
Hydrogen generators using fuel processing technologies —

Part 1: Safety

*Générateurs d'hydrogène utilisant les technologies de traitement
du carburant —*

Partie 1: Sécurité



Reference number
ISO 16110-1:2007(E)



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Published in Switzerland

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 16110-1 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies*.

ISO 16110 consists of the following parts, under the general title *Hydrogen generators using fuel processing technologies*:

- *Part 1: Safety*
- *Part 2: Procedures to determine efficiency*

Introduction

The machine concerned and the extent to which hazards, hazardous situations and events are covered are indicated in the scope of this part of ISO 16110.

This part of ISO 16110 provides requirements and recommendations relating to hydrogen generators using fuel-processing technologies so as to promote:

- safety of persons and property;
- consistency of control response; and
- ease of maintenance.

High performance is not to be obtained at the expense of the essential factors mentioned above.

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Hydrogen generators using fuel processing technologies —

Part 1: Safety

1 Scope

This part of ISO 16110 applies to packaged, self-contained or factory matched hydrogen generation systems with a capacity of less than 400 m³/h at 0 °C and 101,325 kPa, herein referred to as hydrogen generators, that convert an input fuel to a hydrogen-rich stream of composition and conditions suitable for the type of device using the hydrogen (e.g. a fuel cell power system or a hydrogen compression, storage and delivery system).

It applies to hydrogen generators using one or a combination of the following input fuels:

- natural gas and other methane-rich gases derived from renewable (biomass) or fossil fuel sources, e.g. landfill gas, digester gas, coal mine gas;
- fuels derived from oil refining, e.g. diesel, gasoline, kerosene, liquefied petroleum gases such as propane and butane;
- alcohols, esters, ethers, aldehydes, ketones, Fischer-Tropsch liquids and other suitable hydrogen-rich organic compounds derived from renewable (biomass) or fossil fuel sources, e.g. methanol, ethanol, di-methyl ether, biodiesel;
- gaseous mixtures containing hydrogen gas, e.g. synthesis gas, town gas.

This part of ISO 16110 is applicable to stationary hydrogen generators intended for indoor and outdoor commercial, industrial, light industrial and residential use.

It aims to cover all significant hazards, hazardous situations and events relevant to hydrogen generators, with the exception of those associated with environmental compatibility (installation conditions), when they are used as intended and under the conditions foreseen by the manufacturer.

NOTE A list of significant hazards and hazardous situations dealt with in this part of ISO 16110 is found in Annex A.

This part of ISO 16110 is a product safety standard suitable for conformity assessment as stated in IEC Guide 104, ISO/IEC Guide 51 and ISO/IEC Guide 7.

2 Normative references

The following referenced documents are indispensable for the application 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 4080, *Rubber and plastics hoses and hose assemblies — Determination of permeability to gas*

ISO 4413, *Hydraulic fluid power — General rules relating to systems*

ISO 4414, *Pneumatic fluid power — General rules relating to systems*

ISO 16110-1:2007(E)

ISO 5388, *Stationary air compressors — Safety rules and code of practice*

ISO 10439, *Petroleum, chemical and gas service industries — Centrifugal compressors*

ISO 10440-1, *Petroleum and natural gas industries — Rotary-type positive-displacement compressors — Part 1: Process compressors (oil-free)*

ISO 10440-2, *Petroleum and natural gas industries — Rotary-type positive-displacement compressors — Part 2: Packaged air compressors (oil-free)*

ISO 10442, *Petroleum, chemical and gas service industries — Packaged, integrally geared centrifugal air compressors*

ISO 12499:1999, *Industrial fans — Mechanical safety of fans — Guarding*

ISO 13631, *Petroleum and natural gas industries — Packaged reciprocating gas compressors*

ISO 13707, *Petroleum and natural gas industries — Reciprocating compressors*

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

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

ISO 13943, *Fire safety — Vocabulary*

ISO 14121, *Safety of machinery — Principles of risk assessment*

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

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

ISO 16528 (all parts)¹⁾, *Boilers and pressure vessels*

IEC 60079-0:2004, *Electrical apparatus for explosive gas atmospheres — Part 0: General requirements*

IEC 60079-10:2002, *Electrical apparatus for explosive gas atmospheres — Part 10: Classification of hazardous areas*

IEC 60146-1-1, *Semiconductor convertors — General requirements and line commutated convertors — Part 1-1: Specifications of basic requirements*

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

IEC 60335-1:2004, *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 60529:2001, *Degrees of protection provided by enclosures (IP Code)*

IEC 60664 (all parts), *Insulation coordination for equipment within low-voltage systems*

IEC 60704-3, *Household and similar electrical appliances — Test code for the determination of airborne acoustical noise — Part 3: Procedure for determining and verifying declared noise emission values*

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

1) To be published.

