INTERNATIONAL STANDARD

ISO 16110-1

First edition
2007-03-15

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)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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.

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 m^3/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 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* $\leqslant$ *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* $\leqslant$ *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 °C to 55 °C and for short periods not exceeding 24 h at up to 70 °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.

4.6.2 Piping systems

4.6.2.1 General

The provisions of this subclause apply to all piping systems used as part of the hydrogen generator, including interconnection piping if the interconnection piping is provided with the hydrogen generator.

The manufacturer shall specify in the product's technical documentation the connections, piping materials, construction, testing requirements and other applicable limitations for the interconnection piping provided with the hydrogen generator. This refers in particular to the flue gas vent system and to the product delivery piping used to deliver the gaseous hydrogen-containing product stream to distributed components that may or may not be factory matched.

Metallic, non-metallic, rigid and flexible piping and its associated joints and fittings shall conform to the applicable requirements of ISO 15649.

As piping systems which are designed for internal gage pressure at or above zero but less than 105 kPa and for handling fluids that are non-flammable, non-toxic and not damaging to human tissue and which have a design temperature from -29 °C to 186 °C are not included in the scope of ISO 15649, these shall be constructed of suitable materials in accordance with 4.5 and shall meet applicable requirements of 4.4. Such pipes, and their related joints and fittings, shall be designed and constructed to prevent unintended releases.

4.6.2.2 Design and construction

The design and construction of both rigid and flexible pipes and fittings shall consider the following aspects:

— Materials shall meet the requirements specified in 4.5.

— The internal surfaces of piping shall be thoroughly cleaned to remove loose particles, and the ends of piping shall be carefully reamed to remove obstructions and burrs.

— If fluid condensate or sediment accumulation inside gaseous fluid piping can cause damage from water hammer, vacuum collapse, corrosion or uncontrolled chemical reactions during start-up, shutdown and/or use, the manufacturer shall provide means for drainage and removal of deposits from low areas and for access during cleaning, inspection and maintenance. In particular, the manufacturer shall take measures to prevent sediment or condensate accumulation in fuel gas controls. Sediment traps or filters shall be installed or guidelines shall be provided in the product's technical documentation.

— The manufacturer shall take measures to prevent sediment accumulation in liquid fuel controls. A filter shall be provided upstream of the fuel controls.

— Non-metallic piping used to convey combustible gases shall be protected against the possibility of overheating. Measures as required by the safety and reliability analysis specified in 4.1 shall be provided to prevent the temperature of components conveying combustible gases from exceeding their design temperatures.

— Non-metallic piping used to convey combustible gases shall be protected against the possibility of mechanical damage by means of adequate location or provision of guards and/or supports.

— Pressure relief valve discharges shall be controlled in a manner consistent with the requirements of 4.7. Pressure relief valve release shall be piped outdoors either through a dedicated vent or by means of the flue gas vent system or discharged with the ventilation air.

4.6.2.3 Specific requirements for flue gas vent systems

The hydrogen generator shall be provided with a flue gas vent system to convey products of combustion from fuel utilization equipment to the outside atmosphere. The manufacturer shall design and construct the flue gas vent pipe, or shall provide in the product's technical documentation the instructions to do so, in compliance with the following requirements:

- Materials shall meet the requirements specified in 4.5. In particular, the flue gas vent system shall be constructed of material resistant to corrosion by condensate. Non-metallic material shall be judged on its temperature limitation, strength and resistance to the action of condensate.

- The flue gas vent system parts of the hydrogen generator shall be rigidly constructed, leak tight and meet the mechanical test requirements of 5.4.7.

- Pressure switches used in residential, commercial or light industrial hydrogen generators to prove exhaust gas flow shall be factory set. The adjustment means shall be factory locked. A pressure switch shall bear a marking indicating clearly the appliance manufacturer's or distributor's part number, which correlates to the factory locked pressure setting. Pressure switches used in industrial hydrogen generators may not be factory set and locked. In this case, the product's technical documentation shall specify the calibration procedures and frequencies for the pressure switches.

- The parts of a pressure switch in contact with exhaust gas condensate shall be corrosion resistant to exhaust gas condensate at the normal operating temperatures.

- The materials used to construct the flue gas vent system shall have a temperature rating that exceeds the temperature of the exhaust gases conveyed by that flue gas vent system.

The manufacturer shall include in the product technical documentation the installation requirements for the installation of the flue gas vent system.

NOTE Considerations for the installation of flue gas vent systems are included in Annex D.

4.6.2.4 Specific requirements for product delivery piping

The hydrogen generator may include the interconnection piping used to deliver the gaseous hydrogen-containing product stream to distributed components that may or may not be factory matched, e.g. a fuel cell power system or a hydrogen compression, storage and delivery system.

The manufacturer shall design and construct the product delivery piping, or shall provide in the product's technical documentation instructions to do so, in compliance with ISO 15649 and the following requirements:

- Materials shall meet the requirements specified in 4.5. In particular, the product delivery piping shall be constructed of material:

  - suitable for hydrogen service, non-permeable and resistant to the effects of hydrogen on the material's mechanical performance;

  - resistant to corrosion by condensate.

NOTE Non-metallic material should be judged on its temperature limitation, strength and resistance to the action of condensate.

- The product delivery piping shall be designed and constructed to provide allowance for expansion, contraction, vibration, settlement and fire exposure.

- The product delivery piping shall be designed and constructed so as to prevent the occurrence of a hydrogen release.

— The product delivery piping shall be marked “HYDROGEN” at intervals not exceeding 3 m. Letters of such marking shall be in a distinguishable colour.

— The hydrogen generator shall be marked at the connection outlet to the product delivery piping with the following: “This hydrogen generator requires special piping for product delivery. Refer to the installation manual for parts lists and methods of installation.”

The manufacturer shall provide in the product’s technical documentation instructions for installing the product delivery piping.

NOTE Considerations for the installation of product delivery piping are included in Annex D.

4.6.3 Thermal management system

If the thermal management system is such that it cannot affect the potable water supply, any means of heat transfer commensurate with the chemistry of the affected fluids or gases may be used.

If there is a risk that the thermal management system affects the potable water supply, the heat exchanger shall be of double-wall construction. An air gap, open to the atmosphere, shall be provided between the two walls. Notwithstanding the above requirement, single wall separation may be used when the pressure of the toxic coolant is at least 70 kPa lower than the pressure on the potable water side, where this is protected with a pressure gradient monitor, or when the coolant is non-toxic.

4.7 Prevention of fire and explosion hazards

4.7.1 General

The hydrogen generator shall be designed and constructed to avoid any reasonably foreseeable risk of fire or explosion posed by the hydrogen generator itself or by the gases, liquids, dust, vapours or the other substances produced or used by the hydrogen generator.

4.7.2 Prevention of fire and explosion hazards in the vicinity of hydrogen generators provided with cabinets

4.7.2.1 Hydrogen generators provided with cabinets intended for use in non-hazardous areas

4.7.2.1.1 Ventilation of compartments with sources of flammable gas or vapour

Hydrogen generator compartments with sources of flammable gas or vapour shall be mechanically ventilated at negative pressure relative to other compartments and their surroundings. Failure of ventilation, confirmed by measuring either flow or pressure, shall cause a hydrogen generator shutdown.

Notwithstanding the previous requirement, in hydrogen generators intended for outdoor use, compartments with sources of flammable gas or vapour may be positive pressure ventilated as per IEC 60079-2.

The minimum ventilation flow shall be set such that, for the release rate of flammable gases or vapours from the hydrogen generator as determined per leakage test specified in 5.4.3.1, the maximum concentration of any flammable gas in the hydrogen generator ventilation exhaust remains during all operating conditions below 25 % of the LEL except in the case of hydrogen, where the exhaust shall remain below 25 % LFL.

Hydrogen generator compartments that contain electrical or mechanical equipment shall be ventilated with fresh air and maintained at positive pressure with respect to compartments with sources of flammable gas or vapour unless the equipment is suitable for the area classification of the compartment with sources of flammable gas or vapour, according to IEC 60079-10.

4.7.2.1.2 Release of flammable substances

The hydrogen generator shall be provided with passive and active means, or a combination thereof, to avoid the occurrence of releases of flammable gases or vapours inside hydrogen generator compartments at a rate that cannot be diluted by the mechanical ventilation to levels below 25 % of the LEL except in the case of hydrogen, where the releases shall remain below 25 % LFL.

Passive means may include the mechanical limitation of releases of flammable gases or vapours to a maximum value by using pipe orifices and similar methods of flow restriction or joints permanently secured and so constructed that they limit the release rate to a predictable maximum value.

Active means may include flow measurements and controls, or safety devices such as combustible gas sensors. These means shall meet the requirements specified in 4.10, and shall cause a hydrogen generator shutdown upon occurrence of conditions under which the concentration of any flammable gas in the ventilation exhaust exceeds 25 % of the LEL except in the case of hydrogen where the exhaust shall remain below 25 % LFL.

NOTE Sudden and catastrophic failures need not be considered a release scenario in this analysis when protection against such failures has already been contemplated in the vessel and piping design (see also 4.6).

In hydrogen generators intended for indoor use, the ventilation and flue gas exhaust shall be designed for connection to a flue gas or vent system as per 4.6.2.3.

Liquid-fuelled hydrogen generators shall include provisions to prevent fire hazards, e.g. by maintaining cabinet ventilation or other dilution means if released liquid fuel can be captured in drip pans, spill guards, or other containers open to the atmosphere.

4.7.2.2 Hydrogen generators provided with cabinets intended for use in hazardous areas

Hydrogen generators intended for use in hazardous area shall comply with the requirements of IEC 60079-0:2004 and the appropriate parts of IEC 60079 relative to the type(s) of protection used.

4.7.2.3 Hazards within hydrogen generator cabinets

4.7.2.3.1 General

Hydrogen generator cabinets shall be designed, and the product’s technical documentation shall provide operation and maintenance information, so that any releases of flammable liquids, gases or vapours within hydrogen generator cabinets, and consequently the extent of hazardous areas in their interior, are kept to a minimum, whether in operation or otherwise, with regard to frequency, duration and quantity of these releases.

4.7.2.3.2 Classification of hazardous areas

Within hydrogen generator cabinets, compartments with sources of flammable gas or vapour shall be classified and the extent of hazardous areas determined according to IEC 60079-10, taking due account of the likely frequency and duration of release, the release rate, release material physical properties, ventilation, system geometry and other relevant factors.

4.7.2.3.3 Ignition sources within cabinets

The manufacturer shall eliminate ignition sources in cabinet areas classified as hazardous by ensuring that:

— the installed electrical equipment is suitable for the area classification according to IEC 60079-10;

— the installed electrical resistance trace heating, if applicable, complies with IEC 62086-1;

— the surface temperatures do not exceed 80 % of the auto-ignition temperature of the flammable gas or vapour, expressed in degrees Celsius;

NOTE IEC/TR 60079-20 provides guidance regarding auto-ignition temperatures of various flammable fluids.

— the potential for static discharge has been eliminated by proper bonding and grounding as per IEC 60204-1 and by proper material selection as per 4.5;

— equipment containing materials susceptible of catalysing the reaction of flammable fluids with air can suppress the propagation of the reaction from the equipment to the surrounding flammable atmosphere.

4.7.2.3.4 Purge of ventilated areas

When the provided ventilation influences the type of area classification, that area shall be purged with a minimum of five air changes prior to energizing any devices not suitable for the non-ventilated area classification.

