components;

— necessity to have the plug accessible after installation, unless the appliance incorporates a disconnect switch.

#### 7.3.5 Lifting

The documentation for hydrogen generators that are not portable shall include lifting information and instructions, including:

a) mass;

b) centre of gravity;

c) lifting points;

d) suitable types of lifting accessories.

### 7.4 Hydrogen generator operation

Instructions for use shall include, if applicable:

a) identification of operating controls and their use in all operating modes;

b) an instruction not to position the equipment so that it is difficult to operate the disconnecting device;

c) instructions for interconnection to accessories and other equipment, including indication of suitable accessories, detachable parts, and any special materials;

d) specification of limits for intermittent operation;

e) an explanation of symbols related to safety which are used on the equipment;

f) instructions for replacement of consumable materials;

g) instructions for cleaning and decontamination;

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h) a statement listing any potentially poisonous or injurious gases that can be liberated from the equipment, and possible quantities;

i) condition of electrolyte replacement/replenishment to maintain the generator's operation within design parameters;

j) room ventilation requirements as in 4.1.5.3 and 4.1.6.3.

There shall be a statement in the instructions that, if the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

Instructions for use required by this document shall be provided in an official language of the country in which the hydrogen generator is to be sold.

The operation manual shall be such that all information the user needs to safely operate the hydrogen generator is readily and comprehensively accessible. For example, a copy of the operating instructions can be provided as a marking on the generator visible after installation or in a folder kept with the generator for ease of access.

## 7.5 Hydrogen generator maintenance

Instructions for the service personnel concerning preventive maintenance and inspection necessary for safety shall be given in sufficient detail. These shall include the inspection and replacement, if necessary, of any hoses or other parts containing fluids, if their failure could cause a hazard (see 4.2). These shall also include the inspection and, if necessary, re-establishment of unobstructed dilution ventilation intake and exhaust openings, unobstructed natural ventilation, and safety distances as applicable specified in the installation instructions.

A maintenance schedule including preventative and routine maintenance and indicating at a minimum the type and frequency of each maintenance item shall be provided. This shall address in particular protective (safety related) devices, interlocks, and circuits.

Instructions shall advise the service personnel of any tests necessary to check that equipment is still in a safe condition. They shall also warn against the repetition of any tests of this document, which could damage the equipment and reduce protection against hazards.

For equipment using replaceable batteries, the specific battery type shall be stated.

The manufacturer shall specify any parts which are required to be examined or supplied only by the manufacturer or their agent.

The ratings and characteristics of replaceable fuses shall be stated.

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# Annex A
(informative)

# Hydrogen-assisted corrosion

Users of this document should be aware that engineering materials at high stress and high temperature and exposed to atomic hydrogen in their service environment may exhibit an increased susceptibility to hydrogen-assisted corrosion, commonly known as "hydrogen embrittlement". Hydrogen embrittlement is defined as a process resulting in a decrease of the toughness or ductility of a metal due to the presence of atomic hydrogen.

Hydrogen embrittlement has been recognized classically as being of two types. The first, known as internal hydrogen embrittlement, occurs when the hydrogen enters the metal matrix through material processing techniques, which supersaturate the metal with hydrogen. The second type, environmental hydrogen embrittlement, results from hydrogen being absorbed by solid metals from the service environment. Thus, hydrogen embrittlement can occur during elevated-temperature thermal treatments and in service during electroplating, contact with maintenance chemicals, corrosion reactions, cathodic protection, and operating in high-pressure, high-temperature hydrogen.

In the absence of residual stress or external loading, environmental hydrogen embrittlement is manifested in various forms, such as blistering, internal cracking, hydride formation, and reduced ductility. With a tensile stress or stress-intensity factor exceeding a specific threshold, the atomic hydrogen interacts with the metal to induce subcritical crack growth leading to fracture.

The following are some general recommendations for managing the risk of hydrogen embrittlement.

— Select raw materials with a low susceptibility to hydrogen embrittlement by controlling chemistry, microstructure, and mechanical properties.

— When plating parts, manage anode/cathode surface area and efficiency, resulting in proper control of applied current densities. High current densities increase hydrogen charging.

— Clean the metals in non-cathodic alkaline solutions and in inhibited acid solutions.

— Use abrasive cleaners for materials having a hardness of 40 HRC or above.

— Use process control checks, when necessary, to mitigate risk of hydrogen embrittlement during manufacturing.

ISO/TR 15916 and ISO 11114-4 also provide guidance on material resistance to hydrogen embrittlement.

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# Annex B
(informative)

# Flammability limits of hydrogen

## B.1 Flammability limit

Flammability limit is defined as vapour concentrations (usually reported as a volume fraction) of fuel (hydrogen) in a flammable mixture that will ignite and propagate a flame.

## B.2 Flammability limits of hydrogen

As indicated in ISO/TR 15916, the flammability limits for hydrogen in air under ambient conditions range from a volume fraction of approximately 4 % to 75 % of hydrogen in air, or 4 % to 94 % hydrogen in oxygen.

These facts combined with changing nomenclature conventions has led to some confusion between standard references to the lower flammability limit (LFL), the lower explosive limit (LEL), and design limits as percentages of these.

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