IEC 60730-2-5, *Automatic electrical controls for household and similar use — Part 2-5: Particular requirements for automatic electrical burner control systems*

IEC 60730-2-6, *Automatic electrical controls for household and similar use — Part 2-6: Particular requirements for automatic electrical pressure sensing controls including mechanical requirements*

IEC 60730-2-9, *Automatic electrical controls for household and similar use — Part 2-9: Particular requirements for temperature sensing controls*

IEC 60730-2-17, *Automatic electrical controls for household and similar use — Part 2-17: Particular requirements for electrically operated gas valves, including mechanical requirements*

IEC 60730-2-19, *Automatic electrical controls for household and similar use — Part 2-19: Particular requirements for electrically operated oil valves, including mechanical requirements*

IEC 60812, *Analysis techniques for system reliability — Procedure for failure mode and effects analysis (FMEA)*

IEC 61000-3-2, *Electromagnetic compatibility (EMC) — Part 3-2: Limits — Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)*

IEC 61000-3-3, *Electromagnetic compatibility (EMC) — Part 3-3: Limits — Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*

IEC/TS 61000-3-4, *Electromagnetic compatibility (EMC) — Part 3-4: Limits — Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A*

IEC/TS 61000-3-5, *Electromagnetic compatibility (EMC) — Part 3: Limits — Section 5: Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A*

IEC 61000-6-1, *Electromagnetic compatibility (EMC) — Part 6-1: Generic standards — Immunity for residential, commercial and light-industrial environments*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) — Part 6-2: Generic standards — Immunity for industrial environments*

IEC 61000-6-3, *Electromagnetic compatibility (EMC) — Part 6-3: Generic standards — Emission standard for residential, commercial and light-industrial environments*

IEC 61000-6-4, *Electromagnetic compatibility (EMC) — Part 6-4: Generic standards — Emission standard for industrial environments*

IEC 61025, *Fault tree analysis (FTA)*

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

IEC 61511-3, *Functional safety — Safety instrumented systems for the process industry sector — Part 3: Guidance for the determination of the required safety integrity levels*

IEC 61779-4, *Electrical apparatus for the detection and measurement of flammable gases — Part 4: Performance requirements for group II apparatus indicating up to 100 % lower explosive limit*

IEC 61779-6, *Electrical apparatus for the detection and measurement of flammable gases — Part 6: Guide for the selection, installation, use and maintenance of apparatus for the detection and measurement of flammable gases*

IEC 61882, *Hazard and operability studies (HAZOP studies) — Application guide*

IEC 62086-1, *Electrical apparatus for explosive gas atmospheres — Electrical resistance trace heating — Part 1: General and testing requirements*

3 Terms and definitions

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

3.1

air-rich condition

mixtures of fuel and air, in which the air content is greater than that of a stoichiometric mixture

NOTE Air-rich conditions are used when complete fuel reaction is intended (e.g. in flame burners).

3.2

air-rich system

system using air-rich conditions

3.3

ambient temperature

temperature of the medium surrounding a device, item of equipment or installation

3.4

auto-ignition

phenomenon in which a mixture of gases, vapours, mists, dusts or sprays ignites spontaneously with no external ignition source

[ISO/TR 15916:2004]

3.5

auto-ignition temperature

lowest temperature at which auto-ignition occurs

[ISO/TR 15916:2004]

3.6

auto-thermal reforming

coupling of partial oxidation and steam reforming

3.7

burner control system

system that monitors the operation of fuel burners, which is comprised of a programming unit and a flame detector, and which may include an ignition source and/or ignition device

3.8

cabinet

rigid structure that may contain the hydrogen generator that protects it against specific environmental and climatic conditions and incidental contact by people and livestock and that may also provide protection to people and livestock against incidental contact with hazardous parts or materials

3.9

catalytic partial oxidation

exothermic conversion of a hydrocarbon with a small quantity of air into hydrogen over a catalyst

3.10**combustible gas, liquid or vapour**

gas, liquid or vapour which, when mixed with air or oxygen, is capable of propagating flame away from the source of ignition when ignited

3.11**commercial**

relating to the use of hydrogen generators by laymen in non-manufacturing business facilities such as stores, hotels, office buildings, educational institutes and refilling stations

3.12**concealed location**

location that cannot be accessed without damaging permanent parts of a building structure or a finish surface

NOTE Spaces above, below or behind readily removable panels or doors are not considered as concealed.

3.13**conformity assessment**

demonstration that specified requirements relating to a product, process, system, person or body are fulfilled

NOTE The subject of conformity assessment includes activities defined in ISO/IEC 17000, such as testing, inspection and certification, as well as the accreditation of conformity assessment bodies.