Alternatively, the generator may be provided with ventilation exhaust composition measurement capabilities that control the amount of purging required to achieve levels below 25 % of the LEL except in the case of hydrogen where the exhaust shall remain below 25 % LFL.

All devices, which shall be energized prior to purging or in order to accomplish purging, shall be suitable for the non-ventilated area classification.

Purging need not to be performed if the atmosphere within the compartment and associated ducts can be demonstrated by design to be non-hazardous.

4.7.2.3.5 Maintenance of equipment affecting hazardous area classification

The manufacturer shall provide in the product's technical documentation instructions to ensure that all equipment affecting the area classification, when it has been subjected to maintenance, is carefully checked during and after reassembly to ensure that the integrity of the original design, as it affects safety, has been maintained before it is returned to service.

4.7.3 Prevention of fire and explosion hazards in the vicinity of hydrogen generators without cabinets

Outdoor hydrogen generators without cabinets are potentially sources of flammable gas or vapour. They shall be designed, and the product's technical documentation shall provide operation and maintenance information, so that any releases of flammable liquids, gases or vapours from a hydrogen generator, and consequently the extent of hazardous areas in its vicinity, are kept to a minimum, whether in operation or otherwise, with regard to frequency, duration and quantity.

All locations in the vicinity of outdoor hydrogen generators without cabinets should be classified and the extent of hazardous areas determined according to IEC 60079-10, taking due account of the likely frequency and duration of release, the release rate, release material physical properties, ventilation, system geometry and other relevant factors.

The product's technical documentation shall contain installation instructions indicating that, within areas classified as hazardous, ignition sources shall be eliminated by ensuring that:

— the installed electrical equipment is suitable for the area classification according to IEC 60079-10;

— the installed electrical resistance trace heating, if available, complies with IEC 62086-1;

— the surface temperatures do not exceed 80 % of the auto-ignition temperature expressed in degrees Celsius, of the flammable gas or vapour;

NOTE IEC/TR 60079-20 provides guidance regarding auto-ignition temperatures of various flammable fluids.

— the potential for static discharge is eliminated by proper bonding and grounding as per IEC 60204-1, and by proper material selection as per 4.5;

— equipment containing materials capable of catalyzing the reaction of flammable fluids with air is capable of suppressing the propagation of the reaction from the equipment to the surrounding flammable atmosphere.

The manufacturer shall provide in the product's technical documentation the following information:

— when mechanical ventilation is used to influence the type of area classification, instructions to ensure that the area where the hydrogen generator is installed is purged prior to energizing any devices not suitable for the non-ventilated area classification;

NOTE 1 The purge is determined by analysis based on flow characteristics and system geometry.

NOTE 2 All devices, which should be energized prior to purging or in order to accomplish purging, should be suitable for the non-ventilated area classification.

NOTE 3 Purging may not be required if the atmosphere in that area can be demonstrated by design to be non-hazardous.

— instructions to ensure that in the vicinity of outdoor hydrogen generators without cabinets, compartments that contain electrical or mechanical equipment are positive pressure ventilated with fresh air or other non-flammable fluids as per IEC 60079-2, unless the equipment is suitable for the area classification according to IEC 60079-10;

— instructions to ensure that all equipment affecting the area classification, when it has been subjected to maintenance, is carefully checked during and after reassembly to ensure that the integrity of the original design, as it affects safety, has been maintained before it is returned to service;

— information, requirements and other applicable limitations for installing and operating hydrogen generators without cabinets so as to avoid risks to health or safety.

4.7.4 Burners

Hydrogen generators shall be designed such that the unsafe build-up of flammable or explosive gases in burners (start, main and auxiliary burners of a reformer section, tail gas burners) is avoided.

The main burner shall be fitted with a pilot or a direct ignition device.

If used, the direct ignition device shall be controlled automatically and shall not cause deterioration of the main burner. Means shall be provided to prevent incorrect assembly or reversible mounting of any direct ignition device in relation to the burner port being served.

If used, pilots shall be controlled automatically and direct ignition shall light any pilot fuel. Means shall be provided to prevent incorrect assembly or reversible mounting of any pilot in relation to the burner port being served.

When a pilot is an integral part of the start burner, it shall be evaluated only under the construction and performance specifications of this standard.

Automatic electrical burner control systems shall comply with requirements specified in 4.10.2.1.

The main burner or pilot flame, or both, shall be monitored by a flame detector. If a main burner is ignited by a pilot, the presence of flame at the pilot shall be detected before gas is released to the main burner. A system having an interrupted pilot shall monitor the main burner flame following the main flame-establishing period.

Pilot flame monitoring shall only be at a point where the pilot will effectively ignite fuel at the main burner even when the fuel supply to the pilot is reduced so the flame is just sufficient to actuate the primary safety control.

When the heat input of a pilot does not exceed 0,250 kW, there is no requirement for determining the main flame establishing period. When the heat input of a pilot exceeds 0,250 kW, or in the case of direct ignition of the main burner, the main flame establishing period shall be specified by the manufacturer so that in accordance with the delayed ignition test of 5.4.6.2.7 no health or safety hazard for the user or damage to the hydrogen generator occurs.

The signal to open the gas supply to the main burner shall only be given after the pilot burner flame has been detected.

Each pilot or direct main burner ignition attempt shall begin with the opening of the fuel valves and shall end with the closing of the fuel valves. The spark shall continue at least until ignition occurs or until the end of the main flame establishing period.

Pilot or direct main burner ignition shall be attempted a maximum of three times, each time followed by purging. An absence of flame at the end of the third attempt shall result in, at least, a volatile lock-out.

In case of flame failure, the system shall cause at least reignition, recycling or volatile lock-out.

The pilot or main burner flame failure lock-out time shall not exceed 3 s.

If reignition takes place, under the test conditions of 5.4.6*,* the direct ignition device shall be re-energized within a maximum time of 1 s after the disappearance of a flame signal. In this case, the main flame establishing period shall be calculated when the ignition device is energized. An absence of flame at the end of the manufacturer’s specified flame establishing period shall result in, at least, volatile lock-out.

If recycling takes place under the test conditions of 5.4.6*,* this shall be preceded by an interruption of the gas supply and purging; the ignition sequence shall restart from the beginning. In this case, the main flame establishing period shall be calculated to start when the ignition device is energized. Recycling shall be attempted a maximum of three times, each time followed by purging. An absence of flame at the end of the third attempt shall result in at least a volatile lock-out.

A burner circuit shall be arranged so as to prevent a motor, capacitor or similar device energizing a fuel valve or ignition device after a control function has shut off the main burner.

When, for safety reasons, a passive state is required prior to start-up or after shutdown, means shall be provided to automatically purge a burner housing or enclosure of any flammable gas mixture before the trial for ignition at the start and in-between recycling trials. This purge shall provide a minimum of four air changes in the burner housing or enclosure.

Ignition system components shall be installed so the operation of these devices and burner ignition will not be affected by falling particles during normal operation.

When primary air under pressure is mixed with the fuel supply, effective means shall be provided to prevent air from passing back into the fuel line, or fuel into the air supply. The fuel and air supply shall be controlled to prove air flow prior to ignition and to prevent fuel from entering each burner until the air supply is available and, in the event of air fan failure, to shut off the fuel supply.

Mechanical linkage for operating the fuel and air controls, if used, shall be designed to maintain the correct fuel-air ratio and to resist breakage and disengagement.

Upon shutdown, hazardous gases in the process system shall be safely contained or disposed of.

Where air and fuel or combustible process gas streams are put in close contact as part of the thermal management system, the manufacturer shall provide the hydrogen generator with means to prevent health or safety risks arising from the crossing of air into fuel or combustible process gas lines or the crossing of fuel or combustible process gas into air lines.

4.7.5 Catalytic fuel oxidation systems (catalytic burners)

Within hydrogen generator components carrying fluids, in which flammable or explosive gas volumes are intentionally produced to conduct a controlled catalytic fuel oxidation reaction (e.g. catalytic partial oxidation, catalytic combustion), the manufacturer shall avoid the unsafe build-up of flammable or explosive gases.

When, for safety reasons, a passive state is required prior to start-up or after shutdown, means shall be provided to purge the catalytic fuel oxidation system components. The purging system shall utilize a medium specified by the manufacturer such as, but not limited to, nitrogen, air or steam. The extent of purging shall be specified by the manufacturer and determined by considering flow characteristics, system dynamics and geometry.

Where air is mixed with fuel, the manufacturer shall provide means to prevent air from flowing back into the fuel line, or fuel from flowing back into the air supply.

For air-rich systems, the fuel and air supply shall be controlled to prove air prior to reaction initiation, and to prevent fuel from entering the reactor until the air supply is available.

For fuel-rich systems, the fuel and air supply shall be controlled to prove fuel prior to reaction initiation, and to prevent air from entering the reactor until the fuel is available.

Mechanical linkage for operating the fuel and air controls, if used, shall be designed to maintain the correct fuel-air ratio and to resist breakage and disengagement.

The maximum reaction initiation time shall be specified by the manufacturer and shall be determined by considering the response time of the system control devices and the time required to build up the maximum allowable quantity of flammable or explosive mixture that can safely be contained in the system based on flow rates, fuel-air mixture flammability, and system dynamics and geometry.

If the catalytic reaction is not established within the manufacturer’s specified maximum reaction initiation time, the system shall automatically shut off the fuel supply for air-rich operations, or the supply of all reactants for fuel-rich operations.

The temperature of the catalyst shall be monitored either directly or indirectly. If the temperature or rate of temperature change of the catalyst falls outside the range determined by the manufacturer, the system shall automatically lock out, shutting off the fuel supply for air-rich operations, or the supply of all reactants for fuel-rich operations. The reaction failure lock-out time shall not exceed 3 s.

Upon shutdown, hazardous gases in the process system shall be safely contained or disposed of.

If a mixture of fuel and air could potentially build up inside the hydrogen generator following the failure of a reaction to start within the manufacturer’s specified maximum reaction initiation time, the extinction of a reaction, or the decrease or increase of the reaction rate to unsafe levels, the manufacturer shall ensure that the maximum quantity of flammable mixture that could accumulate, if combusted, produces pressures and temperatures that can be contained within the components exposed to such conditions.

Where air and fuel streams are put in close contact as part of the thermal management system, the manufacturer shall provide the hydrogen generator with adequate means to prevent health or safety risks arising from the crossing of air into fuel lines or of fuel into air lines.

4.8 Prevention of electrical hazards

The electric system design and construction, as well as the application of electric and electronic equipment, including electric motors and electric enclosures, shall meet the requirements of IEC 60204-1 for industrial applications or IEC 60335-1 for residential, commercial and light industrial applications.

Electrical components installed in hydrogen generators without cabinets intended for outdoor use shall be protected from rain, with a minimum degree of protection of IPX4D as per IEC 60529:2001.

The manufacturer shall include in the product's technical documentation a requirement stating that hydrogen generator ventilation outlets intended for outdoor termination shall be protected from rain so as to prevent electrical components inside the cabinet from getting wetted.

The type of converter for motor speed control shall be suitable for the application as per IEC 60146-1-1.

Electrical clearance (through air) and creepage (over surface) distances, as well as solid insulation thickness for electrical circuits, shall be in accordance with the applicable part of IEC 60664.

4.9 Electromagnetic compatibility (EMC)

The hydrogen generator shall not generate electromagnetic disturbances above the levels appropriate for its intended places of use. In addition, the equipment shall have an adequate level of immunity to electromagnetic disturbances so that it can operate correctly in its intended environment. As applicable, the hydrogen generator shall comply with the standards listed in Table 2.