3.14**critical failure mode**

failure mode of a software or hardware item, which can result in unacceptable risk of harm

3.15**maximum allowable pressure**

maximum pressure for which equipment is designed

3.16**design temperature**

temperature value applied to the design of pressure-containing components

3.17**direct ignition**

ignition which is applied directly to the main burner without the use of a pilot

3.18**explosion limits**

maximum and minimum concentrations of a gas, vapour, mist, spray or dust, in air or oxygen, for stable detonation to occur

NOTE 1 The limits are controlled by the size and geometry of the environment, the concentration of the fuel, as well as the means by which ignition occurs.

NOTE 2 The terms “explosive limit” and “flammable limit” are widely used as equivalent while in fact they are not identical. The only substance for which the explosive limit is significantly different from the flammable limit is hydrogen.

[ISO/TR 15916:2004]

3.19**explosive atmosphere**

mixture with air, under atmospheric conditions, of flammable substances in the form of gas, vapour, mist or dust in which, after ignition, combustion spreads throughout the unconsumed mixture

[IEC 60079-10:2002]

3.20

explosive gas atmosphere

mixture with air, under atmospheric conditions, of flammable substances in the form of gas or vapour in which, after ignition, combustion spreads throughout the unconsumed mixture

NOTE Although a mixture which has a concentration above the upper explosive limit (UEL) is not an explosive gas atmosphere, it can readily become so and, in certain cases for area classification purposes, it is advisable to consider it as an explosive gas atmosphere.

[IEC 60079-10:2002]

3.21

factory matched unit

system components 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

3.22

Fischer-Tropsch liquids

liquids derived through a technology based on the Fischer-Tropsch synthesis

EXAMPLES Gas-to-liquids (GTL), methanol-to-gasoline (MTG), methanol-to-olefins (MTO), methanol-to-propylene (MTP), methanol-to-olefins-to-gasoline and distillates (MOGD), dimethyl ether (DME) processes, etc.

3.23

flame detector

device that provides a signal indicating the presence or absence of flame

NOTE A flame detector includes a flame sensor and may include an amplifier and a relay for signal transmission. The amplifier and the relay may be embedded in the detector's housing or combined with a programming unit.

3.24

flame sensor

primary device in a flame detector, which detects the presence of flame

EXAMPLES Optical sensors and flame electrodes (flame rods).

3.25

flame failure lock-out time

period of time between the signal indicating an absence of flame and lock-out

3.26

flammability limit

lower (LFL) and upper (UFL) vapour or gas concentration of fuel in air within which a flammable mixture will ignite and propagate a flame

NOTE 1 These limits are functions of temperature, pressure, diluents and ignition energy.

NOTE 2 These limits are usually expressed as percent (volume fraction).

[ISO/TR 15916:2004]

3.27

flashback

recession of a flame into the mixing chamber or further upstream

3.28

frame

assembly of structural members held together through permanent (weldment, riveting) or screw-type joints, carrying the hydrogen generator body and its equipment and components, providing accuracy of location, strength and rigidity of support

3.29**fuel processing system**

sequence of catalytic or chemical reactors that convert an input fuel to a hydrogen-rich stream of pre-specified composition and conditions

3.30**fuel-rich condition**

mixture of fuel and air, in which the fuel content is greater than that of a stoichiometric mixture

NOTE Fuel-rich conditions are used when complete air reaction is intended (e.g. in catalytic partial oxidation, preferential oxidation or auto-thermal reactors).

3.31**fuel-rich system**

system operating under fuel-rich conditions

3.32**harm**

physical injury or damage to the health, or damage to property or the environment

[ISO/IEC Guide 51]

3.33**hazard**

potential source of harm

NOTE The term hazard can be qualified in order to define its origin or the nature of the expected harm (e.g. electric shock hazard, crushing hazard, cutting hazard, toxic hazard, fire hazard, drowning hazard).

[ISO/IEC Guide 51]

3.34**hazardous area**

area in which an explosive gas 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 apparatus

[IEC 60079-10:2002]

3.35**hazardous situation**

circumstance in which people, property or the environment are exposed to one or more hazards

[ISO/IEC Guide 51]

3.36**ignition activation period**

period of time between energizing the main gas valve and deactivation of the ignition means

3.37**incident**

event or chain of events that can, but does not necessarily, result in harm

3.38**industrial**

relating to the use of hydrogen generators by qualified and experienced personnel in a controlled manufacturing or processing environment, e.g. a chemical plant or a mine

3.39

input fuel

chemical substance fed to the hydrogen generator as a reactant or as input energy, usually composed of natural gas, other hydrocarbons, alcohols or other organic compounds

3.40

intermittent pilot

pilot which is automatically ignited when an appliance is called on to operate, which remains continuously ignited during each period of main burner operation, and which is automatically extinguished when each main burner operating cycle is complete

3.41

interrupted pilot

pilot which is automatically ignited prior to the admission of fuel to the main burner and which is automatically extinguished when the main flame is established

3.42

light industrial

relating to the use of a hydrogen generator by personnel with limited qualification and experience in manufacturing environments with limited dedicated controls, e.g. computer and electronics manufacturing facilities

3.43

limit gases

test gases representative of the extreme variations in the characteristics of the gases for which appliances have been designed

3.44

lock-out

safety shutdown in which the system goes into a volatile or non-volatile lock-out

3.45

lower explosive limit

LEL

concentration of flammable gas or vapour in air below which the gas atmosphere is not explosive

3.46

main flame establishing period

the period of time between the signal to energize the main fuel flow means and the signal indicating presence of the main burner flame

3.47

ventilation

movement of air and its replacement with fresh air by artificial suction means, for example fans, and applied to a general area

3.48

non-hazardous area

area in which an explosive gas atmosphere is not expected to be present in quantities such as to require special precautions for the construction, installation and use of apparatus

3.49

non-volatile lock-out

safety shutdown condition of the system, such that a restart can only be accomplished by a manual reset of the system and by no other means

3.50**normal operation**

situation when the equipment is operating within its design parameters

NOTE 1 Minor releases of flammable material may be part of normal operation. For example, releases from seals which rely on wetting by the fluid that is being pumped are considered to be minor releases.

NOTE 2 Failures (such as the breakdown of pump seals, flange gaskets or spillages caused by accidents) which involve urgent repair or shutdown are not considered to be part of normal operation nor are they considered to be catastrophic.

NOTE 3 Normal operation includes start-up and shutdown conditions.

3.51**operating mode**

preset condition of functioning of the system

3.52**packaged unit**

skid or cabinet containing system components pre-assembled in a factory and engineered to work together in one skid or cabinet

3.53**permissive**

condition within a logic sequence that must be satisfied before the sequence is allowed to proceed to the next phase

3.54**pilot**

flame, smaller than the main flame, which is utilized to ignite the main burner or burners

3.55**pressure gradient monitor**

device, fail-safe by design, installed in a heat exchanger to prevent heat exchange fluids from mixing where necessary, and that operates by isolating the heat exchanger when the positive pressure gradient between the fluids is less than a minimum predefined pressure threshold

NOTE A pressure gradient monitor can be used to protect the quality of potable water when the other fluid is a contaminant such as a toxic heat transfer fluid.

3.56**purge time**

period during which air is introduced to displace any remaining air/fuel mixtures or products of combustion from the combustion zone and flue ways

3.57**pyrophoric material**

material capable of igniting spontaneously when brought into contact with air

[ISO 13943]

3.58**reaction failure lock-out time**

time between the moment of reaction failure detection and the automatic shut-off of the fuel supply for air-rich operation, or the automatic shut-off of the supply of all reactants for fuel-rich operations

3.59**reaction initiation failure time**

time between the recognition of failure of reaction initiation and the automatic shut-off of the fuel supply for air rich operation, or for fuel-rich operation, of the supply of all reactants

3.60

recycle time

period of time between the signal to de-energize the fuel flow means following the loss of flame and the signal to begin a new start-up procedure

3.61

recycling

process by which, following an unsuccessful hydrogen generator start-up, repeated complete start-up trials are attempted

3.62

reference conditions

arbitrarily chosen conditions for measured volumes of gases when recalculated to a temperature of 15 °C and an absolute pressure of 101,325 kPa

3.63

reference gases

test gases on which appliances operate under normal conditions, when they are supplied at the corresponding normal pressure

3.64

reignition

process by which, following loss of the flame signal, the ignition device will be re-energized without interruption of the fuel flow means

3.65

residential

relating to the use of hydrogen generators by laymen in private households

3.66

response time

time required for a hydrogen generator to transfer from one defined state to another

3.67

risk

combination of the probability of harm and the severity of that harm

[ISO/IEC Guide 51]

3.68

risk analysis

systematic use of available information to identify hazards and to estimate the risk

[ISO/IEC Guide 51]

3.69

risk assessment

overall process comprising a risk analysis and a risk evaluation

[ISO/IEC Guide 51]

3.70

risk evaluation

procedure based on the risk analysis to determine whether the tolerable risk has been achieved

[ISO/IEC Guide 51]

3.71**safeguarding**

procedure for actions of the controlling system based on monitoring the technical process and aimed at avoiding process conditions which would be hazardous to personnel, plant, product or environment

3.72**safety and reliability analysis**

documented and systematic group of activities intended to recognize and evaluate the potential failure of a product/process and the effects of that failure, and to identify actions that could eliminate or reduce the risk of harm of the potential failure occurring

3.73**safety shutdown**

process which is effected immediately following the response of a protection device or the detection of a fault in the control system and which puts the system out of operation by deactivating terminals for the gas shut-off valves and the ignition device