Table 2 — EMC standards

Standard number	Title
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 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*

4.10 Control systems and protective/safety components

4.10.1 General requirements

The safety and reliability analysis as specified in 4.1 shall provide the basis for setting the protection parameters of the safety circuit.

The hydrogen generator shall be designed such that the single failure of a component does not cascade into a hazardous situation. Means to prevent cascade failures include but are not limited to:

— protective devices in the hydrogen generator (e.g. interlocking guards, trip devices);

— protective interlocking of the electrical circuit;

— use of proven techniques and components;

— provision of partial or complete redundancy or diversity;

— provision for functional tests.

NOTE Guidelines for the design of electrical, electronic and programmable controls can be found in IEC 62061 or IEC 61511-1.

4.10.2 Control systems and operation

4.10.2.1 General

Residential, commercial and light industrial hydrogen generators and automatic electrical and electronic controls shall conform to IEC 60730-1.

Industrial hydrogen generator controls shall conform to IEC 60730-1 or IEC 61511-1.

Automatic electrical burner control systems shall comply with IEC 60730-2-5.

Automatic electrical control systems for catalytic oxidation reactors shall comply, as applicable, with IEC 60730-2-5 and with the specific requirements of 4.7.5.

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

4.10.2.2 Start

The start of an operation shall be possible only when all the safeguards are in place and are functional. Suitable interlocks shall be provided to secure correct sequential starting.

It shall be possible for a hydrogen generator that can be operated remotely, in automatic mode, to be restarted after a stoppage once the safety conditions are fulfilled. It shall also be possible to restart the hydrogen generator by intentional manual actuation of a control provided for the purpose, provided such restarting is verifiably non-hazardous. This requirement does not apply to the restarting of the hydrogen generator resulting from the normal sequence of an automatic cycle.

4.10.2.3 Shutdowns

4.10.2.3.1 General

As determined by the safety and reliability analysis indicated in 4.1 and the functional requirements of the hydrogen generator, the hydrogen generator shall be provided with safety shutdown and controlled shutdown functions as per 4.10.2.3.2 and 4.10.2.3.3.

4.10.2.3.2 Safety shutdown

4.10.2.3.2.1 General

The hydrogen generator shall be provided with safety shutdown functions in order to avert actual or impending danger that cannot be corrected by controls.

These functions shall, for air-rich operation, de-energize the main fuel flow means or, for fuel-rich operation, de-energize both the process air flow and the main fuel flow means, as the result of the action of a limiter, a cut-out or the detection of an internal fault of the system.

In addition, the safety shutdown functions shall:

— remove all power to the equipment and stop the dangerous condition without creating additional hazards;

NOTE Control/monitoring systems that can operate safely in the hazardous situation may be left energized to maintain system integrity or provide system information.

— trigger, or permit the triggering of, certain safeguard actions where necessary;

— override all other functions and operations in all modes;

— prevent reset from initiating a restart;

— be fitted with restart lock-outs such that a new start command may take effect on normal operation only after the restart lock-outs have been intentionally reset.

When a protective device or interlock causes a safety shutdown of the hydrogen generator, that condition shall be signalled to the logic of the control system.

The reset of the safety shutdown function shall not initiate any hazardous condition.

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

4.10.2.3.2.2 Emergency stop

The hydrogen generator shall be provided with emergency stops. The emergency stops shall have clearly identifiable, clearly visible and quickly accessible controls such as buttons, in accordance with ISO 13850.

4.10.2.3.2.3 Control functions in the event of control systems failure

In case of fault in the control system logic, or failure of, or damage to, the control system hardware:

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

b) automatic or manual stopping of the moving parts shall be unimpeded;

c) the protection devices shall remain fully effective;

d) the hydrogen generator shall not restart unexpectedly.

4.10.2.3.3 Controlled shutdown

Upset conditions that can be safely controlled or that do not pose immediate danger may be corrected with controlled shutdown functions.

The controlled shutdown functions shall, for air-rich operation, de-energize the main fuel flow means or, for fuel-rich operation, de-energize both the process air flow and the main fuel flow means, as a result of the opening of a control loop by a control device such as a thermostat. The function shall return the system to the start position.

The controlled shutdown function may remove all power to the equipment, or may leave power available to the generator actuators.

If for safety reasons a passive state is required, a system purging shall be executed (see also 4.3.9).

4.10.2.4 Permissives

Permissives shall be implemented consistent with requirements established from the safety and reliability analysis described in 4.1.

4.10.2.5 Complex installations

When the hydrogen generator is designed to work together with other equipment (e.g. as part of a fuel cell power system), the hydrogen generator stop controls, including the emergency stop, shall be provided with means, such as signal interfaces, to enable a coordinated shutdown with all equipment upstream and/or downstream of the hydrogen generator if continued operation can be dangerous.

4.10.2.6 Operating modes

4.10.2.6.1 Primary operating and transitions modes

There shall be two primary operating modes: On-mode and Off-mode.

During the On-mode, the hydrogen generator components shall be active and operating as necessary to supply hydrogen. The following conditions shall also be considered On-modes:

— idle (zero net hydrogen output); and

— automatic start enabled (power left available to the hydrogen generator terminals).

In the Off-mode, all power to the hydrogen process equipment shall be de-energized. For outdoor applications, care shall be taken to assure adequate winterization of the system during the Off-mode.

There shall be two primary transition modes: start-up and shutdown.

Start-up, which is the automatic transition from the Off-mode to the On-mode, shall be initiated from an external signal.

Shutdown, which is the transition from the On-mode to the Off-mode, may be initiated either via an external signal, or via an internal signal in response to out-of-limits conditions of the hydrogen generator controller.

4.10.2.6.2 Secondary operating and transition modes

Secondary operating and transitions modes may be provided as necessary, such as to allow for different hydrogen production rates or for adjustment, maintenance, or inspection activities.

4.10.2.6.3 Mode selection

If the hydrogen generator has been designed and built to allow for its use in several control or operating modes presenting different safety levels (e.g. to allow for adjustment, maintenance, inspection, etc.), it shall be capable of mode selection that can be secured in each position. Each position of the mode selector shall correspond to a single operating or control mode and shall be fitted with restart lock-outs. A new start command may take effect on normal operation only after the restart lock-outs have been intentionally reset.

The mode selector shall be securable, designed to prevent unintentional change to a different mode that may lead to a hazardous condition by means such as a positioning knob, key lock, or software command.

The mode selector may be designed to restrict user access to certain hydrogen generator operating modes (e.g. access codes for certain numerically controlled functions, etc.).

The mode selected shall override all other control systems with the exception of the safety shutdowns.

4.10.2.7 Remote monitoring and control systems

Hydrogen generators that can be operated remotely shall have a local, labelled switch or other means to disconnect the generator from remote signals while a local operator performs inspection or maintenance. Remote monitoring and control systems shall:

— be allowed on hydrogen generators only where remote control will not lead to an unsafe condition;

— not override locally set manual controls;

— not override protective safety controls.

Procedures to address changes to the remote monitoring system shall be provided as per 6.3.4.2.

4.10.3 Protective/safety components

Protective devices and combinations thereof comprise:

— safety devices; and

— monitoring devices such as indicators and/or alarms which enable adequate action to be taken either automatically or manually to keep the hydrogen generator within the allowable limits.

Safety devices shall:

— be designed and constructed to be reliable and suitable for their intended duty and take into account the maintenance and testing requirements of the devices, where applicable;

— have their safety functions independent of other possible functions; and

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

Overloading of equipment shall be prevented at the design stage by means of integrated measurement, regulation and control devices, such as over-current cut-off switches, temperature limiters, differential pressure switches, flowmeters, time-lag relays, overspeed monitors and/or similar types of monitoring devices.

Safety devices with a measuring function shall be designed and constructed so that they can cope with foreseeable operating requirements and special conditions of use. Where conditions of use may affect the reading accuracy and serviceability, it shall be possible to check the reading accuracy and serviceability of safety devices. These devices shall incorporate a safety factor that ensures that the alarm threshold lies outside the limits to be registered, taking into account, in particular, the operating conditions of the installation and possible aberrations in the measuring system.

Pressure limiting devices, such as pressure switches, shall be provided as per IEC 60730-2-6.

Temperature monitoring devices shall comply with IEC 60730-2-9 shall have a response time consistent with the measurement function, as per IEC 60730-2-9.

Gas sensors relied upon for safety shall comply with IEC 61779-4 and be selected, installed, used and maintained in accordance with IEC 61779-6.

All parts of hydrogen generators which are set or adjusted at the stage of manufacture, and which should not be manipulated by the user or the installer, shall be protected against tampering.

Levers and other controlling and setting devices shall be clearly marked and given appropriate instructions so as to prevent any error in handling. Their design shall be such as to preclude accidental manipulation.

4.11 Pneumatic and hydraulic equipment

Pneumatic and hydraulic equipment of hydrogen generators shall be designed as per ISO 4414 and ISO 4413 respectively.

In particular, pneumatic and hydraulic equipment of hydrogen generators shall be so designed that:

— the maximum allowable pressure cannot be exceeded in the circuits (e.g. by pressure limiting devices);

— no hazards may result from pressure losses, pressure drops or losses of vacuum;

— no hazardous fluid jet may result from leakages or component failures;

- air receivers, fluid reservoirs or similar vessels such as hydro-pneumatic accumulators comply with the design rules of these elements (see 4.6);
- all elements of the equipment, especially pipes and hoses, are protected against harmful external effects;
- reservoirs and similar vessels (e.g. hydro-pneumatic accumulators) are automatically depressurized when isolating the hydrogen generator from its electrical power supply or, if it is not possible, means are provided for their isolation and local depressurization and pressure indication;
- all elements which remain under pressure after isolation of the hydrogen generator from its electrical power supply are provided with clearly identified exhaust devices, and a warning label drawing attention to the necessity of depressurizing those elements before setting or performing maintenance activity on the hydrogen generator.

4.12 Valves

4.12.1 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, upset or emergency conditions.

Shut-off valves shall be rated for the maximum allowable pressure, temperature and fluid characteristics.

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

Electrically, hydraulically or pneumatically operated shut-off valves shall be of a type that moves to a fail-safe position upon loss of actuation energy.

4.12.2 Input fuel valves

Input fuel valves shall meet the following requirements:

- All input fuel supplied to the hydrogen generator shall pass through at least two automatic valves, in series, each of which shall serve as an operating valve and a shut-off valve in case of a safety shutdown.
- Any fuel supplied directly to fuel-fired equipment, such as a start-up boiler or a reformer start burner, shall pass through at least two automatic valves, in series, each of which shall serve as an operating valve and a safety shut-off valve. These valves may or may not be contained in a single control body.
- Electrically operated input fuel valves shall meet the requirements of IEC 60730-2-17 or IEC 60730-2-19 as applicable. Valves serving as safety shut-off valves in the hydrogen generator shall meet the safety shut-off valve requirements of the applicable standard noted above.
- When fuel gases are recycled from appliances using the hydrogen generator output gas, the connection may be exempt from employing shut-off valves if demonstrated safe as per the safety and reliability analysis of 4.1.

4.13 Rotating equipment

4.13.1 General requirements

Rotating equipment shall be designed for the pressures, temperatures and fluids to which they may be subjected under normal operating conditions.

Fluid inlet and outlet lines shall be protected from damage due to vibration.

Shaft seals shall be compatible with the pumped fluids and the operating temperatures and pressures expected in normal and abnormal operation and during normal and emergency shutdowns.