3.74**self contained unit**

unit that is complete and independent in itself

3.75**severity**

qualitative measure of the worst possible incident that could be caused by a specific hazard

3.76**start position**

position which denotes that the system is not in the lock-out condition and has not yet received the start signal, but can proceed with the start-up sequence if required

3.77**steam reforming**

conversion of a hydrocarbon with water for the generation of hydrogen with input of energy usually over a catalyst

3.78**test gases**

gases intended for the verification of the operational characteristics of an appliance using combustible gases

3.79**tolerable risk**

risk which is accepted in a given context based on the current values of society

[ISO/IEC Guide 51]

3.80**transition**

process through which the hydrogen generator changes from one operating mode to another

3.81**upper explosive limit****UEL**

concentration of flammable gas or vapour in air above which the gas atmosphere is not explosive

3.82**volatile lock-out**

safety shutdown condition of the system, such that a restart can only be accomplished by either the manual reset of the system or an interruption of the main power and its subsequent restoration

3.83

water treatment system

system providing for treatment and purification of recovered or added water for use within the hydrogen generator

4 Safety requirements and protective measures

4.1 Safety and reliability analysis

The manufacturer shall demonstrate that a safety and reliability analysis has been performed as per IEC 60812, IEC 61025, or equivalent.

The manufacturer shall ensure that:

- all reasonably foreseeable hazards and hazardous situations associated with the hydrogen generators throughout their anticipated lifetime have been identified;
- the risk for each of these hazards has been estimated as per ISO 14121, IEC 61882, or IEC 61511-3 as applicable;
- the risks have been eliminated or reduced as far as practical through the design (inherently safe design and construction);
- the necessary protection measures in relation to risks that are not eliminated have been taken, including provision of warning and safety devices;
- provisions have been made to inform the users of any additional safety measures that they may be required to implement.

4.2 Configuration

4.2.1 Fuel processing system

The hydrogen generator shall be provided with a fuel processing system.

The fuel processing system may include the following steps:

- fuel clean-up, in which the fuel may be filtered and/or desulfurized;
- primary conversion, in which the fuel is reacted mostly to hydrogen, carbon dioxide, and carbon monoxide by means such as steam reforming, auto-thermal reforming, or catalytic or non-catalytic partial oxidation;
- water-gas shift conversion, in which carbon monoxide reacts with steam to produce additional hydrogen;
- purification, in which carbon monoxide and other impurities are removed from the hydrogen-rich product stream;
- conditioning, in which the stream temperature and humidity are adjusted to levels suitable for the type of device using the hydrogen;
- tail gas combustion, in which unreacted fuel and unused hydrogen are burned in a catalytic or non-catalytic manner prior to their release to the environment.

4.2.2 Fluid management system

The hydrogen generator shall be provided with a fluid management system.

The fluid management system may meter, condition and process fluids, or adjust the fluid pressure for use within the hydrogen generator. These fluids may be reactants such as air (oxidant), fuel, water (or steam), intermediate product streams, or utility fluids such as inert gas and heat transfer fluids (water, oil). The fluid management system may include complex sub-systems such as steam generators, compressors and water treatment units.

4.2.3 Thermal management system

The hydrogen generator shall be provided with a thermal management system that provides cooling and heat rejection to maintain thermal equilibrium within the hydrogen generator, and which may provide for the recovery of excess heat and assist in heating the unit during start-up.

NOTE The thermal management system uses heat and mass exchange networks to minimize external heating and cooling requirements as well as water consumption and energy losses by linking hot and cold process streams in a thermodynamically advantageous way.

4.2.4 Automatic control system

The hydrogen generator shall be provided with an automatic process control system that regulates the efficient interaction of all components in order to maintain the process parameters within the limits specified by the manufacturer, without manual intervention.

NOTE The automatic process control system may comprise mechanical, hydraulic, pneumatic, electrical, electronic, programmable electronic, and computer hardware/software elements.

4.2.5 Electrical system

The hydrogen generator shall be provided with an electrical system.

The electrical system may comprise circuits and devices that regulate and distribute electrical power within the hydrogen generator.

4.2.6 Frame and cabinet

The hydrogen generator shall be mounted on a frame and, whenever required, protected by a cabinet.

Cabinets may include natural or forced ventilation to allow for the circulation of external air through the interior compartments to remove excess heat and hazardous fumes or vapours.

4.2.7 Interconnection piping

The hydrogen generator may include part or all of the interconnection piping, joints and fittings. In particular, the hydrogen generator may include a flue gas vent system and the product delivery piping used to deliver the gaseous hydrogen-containing product stream to distributed components that may or may not be factory matched, such as a fuel cell power system or a hydrogen compression, storage and delivery system.

4.3 Physical environment and operating conditions

4.3.1 General

The hydrogen generator and protective systems shall be designed and constructed as to be capable of performing their intended function in the physical environment and operating conditions specified in 4.3.2 to 4.3.8.

4.3.2 Electrical power input

The hydrogen generator electrical power input shall meet the requirements specified in IEC 60204-1 for industrial applications or IEC 60335-1 for residential, commercial and light industrial applications. In the case of a special source of electrical power such as a fuel cell, the hydrogen generator electrical power input shall meet requirements specified by the manufacturer.

4.3.3 Physical environment

The manufacturer shall specify in the product's technical documentation the physical environment conditions for which the hydrogen generator is designed. Consideration shall be given to:

- indoor and/or outdoor use;
- the maximum altitude above sea level up to which the hydrogen generator shall be capable of operating as intended;
- the range of air temperatures and humidity within which the hydrogen generator shall be capable of operating as intended;
- the seismic zone where the hydrogen generator may be sited;
- the suitability of the hydrogen generator to operate in hazardous areas;
- the suitability of the hydrogen generator to operate where contaminants (e.g. dust, salt, smoke and corrosive gases) are present in the physical environment;
- the risk of lightning for outdoor use.

4.3.4 Input fuels

The manufacturer shall specify in the product's technical documentation the composition limits and supply characteristics of the input fuels that shall be used in the hydrogen generator.

4.3.5 Water

The manufacturer shall specify in the product's technical documentation the quality and supply characteristics of the water that shall be used in the hydrogen generator.

4.3.6 Vibrations, shock and bump

The hydrogen generator shall be designed to withstand, or means shall be provided to protect against, the effects of vibrations, shock and bump, including those generated by the operation of the generator and its associated equipment and those created by the physical environment except the seismic shocks, which shall be addressed separately (see 4.3.3). This may be accomplished by selecting vibration resistant equipment, mounting the source of vibration away from the hydrogen generator, or using anti-vibration mountings.

The manufacturer shall specify in the product's technical documentation the means that shall be used to protect the hydrogen generator from vibrations, shocks and bumps whenever any is required.

4.3.7 Wind

The hydrogen generator shall meet the wind tests specified in 5.4.11.

4.3.8 Handling, transportation and storage

The hydrogen generator shall be designed to withstand, or precautions shall be taken to protect against, the effects of transportation and storage temperatures within a range of $-25\text{ }^{\circ}\text{C}$ to $55\text{ }^{\circ}\text{C}$ and for short periods not exceeding 24 h at up to $70\text{ }^{\circ}\text{C}$, as per IEC 60204-1. Alternative temperature ranges may be specified by the manufacturer and shall then be included in the product's technical documentation.

The hydrogen generator or each component thereof shall:

- be capable of being handled and transported safely, and when necessary, be provided with means for handling by cranes or similar equipment; and
- be packaged or designed so that it can be safely stored (e.g. adequate stability, special supports, etc.).

The manufacturer shall specify in the product's technical documentation the special means for handling, transportation and storage whenever any is required.

4.3.9 System purging

Where for safety reasons a passive state is required after shutdown or prior to start-up, the hydrogen generator compartment(s) shall be provided with a purging system. The manufacturer shall specify in the product's technical documentation the characteristics of the medium that shall be used for purging and the procedures to avoid human error during manual purging.

4.4 Design requirements

4.4.1 General

The hydrogen generator shall be able to perform, to function, to be transported, installed, adjusted, maintained, dismantled and disposed of without causing an injury or damage to health under the conditions of intended use specified in the product's technical documentation.

The hydrogen generator shall be so designed, constructed and/or equipped that reasonably foreseeable risks due to gases, liquids, dust or vapours released during its operation and its maintenance, or used in its construction, are avoided.

Where explosive, flammable, or toxic fluids are contained in the piping, precautions shall be taken in the design and marking of sampling and take-off points.

Components in which condensation or other sources of liquid may collect prior to start-up or during normal operation shall be equipped with means to safely relieve pressure if the potential exists for thermal energy to evaporate the liquid.

Liquid-fuelled hydrogen generators shall include provisions for capturing, recycling and/or safely disposing of released liquid fuel. Drip pans, spill guards or double-walled pipes shall be designed to prevent uncontrolled releases e.g. by provision of level switches.

In so far as their purpose allows:

- a) accessible parts of the hydrogen generator shall have no exposed sharp edge and no rough surfaces likely to cause injury;
- b) the hydrogen generator, or parts of it where people are intended to move about or stand, shall be designed and constructed to prevent persons slipping, tripping or falling on or off these parts;
- c) the moving parts of the hydrogen generator shall be designed, built and laid out to avoid hazards or, where hazards persist, fixed with guards or protective devices in such a way as to prevent all risk of contact that could lead to accidents;

- d) any areas requiring access for production, adjustment and maintenance operations shall be designed and equipped to allow safe entry or access.