Shaft seals shall be designed such that hazardous fluid leakage is avoided or, if it is not possible, the manufacturer shall provide hazardous fluid containment or dilution means as necessary to avoid risks to health or safety.

Motors, bearings and seals shall be suitable for the expected duty cycles.

The rotating equipment and the related piping system shall be analysed to assure that forces and moments exerted by piping on the rotating equipment unit remain within the manufacturer's tolerances under normal operating conditions.

4.13.2 Compressors

4.13.2.1 Where applicable, packaged compressors shall conform to one of the standards listed in Table 3.

Table 3 — Compressor standards

Standard Number	Application
ISO 5388	*Stationary air compressors — Safety rules and code of practice*
ISO 10439	*Petroleum, chemical and gas service industries — Centrifugal compressors*
ISO 10442	*Petroleum, chemical and gas service industries — Packaged, integrally geared centrifugal air compressors*
ISO 13707	*Petroleum and natural gas industries — Reciprocating 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 13631	*Petroleum and natural gas industries — Packaged reciprocating gas compressors*

4.13.2.2 Unless determined unnecessary by the safety and reliability analysis of 4.1, compressors, or compressor systems, shall be provided with the following:

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

— an automatic shutdown control for high discharge and low suction pressure;

— where required to restart the compressor after shutdown, an unloading device that captures and recycles blown gas for re-use and/or safe venting;

— vibration isolation from the inlet pipe to the compressor suction line;

— a pressure limiting device to avoid overpressurization at the inlet.

4.13.2.3 Compressors excluded from the scope of the standards referenced in 4.13.2.1 due to small capacity or low discharge pressure need only to comply with the requirements specified in 4.13.2.2.

4.13.2.4 Packaged low discharge pressure compressors (fans and blowers) shall be guarded as per ISO 12499 (see also 4.3.1).

4.13.3 Electric pumps

4.13.3.1 Where applicable, packaged electric pumps for process liquids shall conform to ISO 13709 or ISO 14847. Packaged electric pumps for water shall conform to IEC 60335-2-41 or IEC 60335-2-51.

4.13.3.2 Electric pumps, or electric pump systems, shall be provided with:

— pressure relief devices that limit both inlet and outlet pressure to less than the maximum allowable pressure of the piping unless the shut-off head of the electric pump is less than the pressure rating of the piping, in which case pressure relief valves need not to be installed;

— an automatic shutdown control for high discharge pressure;

— suction and discharge lines that are protected from damage due to vibration.

4.13.3.3 Pumps excluded from the scope of the standards referenced in 4.13.3.1 due to small capacity or low discharge pressure need only to comply with the requirements specified in 4.13.3.2.

4.14 Cabinets

Hydrogen generator cabinets shall have the strength, rigidity, durability, resistance to corrosion and other physical properties to support and protect all hydrogen generator components and piping and to meet the requirements of storage, transport, installation and final location conditions.

All parts of residential, commercial or light industrial hydrogen generators intended for indoor use shall be enclosed by a suitable containment structure, such as a cabinet, casing or jacket.

Hydrogen generator cabinets intended for indoor use shall be designed and tested to meet a minimum degree of protection of IP20 as per IEC 60529:2001. Hydrogen generators used under conditions of weather-protected outdoor locations shall be designed and tested to meet a minimum degree of protection of IP 44 as per IEC 60529:2001.

The hydrogen generator intended for use under conditions of non-weather-protected outdoor locations shall start and operate normally, without damage or malfunctioning of any part that would create a hazardous condition when subjected to a simulated rain test as per IEC 60529:2001, Test Condition 14.2.4 a).

Ventilation openings shall be designed so that they will not become obstructed during normal operation by dust, snow or vegetation in accordance with the expected application.

All materials used to construct cabinets, including door joints or gaskets, shall be able to withstand the physical, chemical and thermal conditions that are reasonably foreseeable throughout the hydrogen generator life.

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 insulating value and shall not be interchangeable if that interchange may lead to an unsafe condition.

Access panels, covers or doors that are intended to protect equipment from entry by users or untrained personnel shall have means for retaining them in place and shall require the use of a tool, key or similar mechanical means to open. For residential units, this shall include all access panels, covers and doors.

All parts of hydrogen generators that are set or adjusted at the stage of manufacture and that shall not be manipulated by the user or the installer shall be protected against tampering.

Means shall be provided to drain collected liquids and to pipe them to the exterior of cabinets for disposal or redirect them to processes associated with the hydrogen generator.

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

4.15 Thermal insulating systems and materials

Thermal insulating systems employed in the hydrogen generator shall:

— be chemically compatible with the metals being insulated, with the atmosphere and the temperatures to which the systems will be exposed, and with the various components of the insulation system itself;

— be protected from expected thermal and mechanical abuse, including damage by atmospheric conditions;

— be designed to provide fire safety, e.g. by avoiding to increase temperatures around heat-producing objects to the extent that these become sufficiently hot to ignite materials in contact with or near them;

— be designed to provide for future accessibility of piping, fittings, etc. for maintenance purposes.

Thermal insulating materials and their internal bonding or adhesive attachment means mounted on components of the hydrogen generator shall:

— be mechanically or adhesively retained in place and shall be protected against displacement or damage from foreseeable mechanical loads and service operation;

— withstand all air velocities, temperatures and fluids to which they may be subjected in normal operation.

If necessary to avoid hazards to health and safety, the manufacturer shall specify in the maintenance manual the thermal insulation system inspection and safety requirements.

4.16 Utilities

The hydrogen generator shall be designed and constructed such that in case of loss of utility supply, such as interruption of electrical supply, feed water, cooling water, or instrument air, the system shall shut down safely without:

a) creating any health or safety hazards; or

b) resulting in permanent distortion or damage to the system.

4.17 Installation and maintenance

4.17.1 Installation

Errors likely to be made when fitting or refitting certain parts, and which could be a source of risk, shall be minimized by the design of such parts. Failing this, attention shall be drawn to the likely errors by information given on the parts themselves and/or the housings. The same information shall be given on moving parts and/or their housings where the direction of movement shall be known to avoid a risk. Any further information that may be necessary shall be given in the product's technical documentation.

Where a faulty fluid or electrical connection can be the source of risk, incorrect connections shall be minimized by the design. Failing this, attention shall be drawn to the possible incorrect connections by information given on the pipes, cables and/or connector blocks.

NOTE Annex D deals with the installation of hydrogen generators.

4.17.2 Maintenance

Adjustment, lubrication and maintenance points shall not be placed in locations in which a person is exposed to risk of injury or damage to health. Failing this, instructions shall be provided in the product's maintenance manual as necessary to avoid risks to health or safety.

When adjustment, maintenance, repair, cleaning or servicing are to be conducted while the generator is operating, means shall be provided to do this safely and instructions shall be provided in the maintenance manual as necessary to avoid risks to health or safety.

For hydrogen generator components that have to be changed frequently, it shall be possible to remove and replace them in safety. Access to the components shall enable these tasks to be carried out with the necessary technical means (tools, measuring instruments, etc.) in accordance with the product's technical documentation.

Where for protection of health or safety, instructions or diagrams are to be adhered to the hydrogen generator, they shall be displayed using a permanent method, and shall be resistant to, or protected from, the environmental conditions of use.

5 Test methods

5.1 Measurement uncertainties

Except where otherwise stated, measurements shall be carried out with the maximum uncertainties indicated below:

a) atmospheric pressure: ± 0,5 kPa;

b) combustion chamber and test flue pressure: ± 5 % full scale or 5 Pa;

c) gas pressure: ± 2 % full scale;

d) water-side pressure loss: ± 5 %;

e) water flow: ± 1 %;

f) gas flow: ± 1 %;

g) air flow: ± 2 %;

h) time:

- up to 1 h: ± 0,2 s;
- beyond 1 h: ± 0,1 %;

i) auxiliary electrical energy: ± 2 %;

j) temperatures:

1) for temperatures above or equal to 273 K:
   - ± 2 % of reading for temperatures between 273 K and 473 K;
   - ± 5 % of reading for temperatures higher than 473 K;
2) for temperatures below 273 K:
   - ambient: ± 1 K;
   - water: ± 2 K;
   - combustion products: ± 5 K;

— gas: ± 0,5 K;

— surface: ± 5 K;

k) CO, CO_2 and O_2 for the calculation of flue losses: ± 6 % reading;

l) gas calorific value: ± 1 %;

m) gas density: ± 0,5 %;

n) mass: ± 0,05 %;

o) torque: ± 10 %;

p) force: ± 10 %;

q) current: ± 1 %;

r) voltage: ± 1%;

s) electrical power: ± 2 %.

The full range of the measuring apparatus shall be chosen to be suitable for maximum anticipated value.

For the determination of the leakage rate, the method used shall give such accuracy that the error in its determination does not exceed 0,01 dm^3/h.

The measurement uncertainties indicated concern individual measurements. For measurements requiring a combination of individual measurements, lower uncertainties for individual measurements may be necessary to limit the total uncertainty.

5.2 Test fuels and pressures

A hydrogen generator intended for use with natural gas shall have the tests specified herein conducted with a gas whose composition and maximum and minimum expected pressures reflect that of commercially available natural gas. If required by the country of destination, the tests shall also be conducted with limit gases.

A hydrogen generator intended for use with liquefied petroleum gases shall have the tests specified herein conducted with a gas whose composition and supply pressures reflect that of commercially available liquefied petroleum gas. If required by the country of destination, the tests shall also be conducted with limit gases.

A hydrogen generator intended for use with other types of fuel shall have the tests specified herein conducted with a test fuel that is representative of the extreme variations in the composition and supply pressures of the fuels for which the hydrogen generator has been designed.

A hydrogen generator using more than one type of fuel shall be tested with only one test fuel, provided that there are no changes in equipment and ratings for the other fuels that would affect the results of the tests.

5.3 Basic test arrangements

In conducting the tests, the entire hydrogen generator, including any air filters, start-up devices, venting or exhaust systems, and all field-furnished equipment shall be installed and operated in accordance with the manufacturer's instructions.

Unless otherwise stated, the entire hydrogen generator shall be operated:

— at the supply pressure(s) defined in 5.1;

- within two percent of the rated input voltage and frequency;
- within five percent of the rated fuel consumption when operated at rated hydrogen output conditions, as specified by the manufacturer;
- at reference conditions specified as follows:
  - reference temperature: t_0 = 288,15 K (15 °C);
  - reference pressure: p_0 = 101,325 kPa.

Variations in the ambient conditions are allowed because they do not influence the test results.

Testing shall commence when the hydrogen generator components are at equilibrium temperature, unless otherwise specified.

5.4 Type/qualification tests

5.4.1 General

A design examined for compliance with this International Standard shall be a representative production sample of the hydrogen generator. The sample shall be subjected to the type/qualification tests described in 5.4.2 to 5.4.14.

5.4.2 Pressure tests

5.4.2.1 General

Hydrogen generator subsystems subject to a national/regional pressure standard, such as one of the standards recognized by ISO 16528, need not undergo the pressure tests specified in 5.4.2.2 and 5.4.2.3. All hydrogen generator subsystems containing hazardous liquids or gases not covered by 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 recognized by ISO 16528, shall be tested for strength as per 5.4.2.2 and 5.4.2.3.

A hydrostatic pressure test shall be performed last or, when judged feasible, on parts not used for other tests specified herein.

Where the manufacturer considers a hydrostatic pressure test impractical, a pneumatic test shall be substituted recognizing the hazard of energy stored in compressed gas.