All equipment and components whose failure may result in a hazardous situation, as identified by the safety and reliability analysis of 4.1, shall be separately tested and recognized or shall be certified for their intended usage.

4.4.2 Design temperature

The maximum and minimum temperature of components and materials, as installed in the hydrogen generator, shall not exceed their temperature ratings.

4.4.3 Mechanical stability

The hydrogen generator, components and fittings shall be so designed and constructed that they are stable in the physical environment and operating conditions specified in 4.3, including climatic and seismic conditions. Otherwise, appropriate means of anchorage shall be incorporated and indicated in the product's technical documentation.

The various parts of the hydrogen generator and their linkages shall be so constructed that, when used normally, no instability, distortion, breakage or wear likely to impair their safety can occur.

All parts shall be securely mounted or attached and rigidly supported. Shock-mounts may be used when suitable for the application.

4.4.4 Temperature of surfaces accessible to the users

The manufacturer shall take steps to eliminate any risk of injury caused by contact with, or proximity to, hydrogen generator parts or materials at high temperatures.

When external surfaces of the hydrogen generator may be contacted by users without personal protective equipment while the hydrogen generator is in operation, the manufacturer shall either:

- limit the temperature rise above ambient temperature of these surfaces as per Table 1; or
- fix guards or protective devices in such a way as to prevent risk of contact that could lead to accidents.

Table 1 — Maximum surface temperature rises above ambient temperature of external components and/or cabinets that may be contacted during operation by users without personal protective equipment (based on IEC 60335-1:2004, Clause 11)

Material	Maximum surface temperature rise above ambient temperature °C
	Surface contacted for short periods only, in normal use
Metal	35
Porcelain or vitreous material	45
Plastics, rubber or wood	60
NOTE 1 The temperature rise values are based on an ambient temperature of 25 °C.	
NOTE 2 The temperature rise limit for metal applies to parts having a metal coating at least 0,1 mm thick and to metal parts having a plastic coating less than 0,3 mm thick.	

4.4.5 Temperatures of adjacent walls, floor and ceiling

The heat generated by the hydrogen generator intended for indoor use shall not raise the temperature of adjacent walls, floor and ceiling by more than 50 °C above ambient temperature under the test conditions of 5.4.9.

4.4.6 Temperature of polymeric components

Polymeric components equipped onto hydrogen generators (including manufacturer's specified or provided vent systems) shall retain their functional integrity in the intended range of operational temperatures. This provision shall be deemed met if the polymeric components meet the requirements of 5.4.10.

4.4.7 Noise

The hydrogen generator shall be so designed and constructed that the emission of airborne noise is reduced to a level suited for the intended use or location in compliance with applicable regional or national airborne noise codes and standards.

4.4.8 Exhaust gas condensate discharge system

The exhaust gas condensate formed in the flue and its connecting pipes, shall be removed by means of a discharge pipe (or pipes) or any other device that will ensure safe removal of the condensate. The internal diameter of the outside connection of the condensate discharge system shall be at least 13 mm. The condensate discharge system shall be a part of the hydrogen generator and shall be such that it can be easily inspected and cleaned in accordance with the manufacturer's instructions.

The condensate discharge system shall not transmit combustion products into the room where the hydrogen generator is installed. If a water trap is used, the water seal shall be at least 25 mm at the maximum pressure in the combustion chamber at the maximum flue gas length specified by the manufacturer.

Surfaces in contact with condensates (e.g. drains, water traps and siphons) shall be designed to prevent (unintended) condensate retention.

4.4.9 Carbon monoxide

The hydrogen generator exhaust to atmosphere, under normal steady state operating conditions, shall not contain concentrations of carbon monoxide in excess of 300 µl/l in an air-free sample of the effluents.

NOTE This threshold value may be further restricted by the manufacturer for specific applications depending on expected usage patterns and the potential exposure of CO gas to humans or animals.

The hydrogen generator exhaust to atmosphere, under abnormal conditions of a blocked outlet, shall not contain concentrations of carbon monoxide in excess of 600 µl/l in an air-free sample of the effluents as per the test in 5.4.12.2. Additionally, the hydrogen generator shall not produce a carbon monoxide concentration in excess of 600 µl/l in air-free sample of the effluents when the air supply inlet is blocked as per the test in 5.4.12.3.

4.4.10 Soundness of gas-carrying parts

All gas-carrying parts of the hydrogen generator shall be sound. Soundness shall be verified as per 5.4.3.

4.5 Selection of materials

4.5.1 Materials known to pose health and physical hazards

When materials used in the construction of the hydrogen generator are known to pose health hazards under certain circumstances, the manufacturer shall implement the measures and include in the product's technical documentation the requirements and the information necessary to avoid endangering persons' safety or health during all phases of the hydrogen generator's life cycle, i.e. packing, transportation, installation, commissioning, operation, housekeeping, maintenance, decommissioning, recycling and disposal.