Prior to the conduct of the pressure testing, it shall be established which parts, through (inter)connection, are subjected to the same internal pressure during normal operation of the hydrogen generator. These parts shall be taken as an individual test section that shall then be pressurized separately and, when deemed necessary, isolated from the rest of the hydrogen generator by any convenient means.

5.4.2.2 Hydrostatic strength test

5.4.2.2.1 General

This test method shall be used for evaluating test sections that contain hazardous liquids, e.g. liquid fuels, toxic coolants. It shall also be used for evaluating the strength of test sections that contain gases.

5.4.2.2.2 Test fluid

The test fluid shall be the design liquid (liquid fuel, toxic coolant). When evaluating the strength of gas-containing test sections or if the manufacturer considers that testing with the design liquid is impractical, then the test fluid shall be water. If there is the possibility of damage due to freezing or to adverse effects of water on the piping system, another suitable non-toxic liquid may be used. If the liquid is flammable, its flash point shall be at least 50 °C and consideration shall be given to the test environment.

5.4.2.2.3 Metallic test section

The hydrostatic test pressure at any point on a test section made of metallic components shall be as follows:

a) not less than 1,5 times the maximum allowable pressure;

b) for design temperature above the test temperature, the minimum test pressure shall be calculated by the following equation, except that the value of S_T/S shall not exceed 6,5:

$$P_T = 1{,}5\ (PS_T)/S$$

where

P_T is minimum test gage pressure;

P is internal design gage pressure;

S_T is stress value at test temperature as per Table A-1 of ANSI/ASME B31.3 as required by ISO 15649;

S is stress value at design temperature as per Table A-1 of ANSI/ASME B31.3 as required by ISO 15649;

c) if the test pressure would produce a nominal pressure stress or longitudinal stress in excess of yield strength at test temperature, the test pressure may be reduced to the maximum pressure that will not exceed the yield strength at test temperature;

d) where the test pressure of the piping attached to a vessel is the same as or less than the test pressure for the vessel, the piping may be tested with the vessel at the piping test pressure;

e) where the test pressure of the piping exceeds the vessel test pressure and it is not considered practicable to isolate the piping from the vessel, the piping and the vessel may be tested together at the vessel test pressure provided the manufacturer agrees and the vessel test pressure is not less than 77 % of the piping test pressure calculated in accordance with the equation above.

A preliminary test using air at more than 170 kPa gage pressure may be made prior to hydrostatic testing to locate major leaks.

5.4.2.2.4 Non-metallic test section

The hydrostatic test pressure at any point in a test section made of non-metallic components shall be not less than 1,5 times the maximum allowable pressure, but shall not exceed 1,5 times the maximum rated pressure of the lowest rated component in the system. Thermoplastic piping in which the design temperature is above the test temperature, the hydrostatic formula of 5.4.2.2.3 applies except that:

— S_T = stress value at test temperature from Table B-1 of ANSI/ASME B31.3 as required by ISO 15649;

— S = stress value at design temperature for Table B-1 of ANSI/ASME B31.3 as required by ISO 15649.

5.4.2.2.5 Test procedure

The test section shall be filled with the test liquid and connected to a suitable hydraulic system, including a pressure-measuring device capable of sustaining the required leak test pressure. Care shall be taken to purge any air from the test section. The pressure shall then be gradually increased in steps until the leak test pressure is reached holding the pressure at each step long enough to equalize the piping strains. The test pressure shall be held for at least 10 minutes and until all joints and connections are examined for leakages.

5.4.2.2.6 Acceptance criteria

The parts under pressure shall withstand the hydrostatic test pressure without rupture, fracture or other physical damage. The test section shall show no signs of leakage during the test.

5.4.2.3 Pneumatic strength test

5.4.2.3.1 Test fluid

Portions containing gas or vapours shall have the tests specified herein conducted with a non-flammable and non-toxic gas or vapour (e.g. clean dry air or any inert gas) that is representative of the physical characteristics (e.g. molecular weight) of the constituents expected during operation and shutdown and for which the hydrogen generator has been designed.

5.4.2.3.2 Test pressure

The gaseous leak test pressure shall be 110 % of the maximum allowable pressure.

Piping subject to external pressure shall be tested at an internal gage pressure 1,5 times the external differential pressure but not less than 105 kPa.

5.4.2.3.3 Test procedure

The test section shall be filled with the test gas and connected to a suitable pressurizing system, including a pressure-measuring device capable of sustaining the required leak test pressure and a flow-measuring device or pressure decay device to determine leakage. The leakage-measuring device shall be located at the inlet of the portion under test after the pressure-measuring device. The test section shall be sealed by any convenient means.

The pressure shall then be gradually increased in steps until the leak test pressure is reached, holding the pressure at each step long enough to equalize the piping strains. The test pressure shall be held for at least 10 minutes, at which time any leakage, as indicated by the flow-measuring device or other leak detection means such as a pressure decay device, shall be noted.

5.4.2.3.4 Acceptance criteria

The parts under pressure shall withstand the pneumatic test pressure without rupture, fracture or other physical damage.

5.4.3 Allowable hazardous gas leakage test

5.4.3.1 Leak test method for portions of the system containing hazardous gas

5.4.3.1.1 General

All portions of the hydrogen generator that may contain hazardous gases, e.g. flammable or combustible mixtures, shall be tested for leakage.

The procedures of this subclause shall be performed twice: prior to and after all tests specified in 5.4.6 to 5.4.14.

Prior to conducting the leak test, it shall be established which parts, through (inter)connection, are subjected to the same internal pressure during normal operation of the hydrogen generator. These parts shall be taken as an individual test section that shall then be pressurized separately and, when deemed necessary, isolated from the rest of the hydrogen generator by any convenient means.

5.4.3.1.2 Test fluid

Portions containing hazardous gas or vapours shall have the tests specified herein conducted with a non-flammable and non-toxic gas or vapour (e.g. clean dry air or any inert gas) that is representative of the physical characteristics (e.g. molecular weight) of the constituents expected during operation and shutdown and for which the hydrogen generator has been designed.

5.4.3.1.3 Test pressure

The gaseous leak test pressure shall be 110 % of the maximum allowable pressure.

Piping subject to external pressure shall be tested at an internal gage pressure 1,5 times the external differential pressure but not less than 105 kPa.

5.4.3.1.4 Test procedure

The test section shall be filled with the test gas and connected to a suitable pressurizing system, including a pressure-measuring device capable of sustaining the required leak test pressure and a flow-measuring device or pressure decay device to determine leakage. The leakage-measuring device shall be located at the inlet of the portion under test after the pressure-measuring device. The test section shall be sealed by any convenient means.

The pressure shall then be gradually increased in steps until the leak test pressure is reached, holding the pressure at each step long enough to equalize the piping strains. The test pressure shall be held for at least 10 minutes, at which time any leakage, as indicated by the flow-measuring device or other leak detection means such as a pressure decay device, shall be noted.

5.4.3.1.5 Expression of results

If helium is used as test gas, the gas leakage rate shall be corrected according to the following algorithm. If other gases are used, the algorithm shall be adapted.

$$L_{\mathrm{H}} = R \bullet L_{\mathrm{Test}}$$

where

L_{H} is hazardous gas leakage rate;

L_{Test} is the test gas leakage rate;

$R = (d_{\mathrm{Test}} / d_{\mathrm{Fuel}})^{1/2}$

where

d_{Test} is the test gas specific gravity;

d_{Fuel} is the fuel gas specific gravity;

or

$R = \mu_{Test}/\mu_{Fuel}$

where

μ_{Test} is the test gas absolute viscosity;

μ_{Fuel} is the fuel gas absolute viscosity.

These two equations shall be used to calculate R, and the worst-case scenario, i.e. the higher value for the hazardous gas leakage rate, shall be reported.

5.4.3.1.6 Acceptance criteria

The total hydrogen generator leak rate shall be such that, for the provided cabinet ventilation flow, the maximum concentration of any flammable gas in the hydrogen generator ventilation exhaust remains below 25 % of the LEL except in the case of hydrogen where the exhaust shall remain below 25 % LFL.

The parts under pressure shall withstand the pneumatic test pressure without rupture, fracture or other physical damage.

5.4.3.2 Leak test method for flue gas vent system

5.4.3.2.1 Test procedure

This test shall be conducted using the maximum air intake and vent pipe length and number of joints, including fittings, as specified by the manufacturer. For purposes of this test, the manufacturer shall supply:

— the venting system which incorporates the maximum specified number of fittings; and

— a sealed test fitting incorporating the vent collar to which the venting system is to be attached.

This test fitting shall also have inlet tap(s) to which a pressure source and a pressure-measuring device can be attached.

The entire vent-air intake system, including the piping and terminal cap, shall be installed (and sealed, if applicable) in accordance with the manufacturer’s instructions.

5.4.3.2.2 Hydrogen generators having a separate air intake section and a separate exhaust-vent section

The vent and air intake terminals shall be removed, and the entrance of the process air intake section sealed at the point it enters the hydrogen generator. The entire system, including the process air and exhaust gas connections between the hydrogen generator and the vent and air intake terminals, shall be installed and sealed in accordance with the manufacturer’s instructions.

Both the exhaust outlet and the air inlet shall then be sealed at the point of connection to the vent and air intake terminals. The sealing means shall include fittings for supplying air to both the air intake and exhaust sections of the system and provisions for measuring the internal pressure in each section of the system.

The internal pressure in the system shall be determined by connecting the means for determining internal pressure to a water-filled manometer that may be read directly to 2,5 Pa.

A suitable supply of clean air shall be permitted to flow through a metering device and into the section of the direct vent system being pressurized through the air supply fitting. The air supply fitting to the section of the system not being pressurized shall be open.

The internal pressure in the section of the system being pressurized shall be adjusted to:

a) 25 Pa above the normal operating system pressure for forced draft systems operating at positive combustion chamber pressures; and

b) 25 Pa for all other systems. The leakage rate shall be noted for both the air intake and exhaust sections of the direct vent system.

This provision of this test shall be deemed met if leakage from the exhaust section of the system does not exceed a volume fraction of 2 % of the effluents, and leakage from the air intake section of the system does not exceed a volume fraction of 8 % of the effluents.

5.4.3.2.3 Hydrogen generator with all or part of the vent portion of the exhaust section enclosed within the air intake section

On these hydrogen generators, the exhaust-vent section of the system shall be considered that portion of the exhaust-vent section not contained within the air intake section.

The vent-air intake terminal shall be removed and the entrance of the air intake section sealed at the point it enters the hydrogen generator. The entire system, including the process air and exhaust gas connections between the hydrogen generator and the vent-air intake terminal, shall be installed and sealed in accordance with the manufacturer's installation manual. Any vent extension located within the air intake section need not be installed.

The direct vent system shall then be sealed at the point of connection to the vent-air intake terminal. The sealing means shall include fittings for supplying air simultaneously to the air intake and exhaust-vent sections of the system and provisions for measuring the internal pressure.

Using the test apparatus and the method of test specified in this subclause, the total system shall be pressurized and the leakage rate noted.

The exhaust section of the system shall then be sealed, with the appropriate fittings noted above, at the first joint of the vent portion of the exhaust section contained within the air intake section downstream of the hydrogen generator. Using the test apparatus and the method of test specified in this subclause, the exhaust section shall be pressurized and the leakage rate noted.

This provision of this test shall be deemed met if leakage from the exhaust section of the system does not exceed a volume fraction of 2 % of the effluents, and leakage from the total system does not exceed a volume fraction of 8 % of the effluents plus the leakage determined for the exhaust-vent section.

5.4.4 Protection parameter tests

For each critical failure mode resulting from the safety and reliability analysis described in 4.1, a simulated test procedure or supportive evidence from the manufacturer shall be used to verify that the required action occurs.

The verification shall include that of the:

— automatic shutdown of the appropriate system(s) of the hydrogen generator for any of the critical failure modes resulting from the safety and reliability analysis described in 4.1; and

— permissives required as per 4.10.2.4 to avoid the creation of critical failure modes or unsafe conditions, where sequential phases of system operation require certain conditions to be satisfied prior to initiating those applicable sequential phases of operation.

5.4.5 Burner operating characteristics test

5.4.5.1 Applicability

The following procedures are applicable to hydrogen generators equipped with any fuel-fired boiler or heating device such as the start burner of the reformer section, and shall be performed with the burner both hot and cold under the following conditions:

a) at the supply pressures and using test gases as defined in 5.2;

b) at the maximum and minimum fuel supply pressures specified by the manufacturer, if different from those pressures defined in 5.4.5.1 a);

c) when operating at 85 % and 110 % of the rated input voltage. When the hydrogen generator is provided with voltage variation protection within this range, the system shall be tested at the limits specified for the protection device. In addition, the voltage variation protection shall be verified as per 5.4.4.

5.4.5.2 General testing

The automatic ignition system shall effect ignition of burner fuel immediately after the fuel reaches the burner port(s). A continuous pilot, when provided, shall not extinguish when the burner fuel gas is turned “on” or “off”. This provision does not apply to an intermittent or interrupted type pilot when the burner fuel is turned “off”.

During the test it shall be verified that:

— when the burner fuel is turned “on”, the burner fuel ignites effectively without delayed ignition, flashback, undue noise or equipment damage;

— when the burner fuel is turned “off”, the burner flames extinguish without flashback or undue noise;

— the burner flames do not flash outside the combustion chamber;

— the burner does not deposit carbon; and

— there is no gas escaping or backpressure at the burner’s primary air openings.

5.4.5.3 Limit testing

The test shall be carried out without altering the adjustment of the burner and ignition burner. The pressure at the inlet shall be reduced to 70 % of the normal pressure. Under these supply conditions, it shall be demonstrated that the burner is safely operating, and that the CO emissions remain below the level required in 4.4.9. This test shall be repeated at the minimum heat input permitted by the controls, if ignition is possible under these conditions.

5.4.6 Tests of automatic control of burners and catalytic oxidation reactors

5.4.6.1 General

The following procedures are associated with the start of all components intended to conduct a controlled oxidation reaction, such as combustion in the start burner of a reformer section, catalytic partial oxidation and catalytic combustion.

5.4.6.2 Tests of automatic ignition control of hydrogen generators burners

5.4.6.2.1 Effective ignition test

With the hydrogen generator maintained at rated voltage, the igniter shall be activated and ignition observed. The igniter shall light the main burner fuel immediately after fuel reaches the main burner ports. Flames shall not flash outside of the hydrogen generator, nor shall there be any damage to the hydrogen generator.

At least five ignition attempts shall be made. In each instance, ignition shall occur immediately after fuel reaches the main burner ports.

5.4.6.2.2 Ignition-voltage variation test

5.4.6.2.2.1 Undervoltage test

The voltage to the hydrogen generator shall be adjusted to 85 % of the rating plate voltage. Under this condition, the igniter shall light the main burner fuel within the main flame establishing period. The CO emissions shall be measured to verify compliance with the requirement of 4.4.9. Flames shall not flash outside the hydrogen generator, nor shall there be any damage to the hydrogen generator.

At least five ignition attempts shall be made. In each instance, ignition shall occur within the main flame establishing period.

5.4.6.2.2.2 Overvoltage test

The voltage to the hydrogen generator shall be adjusted to 110 % of the rating plate voltage. Under this condition, the igniter shall light the main burner fuel within the main flame establishing period. The CO emissions shall be measured to verify compliance with the requirement of 4.4.9. Flames shall not flash outside the hydrogen generator, nor shall there be any damage to the hydrogen generator.

At least five ignition attempts shall be made. In each instance, ignition shall occur within the main flame establishing period.

5.4.6.2.3 Main flame establishing period test

The flame establishing period shall be checked when the hydrogen generator is being operated as specified in 5.3. The time from energizing the main fuel flow to the time of proof of the ignition device or burner flame, as applicable, shall not exceed the manufacturer's specified main flame establishing period.

5.4.6.2.4 Flame failure lock-out time test

The hydrogen generator shall operate at its rated fuel consumption rate until thermal equilibrium is achieved. The flame failure lock-out time shall be measured between the moment when the pilot (if equipped) and main burner are intentionally extinguished by shutting off the fuel, and the moment when the automatic ignition control effectively shuts off the fuel supply. The automatic ignition control shall de-energize all fuel safety shut-off valves within the flame failure lock-out time specified in 4.7.4.

With the burner alight, flame failure shall be simulated by disconnecting the flame detector. The time that elapses between this moment and that when the flame monitoring device effectively shuts off the fuel supply shall be measured. For the purposes of this test, the manufacturer's specified maximum flame failure lock-out time shall be used as acceptance criteria.

5.4.6.2.5 Recycling/spark restoration test

With a recycling ignition system, the recycle time shall be checked with the hydrogen generator being adjusted to its rated fuel consumption rate. When spark restoration occurs, it shall be verified that after flame failure the igniter effectively relit the fuel within the main flame establishing period. Flames shall not flash outside the hydrogen generator, nor shall there be any damage to the hydrogen generator.

With the burner alight, flame failure shall be simulated by disconnecting the flame detector. The time that elapses between flame outage and the moment when the flame detector acts to shutdown fuel flow shall be measured. Also, the time that elapses between the moment when the fuel flow stops and the moment when the igniter re-energizes shall be measured. For the purposes of this test, the manufacturer's specified maximum flame failure lock-out time and minimum recycle time shall be used as acceptance criteria.

5.4.6.2.6 Pilot flame reduction test

A pilot, when provided, shall effect safe ignition of fuel at the main burner when the pilot fuel supply is reduced to an amount just sufficient to keep the safety shut-off valve open or just above the point of flame extinction, whichever represents the higher pilot fuel rate. Flames shall not flash outside the hydrogen generator, nor shall there be any damage to the hydrogen generator.

This test shall be initiated from both a cold start and immediately after the hydrogen generator has been shut off after equilibrium condition. At the reduced pilot fuel rate, the main burner shall be ignited within the main flame failure lock-out time.

5.4.6.2.7 Delayed ignition test

For a hydrogen generator that is arranged for ignition of the main burner directly by an electric igniter, delay of ignition of the fuel shall not result in flashback of flame to the outside of the hydrogen generator or in any damage to the hydrogen generator and the connected vent system. For purposes of this test, the manufacturer's specified maximum trial for ignition period for the automatic fuel ignition system shall be used. For systems that deactivate the igniter prior to the end of the trial for ignition period, the test shall be conducted using the manufacturer's specified maximum ignition activation period timing.

With the hydrogen generator at room temperature, the hydrogen generator shall be placed into operation at normal heat input rate with the ignition means temporarily circumvented for varying intervals of time up to the manufacturer's specified maximum trial for ignition period or the manufacturer's specified maximum ignition activation period, whichever is shorter. For multi-try systems, ignition attempts shall be made for varying intervals of time for each trial for ignition period and any time the ignition means is activated throughout the total operating sequence up to lock-out.

The ignition of the main burner shall be observed for each of the trials.

The delayed ignition testing shall also be used to confirm the main flame establishing period specified by the manufacturer.

5.4.6.2.8 Temperature test of ignition system components

Thermocouples or equivalent temperature-measuring devices shall be attached to applicable points of each ignition system component. The hydrogen generator shall be operated at rated fuel consumption rate until equilibrium condition is obtained. Temperatures of the components shall then be measured. The temperatures measured shall not exceed their manufacturer's specified maximum temperature.

5.4.6.2.9 Burner purge test

This test is applicable to systems that require purging as per 4.7.4.

According to the option chosen by the manufacturer, the purge volume or the purge time shall be determined and checked according to the manufacturer's specification.

The purge volume shall be determined as follows:

a) The hydrogen generator shall be at ambient temperature and not operating. The purge fan shall be supplied with electricity under actual purge conditions.

b) The purge rate shall be measured with a limit of error of ± 5 % at the outlet of the combustion product evacuation duct at ambient temperature, and corrected to reference conditions.

c) The manufacturer shall state the volume of the combustion circuit.

The purge time shall be determined as follows:

d) The hydrogen generator shall be at ambient temperature and not operating.

e) The time between the starting of the purge fan and the moment when the safety shut-off valves are opened shall be measured.

5.4.6.3 Tests of automated control of catalytic oxidation reactors

5.4.6.3.1 Reaction initiation time test

The hydrogen generator shall be operated as specified by the manufacturer until conditions for reaction initiation are attained. Then the fuel supply for air-rich operation, or the supply of air for fuel-rich operation, shall be opened. The time between this moment and the moment when the reactor monitoring devices signal that the reaction has been successfully initiated shall be measured. The time measured shall not exceed the maximum reaction initiation time specified by the manufacturer.

5.4.6.3.2 Reaction failure lock-out time

The hydrogen generator shall be operated as specified in 5.3 until equilibrium conditions are attained. Then the fuel supply for air-rich operation, or the supply of air for fuel-rich operation, shall be shut off.

With the catalytic reactor alight, reaction failure shall be simulated by disconnecting the device monitoring the reaction temperature. The time measured between this moment and the moment when the system control shuts off the fuel supply for air-rich operation, or the supply of all reactants for fuel-rich operation, shall not exceed the reaction failure lock-out time specified in 4.7.5.

5.4.7 Mechanical testing of vent systems

5.4.7.1 General

Vent systems shall be mechanically tested unless it can be demonstrated by calculation that the vent systems meet the requirements below.

5.4.7.2 Pull and torque tests

The venting system shall be installed on the hydrogen generator in accordance with the manufacturer's instructions. The venting system components shall be assembled such that the vent pipe extends beyond the hydrogen generator casing. If cemented joints are included in the assembly of the hydrogen generator vent system, the cement shall be allowed to dry as specified in the manufacturer's instructions.

A 223 N force shall be applied along the longitudinal centreline of the vent pipe in a direction tending to pull the vent from the hydrogen generator. A similar force shall then be applied in the opposite direction. In each case, the force shall be applied for five minutes.

A torque of 34 N-m shall be applied to the centreline of the assembly for one minute in one rotation direction. The torque shall then be applied in the opposite direction for one minute. Rotation of the vent pipe with respect to the exhaust collar shall be considered as acceptable if the joint then passes the following vent leakage test.

After the test, the vent connections and the other internal parts shall be examined for signs of leakage, breakage or disassembly. This provision shall be deemed met if the hydrogen generator meets the blocked outlet combustion test and vent leakage tests specified in 5.4.12.2 and 5.4.3.2.

5.4.7.3 Load test on vent termination

The vent system shall be assembled in accordance with the manufacturer's installation manual. A vertical suspension load of seven times the nominal pipe diameter, expressed in mm, to a maximum of 750 N, shall then be evenly distributed without impact over the vent terminal and shall be left in place for one minute. The load shall be removed and shall not have caused substantial distortion of any part of the vent terminal or alteration of its position relative to the hydrogen generator so the appliance would not operate satisfactorily.