4.5.2 Asbestos

Asbestos or asbestos-containing material(s) shall not be used in the construction of the hydrogen generator.

4.5.3 Pyrophoric materials

When materials known to be pyrophoric are used in the construction of the hydrogen generator, the manufacturer shall provide in the product's technical documentation the requirements and procedures to passivate or isolate these materials for their safe handling, transportation, recycling or disposal in accordance with applicable national or regional codes and standards for hazardous materials.

4.5.4 Nickel carbonyl formation

When materials used in the construction of the hydrogen generator may form nickel carbonyl at conditions potentially present during the operation of the hydrogen generator, the manufacturer shall provide means to ensure that at all times the conditions in the hydrogen generator favour nickel carbonyl decomposition rather than formation.

This may be achieved by ensuring that all carbon monoxide is purged before any part of the catalyst beds or other nickel-containing components falls below 200 °C. If this means is used and the purge fails, a purge interlock shall prevent restart until a manual purge has taken place.

In addition, the manufacturer shall include in the product's technical documentation warnings to inform the user that the area near the exhaust shall be cleared during the manual purge.

4.5.5 Material properties

4.5.5.1 General properties

Metallic and non-metallic materials used in the construction of internal or external parts of the hydrogen generator shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable within the scheduled lifetime of the equipment and for all test conditions.

This requirement applies in particular to those materials exposed directly or indirectly to moisture or that contain process gas or liquid streams as well as all parts and materials used to seal or interconnect the same, such as welding consumables.

4.5.5.2 Mechanical properties

The materials shall retain their mechanical stability with respect to strength including fatigue properties, endurance limit, and creep strength when exposed to the full range of service conditions and lifetime specified by the manufacturer.

4.5.5.3 Chemical and physical properties

The materials shall be resistant to the chemical and physical action of the fluids that they contain, as well as to environmental degradation.

The chemical and physical properties necessary for operational safety shall not be affected within the scheduled lifetime of the equipment unless replacement is foreseen. When selecting materials and manufacturing methods, due account shall be taken of the following material's properties:

- corrosion and wear resistance;
- electrical conductivity;
- impact strength;

- ageing resistance;
- effects of temperature variations;
- effects of ultraviolet radiation;
- effects arising when dissimilar materials such as galvanic corrosion are put together;
- resistance to carburization attack and to the degradation effects of hydrogen on a material's mechanical performance.

NOTE Guidance on accounting for carburization attack and the degradation effects of hydrogen on a material's mechanical performance can be found in ISO/TR 15916 and in Annex B.

Where conditions of erosion, abrasion, corrosion, or other chemical attack or temperature degradation exist, as determined by the safety and reliability analysis of 4.1, measures shall be taken to:

- minimize that effect by design, e.g. additional thickness, or by protection, e.g. measures such as use of liners, cladding materials or surface coatings, taking due account of the intended and reasonably foreseeable use;
- permit replacement of parts which are affected; and
- indicate in the maintenance manual the type and the frequency of inspection as well as the maintenance measures necessary for continued safe use, indicating where appropriate which parts are subject to wear and the criteria for replacement.

4.5.5.4 Permeability to hydrogen

Leakage due to permeability of materials used for the construction of components containing combustible gases, in particular hydrogen, shall be consistent with the requirements of 4.7.

The permeability of rubber, plastic hoses and hose assemblies to hydrogen and to other combustible gases non-soluble in water shall be tested as per ISO 4080.

4.5.6 Plastic and elastomeric materials

Plastic or elastomeric materials shall only be used in non-classified areas or Zone 2 locations as per IEC 60079-10. Plastic or elastomeric materials used in Zone 2 locations shall be antistatic to avoid static build-up when conveying dry gases. These materials shall meet the requirements and be tested as per IEC 60079-0:2004, subclauses 7.3 and 26.13.

4.6 Pressure equipment and piping

4.6.1 Pressure equipment

Pressurized vessels, such as reactors, heat exchangers, gas-fired tube heaters and boilers, electric boilers, coolers, accumulators and similar containers, and associated pressure relief mechanisms, such as pressure relief valves and similar devices, shall be constructed and marked in accordance with a commonly used national/regional standard that has a proven history of supporting public safety and has a good commercial operating experience, such as one of the standards recognized by ISO 16528.

Vessels that do not qualify as "pressure vessels" in accordance with a commonly used national/regional standard that has a proven history of supporting public safety and has a good commercial operating experience, such as one of the standards recognized by ISO 16528, shall be constructed of suitable materials in accordance with 4.5 and shall meet applicable requirements of 4.4. Such vessels, and their related joints and fittings, shall be designed and constructed to prevent unintended releases.