The hydrogen generator shall then be operated at normal input rate until equilibrium conditions are attained. A sample of the effluents shall then be taken and analysed. The concentration of carbon monoxide, based on an air-free sample, shall not exceed the requirements of 4.4.9.

5.4.7.4 Impact test on vent termination

The impact shall be produced by a pendulum action.

A bag filled with sand weighing 12 kg shall be suspended from a cable or rope so that the length of the pendulum measured from the point of rotation to the centre of gravity of the bag shall be 2,20 m. The bag shall have an at-rest position such that not more than 25 mm separate the edge of the bag from the edge of the vent terminal. The point of impact on the vent shall be opposite the centre of gravity of the bag. The bag shall then be elevated so that the specified test angle is measured between the pendulum arm with the bag at its at-rest position and pendulum arm at its elevated position.

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

a) the centre of the vertical front surface of the vent terminal;

b) the leading edge on the left side of the vent terminal, pendulum trajectory rotated left at an angle of 45 degrees from the trajectory applied in a);

c) the leading edge on the right side of the vent terminal, pendulum trajectory rotated right at an angle of 45 degrees from the trajectory applied in a).

Following each impact, the hydrogen generator shall be operated at normal input rate until equilibrium conditions are attained. A sample of the effluents shall then be taken and analysed and in each case the concentration of carbon monoxide on an air-free sample shall not exceed the requirements of 4.4.9.

According to the manufacturer's instructions, the vent terminal may be replaced following each impact and combustion test.

5.4.8 Surface and component temperature test

When the hydrogen generator has attained equilibrium operating conditions, temperatures shall be measured to determine that the requirements of 4.4.5, 4.4.2 and, if applicable, 4.7.2.3.3 and 4.7.3 are met.

5.4.9 Wall, floor and ceiling temperatures test

This test shall be performed on hydrogen generators intended for indoor use only. The hydrogen generator shall be placed in a six-sided rectangular non-ventilated test enclosure made of dull black-painted plywood with a nominal thickness of 20 mm. The test enclosure shall be built with dimensions such that the hydrogen generator fits in it, respecting the minimum clearance distances to combustible material specified by the manufacturer in the installation manual.

Temperature rises shall be determined by means of fine-wire thermocouples.

NOTE Thermocouples having wires with a diameter not exceeding 0,3 mm are considered to be fine-wire thermocouples.

Thermocouples used for determining the temperature rise of the surface of walls, ceiling and floor of the test enclosure shall be attached to the back of blackened disks of copper or brass, 15 mm in diameter and 1 mm thick. The front of the disk shall be mounted flush with the surface of the test panels.

Thermocouples shall be positioned so as to detect the highest temperatures, changing their position if required during the test.

Ambient temperature shall be measured and recorded before starting the operation of the hydrogen generator.

The hydrogen generator shall be operated at maximum power output. After equilibrium temperatures are obtained, the temperatures of the test panels shall be measured.

The temperature rise shall not exceed the requirements of 4.4.5.

5.4.10 Temperature of polymeric components

The highest operating temperature of polymeric components shall be determined:

— for indoor hydrogen generators by placing thermocouples on polymeric components during the wall, floor and ceiling temperature test of 5.4.9;

— for outdoor hydrogen generators by placing thermocouples on polymeric components when operating the hydrogen generator at maximum power output in a wind-protected environment and at the maximum air temperature specified by the manufacturer as per 4.3.3.

The functional integrity of a polymeric component shall be determined after it has been exposed to a temperature of not less than 70 °C, or to a temperature of 10 °C above the highest operating temperature, whichever is greater, for seven hours in a full draft circulating-air oven.

There shall be no shrinkage, warpage or other distortion of the component that would affect its intended function or create a safety hazard.

5.4.10.1 Outlet piping temperature test

When the hydrogen generator has attained equilibrium operating conditions, the temperature of all outlet piping shall be measured. The temperature obtained shall not exceed the maximum temperature specified by the manufacturer.

5.4.11 Wind tests

5.4.11.1 Wind source calibration procedure for winds directed perpendicular to the wall

The wind source calibration configuration shall consist of the centre of the wind source being directed perpendicular to the centre of a test wall equipped with four ports located around a vent terminal which is installed in accordance with the manufacturer’s installation manual in the centre of the test wall. The ports shall be manifolded to obtain a single average static pressure reading. With the wind source directed against the wall, the average static pressure reading as measured by a manometer referenced at the hydrogen generator combustion air opening shall form the basis for calibrating the wind source using the relationships shown in Table 4.

Table 4 — Relationships

Nominal wind velocity km/h	Average static pressure Pa
16	10
54	116

Additionally, the wind source calibrated at 50 km/h shall not generate a velocity pressure exceeding 12 Pa (16 km/h) at a distance of 305 mm perpendicular to the test wall and in line with the ports.

5.4.11.2 Hydrogen generators intended for outdoor use

5.4.11.2.1 Applicability

These tests apply only to hydrogen generators intended for outdoor use or components of hydrogen generators intended for outdoor use.

5.4.11.2.2 Verification of operation under wind conditions

Cabinets of hydrogen generators intended for outdoor use or enclosures of components of hydrogen generators intended for outdoor use shall be subject to, and pass, a wind test as per the following method.

The hydrogen generator shall start and operate normally, without damage or malfunctioning of any part and without creating a hazardous or unsafe condition, when exposed to winds having nominal velocities up to and including 50 km/h.

A wind source calibrated as per 5.4.11.1 shall be directed against an outer surface of the hydrogen generator at the point(s) deemed most critical. The wind source shall be located so that a uniform wind, covering the entire projected area of the outer surface, is directed horizontally toward the hydrogen generator at the specified velocity measured in a vertical plane 50 cm from the windward surface of the hydrogen generator.

With the hydrogen generator subjected to a wind having a nominal velocity of 16 km/h, the pilot, when provided, shall be capable of being ignited.

With the hydrogen generator subjected to a wind having a nominal velocity of 50 km/h, the burner gas shall ignite from the ignition device in a time within the main flame establishing period and the burner and pilot flames shall not extinguish. The pilot, when provided, shall be operated alone, as well as simultaneously with the burner.

5.4.11.2.3 CO emissions under wind

During the test of 5.4.11.2.2, the CO emissions shall be checked when the hydrogen generator is exposed to a wind ranging from 0 km/h to 50 km/h. The hydrogen generator shall operate at nominal input rate until a constant exhaust gas temperature is achieved. During the application of this range of velocities, the CO emissions shall be measured to verify compliance with the requirements of 4.4.9.

5.4.11.3 Hydrogen generators intended for indoor use

5.4.11.3.1 Applicability

These tests apply only to hydrogen generators intended for indoor use. These tests shall be conducted using the maximum air intake and flue gas vent pipe length, as specified by the manufacturer. For the purpose of these tests, the manufacturer shall provide the flue gas vent-air intake. The entire flue gas vent-air intake system, including the piping and terminal cap, shall be installed (and sealed, if applicable) in accordance with the manufacturer’s installation manual on a test wall.

5.4.11.3.2 Verification of operation under wind conditions

5.4.11.3.2.1 Wind parallel to the test wall

The wind source shall be calibrated at a nominal velocity of 50 km/h (117 Pa free-stream velocity pressure) when measured with the wind parallel to the test wall with a Pitot tube at three locations positioned on a plane perpendicular to the test wall and also bisecting the flue gas vent system.

For the purpose of this test, the test wall shall be subjected to a parallel wind having a nominal velocity of 50 km/h. The hydrogen generator shall start and not shut down during a 10-minute period when exposed to the 50 km/h calibrated wind source.

5.4.11.3.2.2 Wind perpendicular to the wall

For the purpose of this test, the test wall shall be subjected to a perpendicular wind having a nominal velocity of 50 km/h, produced from a wind source calibrated as specified in 5.4.11.1.

When exposed to the 50 km/h wind source, the burner gas shall ignite from the ignition device in a time within the main flame establishing period and the burner and pilot flames shall not extinguish. The pilot, when provided, shall be operated alone, as well as simultaneously with the burner. The hydrogen generator shall not shut down during a 10-minute period and shall also continue to operate when cycled on and off by the automatic controls.

5.4.11.3.2.3 CO emissions under wind

During the test of 5.4.11.3.2.1, the CO emissions shall be checked when a wind ranging from 0 km/h to 50 km/h is exerted against the vent-air intake terminal(s). The hydrogen generator shall operate at nominal input rate until a constant exhaust gas temperature is achieved. During the application of this range of wind velocities, the CO emissions shall be measured to verify compliance with the requirement of 4.4.9.

5.4.12 CO emissions tests

5.4.12.1 Operation under equilibrium conditions

When the hydrogen generator has attained equilibrium operating conditions, CO emissions shall be measured to verify compliance with the requirement of 4.4.9. Hydrogen generators that have variable output capacity shall be tested at 25 %, 50 %, 75 % and 100 % capacity levels.

5.4.12.2 Blocked outlet test

The CO emissions shall be checked with the hydrogen generator's exhaust outlet progressively blocked to any degree up to and including complete closure. The hydrogen generator shall be operated at nominal fuel input rate for at least 15 minutes. When the hydrogen generator incorporates a control to automatically shut off the main fuel supply under blocked outlet conditions, the area of the exhaust outlet shall be gradually decreased to the lowest point at which the control remains in its open position. The CO emissions shall then be measured to verify compliance with the requirement of 4.4.9.

5.4.12.3 Blocked air supply test

This test shall be performed on hydrogen generators that rely on outside air routed through an air intake conduit. The hydrogen generator shall be operated at nominal fuel input rate for at least 15 minutes.

The air intake duct shall be progressively blocked. The CO emissions shall then be measured to verify compliance with the requirement of 4.4.9. With the hydrogen generator at ambient temperature, the air supply duct shall be reopened gradually and the blockage at which the burner ignites shall be determined. At this blockage, and once thermal equilibrium is achieved, the CO emissions shall be measured to verify compliance with the requirement of 4.4.9.

5.4.12.4 Voltage variation test

This test shall be performed on hydrogen generators that rely on mechanical means, such as fans, to bring air to the hydrogen generator burners or to vent its emissions. The hydrogen generator shall be operated at nominal fuel input rate for at least 15 minutes.

The voltage at the fan terminals shall be progressively reduced. It shall be checked that the gas supply is shut off before the CO concentration of the combustion products exceeds the requirement of 4.4.9. With the hydrogen generator at ambient temperature, the voltage at the fan terminals shall be progressively increased from zero. The voltage at which the burner ignites shall be determined. At this voltage, the CO emissions shall be measured to verify compliance with the requirement of 4.4.9.

5.4.13 Limit testing due to loss of utility and fuel supply

The hydrogen generator shall be installed and operated as specified in the applicable provisions of 5.3. A test shall be conducted for each utility and fuel system, i.e. electrical, feed water, cooling water, instrument air, etc., where the supply is gradually interrupted.

The system shall safely shut down without:

— the creation of any health or safety hazards;

— permanent distortion or damage to the system;

If the hydrogen generator requires a purge gas for protection during shutdown and/or storage, the simultaneous failure of the inert gas and a second utility need not be tested. However, the test shall verify that loss of purge gas supply results in an alarm.

5.4.14 Verification of operation

5.4.14.1 General

The purpose of this test is to verify that the hydrogen output, under the test conditions of 5.3 while using the nominal fuel input, is not less than the nominal hydrogen output and that the hydrogen purity is not less than the nominal hydrogen purity.

5.4.14.2 Functions

The functions of the hydrogen generator shall be tested, particularly those related to safety and safeguarding. All modes and transition conditions specified by the manufacturer shall be tested. The system shall safely operate without:

— the creation of any health or safety hazards;

— permanent distortion or damage to the system.

5.4.14.3 Operation

The product gas stream flow rate and the fuel supply shall be measured at 100 % capacity when conditions of equilibrium are achieved. The fuel supply gas stream shall be measured using the same method for gas streams or using another method suitable for liquid fuels.

Hydrogen generators that have variable output capacity shall be tested at 25 %, 50 %, 75 % and 100 % capacity levels.

Hydrogen generators that have different output settings shall be tested at each different output setting.

Each capacity level or output setting shall have the measurements made at equilibrium operating conditions.

Airborne noise emissions shall be determined as per IEC 60704-3.

Based on the measurements made according to 5.1, the following characteristics shall be determined:

- hydrogen production rate;
- fuel input rate;
- hydrogen content in the output stream on a dry basis;
- pressure, temperature and humidity of the hydrogen output stream;
- electrical consumption at rated output;
- airborne noise emissions.

5.4.14.4 Accumulated operation

Subsequent to tests 5.4.13 and 5.4.14.3, a 720-hour accumulated operation test shall be completed. Subsequent to the 720-hour accumulated operation test, the allowable leakage test as per 5.4.3 shall be repeated.

5.5 Routine tests

Each hydrogen generator shall be subjected to the following routine tests prior to delivery:

- leakage test of the hydrogen generator section(s) carrying flammable fluids, as per 5.4.2.2 and 5.4.3;
- burner operating characteristics test as per 5.4.5;
- dielectric withstand (hypot) test on the generator’s high voltage circuitry as per IEC 60204-1 for industrial applications or IEC 60335-1 for residential, commercial and light industrial applications, applied for one minute, or using a potential of 120 percent of that value applied for one second;

NOTE If the hydrogen generator employs a component, such as solid-state device that can be damaged by the dielectric potential, the test may be conducted with the point of connection of the component to ground disconnected or before the component is electrically connected.

- protective bonding circuit continuity test, as per IEC 60204-1 for industrial applications or IEC 60335-1 for residential, commercial and light industrial applications.

6 Marking, labelling and packaging

6.1 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 its intended installed position.

The marking shall clearly state any restrictions on use, in particular the ventilation requirements of the area in which the hydrogen generator is to be installed.

NOTE Subclause 7.5.8 of ISO/TR 15916:2004 presents principles related to ventilation of spaces containing equipment for handling hydrogen.

The data plate and/or label(s) shall include the following information:

a) the manufacturer’s name, trademark, and location;

b) the catalogue number and the model number or type;

c) the serial number;

d) the electrical input range in volts;

e) the current rating in amperes;

f) the frequency in hertz and number of phases;

g) the rated nominal power input in watts;

h) the rated nominal thermal input (if applicable);

i) the input fuel type and quality to be used by the hydrogen generator;

j) the permissible range of fuel supply pressures;

k) outdoor or indoor use;

l) the capacity of generation of hydrogen in kilograms per hour;

m) the hydrogen content in the output stream on a dry basis;

n) the hydrogen output pressure in kilopascals;

o) a reference to this International Standard.

If the hydrogen generator is rated to operate in hazardous areas as per IEC 60079-10, it shall be marked accordingly.

The hydrogen generator shall be marked with the following: “Refer to the installation instructions for parts lists and installation procedures for piping, electrical and instrument interconnects.”

6.2 Marking of components

Warning signs shall be placed to identify electrical hazards, contents from drain valves, hot components and mechanical hazards. Preference should be given to the use of standard symbols given in ISO 3864. If a warning statement is employed in lieu of a symbol, the statement should include a signal word, such as Danger, Warning or Caution, the hazard, and how to avoid the hazard. As a minimum, the hydrogen generator cabinet shall be visibly marked with the warning signs specified in 6.3.3.

Control devices, visual indicators, and displays used in the man-machine interface shall be clearly marked with regard to their functions either on or adjacent to the item. Special attention shall be paid to those related to safety. Preference should be given to the use of standard symbols given in IEC 60417 and ISO 7000.

6.3 Product’s technical documentation

6.3.1 General

The manufacturer shall provide with each hydrogen generator the information necessary for safe installation, operation and servicing of the hydrogen generator, and shall in particular draw attention to any restrictions on use. The information shall be provided in the form of technical documents such as drawings, diagrams, charts, tables and instructions, and these shall be on a suitable data medium and in a suitable language.

Part of the technical information may be intended only to qualified personnel, in which case the manufacturer shall specify criteria for qualification of personnel.

The information provided with the hydrogen generator shall include:

a) a clear, comprehensive description of the equipment, installation and mounting, and the connection to electrical supply(ies);

b) the technical specifications of the hydrogen generator, including at least the information required for marking in 6.1;

c) electrical supply(ies) requirements;

d) physical environment and operating conditions as per 4.3;

e) electric circuit diagrams;

f) information (where appropriate) on

   1) handling, transportation and storage,

   2) software programming,

   3) sequence of operations,

   4) frequency of inspection,

   5) frequency and method of functional testing,

   6) the adjustment, maintenance, and repair, particularly of the protective devices and circuits, and

   7) a parts list and recommended spare parts list;

g) a description (including interconnection diagrams) of the safeguards, interlocking functions and interlocking of guards for potentially hazardous situations, particularly for hydrogen generators operating in a coordinated manner with other equipment items (e.g. a fuel cell power system or a hydrogen compression, storage and delivery system);

h) a description of the safeguarding and of the means provided where it is necessary to suspend the safeguarding (e.g. for manual programming, program verification);

i) all the information that is required by this International Standard to be included in the product's technical documentation.

6.3.2 Installation manual

The installation manual shall provide the installer all the information necessary for the preliminary work of setting up the generator.

In particular, an interconnection diagram or table shall be provided. That diagram or table shall give full information about all external connections (e.g. electrical supply, fuel supply, water supply, control signals, exhaust venting, ventilation connections, product delivery interconnection, etc.).

These installation instructions shall provide, as applicable, guidelines on the following:

a) location and design of the hydrogen generator foundation including the anti-vibration mountings;

b) ventilation requirements;

c) design, construction and installation of the pressure relief venting pipe, flue gas venting system and product delivery piping;

d) protection from weather hazards;

e) recommended height in relation to the base flood elevation;

f) security enclosure;

g) minimum clearance distances from combustible materials or ignition sources, vegetation, sidewalks, public ways, roads, and railroad tracks;

h) protection from vehicular impact;

i) clearances around air supply, ventilation and exhaust openings in metres;

j) clearances for maintenance, servicing and proper operation in metres; and

k) anchorage means.

NOTE Annex D provides information on the installation of hydrogen generators.

6.3.3 User's information manual

For hydrogen generators intended for residential, commercial and light industrial use such as a hydrogen source for residential fuel cell power systems, the manufacturer shall provide to the hydrogen generator owner a user's information manual together with any appropriate additional information to facilitate maintenance such as addresses of the importer, repairer, etc.

The user's information manuals shall be in the user's national language.

The user's information manuals shall be typed or typeset and formatted to provide easy-to-follow procedures.

Illustrations shall be used to identify hydrogen generator components, dimensions and clearances, assembled components, and connection points as needed to make the instructions clear. Illustrations shall also be used to identify the location of serviceable components and illustrate correct methods for performing service procedures.

When text is shown in quotation marks, it shall appear in the user's information manual exactly as shown.

The user's information manual shall be affixed to the hydrogen generator in a pocket or attached by a clip which is part of the hydrogen generator or shall be supplied in an envelope marked with instructions to the installer to affix them on or adjacent to the hydrogen generator, and to the user to retain them for future reference.

Each user's information manual should be divided into appropriate chapters or sections, and should include a table of contents and clearly marked page numbers.

The front cover shall present the user(s) with only the most important safety instructions. As a minimum, the front cover or, in the absence of a cover, the first page of the manual shall bear the following safety precautions boxed as shown in Figures 1 to 3, as applicable.

⚠ **WARNING:**

FIRE OR EXPLOSION HAZARD

Failure to follow safety warnings exactly could result in serious injury, death or property damage.

— **Do not store or use gasoline or other flammable vapours and liquids in the vicinity of this or any other related appliance.**

— **WHAT TO DO IF YOU SMELL GAS**

- **Do not try to light any appliance.**
- **Do not touch any electrical switch; do not use any phone in the area.**
- **Leave the area immediately.**
- **Immediately call your gas supplier. Follow the gas supplier's instructions.**
- **If you cannot reach your gas supplier, call the fire department.**

— **Installation and service must be performed by a qualified installer, service agency or the gas supplier.**

Figure 1 — Minimum safety precautions for odorized gas-fueled systems

⚠ **WARNING:**

FIRE OR EXPLOSION HAZARD

Failure to follow safety warnings exactly could result in serious injury, death or property damage.

— **Do not store or use gasoline or other flammable vapours and liquids in the vicinity of this or any other related appliance.**

— **Installation and service must be performed by a qualified installer, service agency or the gas supplier.**

Figure 2 — Minimum safety precautions for odorant-free gas-fueled systems

WARNING:

FIRE OR EXPLOSION HAZARD

Failure to follow safety warnings exactly could result in serious injury, death or property damage.

- **Do not store or use gasoline or other flammable vapours and liquids in the vicinity of this or any other related appliance.**
- **WHAT TO DO IF YOU SEE LIQUID LEAKAGE**
  - **Do not try to light any appliance.**
  - **Do not touch any electrical switch; do not use any phone in the area.**
  - **Leave the area immediately.**
  - **Immediately call your fuel supplier. Follow the fuel supplier's instructions.**
  - **If you cannot reach your fuel supplier, call the fire department.**
- **Installation and service must be performed by a qualified installer, service agency or the fuel supplier.**

Figure 3 — Minimum safety precautions for liquid-fueled systems

The front cover shall include a statement informing users that they shall read all instructions in the manual, and shall keep all manuals for future reference.

A safety section shall be included near the front of the manual to present hydrogen generator users with a list of potential hazards and safety-related instructions for a particular hydrogen generator. Statement of at least the following shall be included in the safety section with references to specific sections or pages of the manual:

a) directions that the area surrounding the hydrogen generator must be kept clear and free of combustible materials, gasoline and other flammable vapours and liquids;

b) where air is required for combustion or ventilation, instructions not to block or obstruct air openings on the hydrogen generator, air openings communicating with the area in which the hydrogen generator is installed, and the required spacings around the hydrogen generator that provide clearances to secure and discharge the required air;

c) instructions for starting and shutting down the hydrogen generator, which shall pictorially illustrate and locate all user interface components;

d) the following statement: "Do not use this hydrogen generator if any part has been under water. A flood-damaged hydrogen generator is potentially dangerous. Attempts to use the hydrogen generator can result in fire or explosion. A qualified service agency should be contacted to inspect the hydrogen generator and to replace all gas controls, control system parts and electrical parts that have been wet.";

e) specifications for the frequency of filter change or cleaning and the dimensional size and type of filter for replacements, which shall contain directions for removal and replacement of filters and pictorially illustrate and locate all components supplied by the manufacturer referred to in the instructions for removal and replacement of filters;

f) recommended methods for periodic cleaning of necessary parts;

g) instructions for examining the hydrogen generator installation to determine that:

1) any intake or exhaust openings associated with drain, venting and ventilation exhaust systems are clear and free of obstructions;

2) the physical support of the hydrogen generator is sound without sagging cracks, gaps, etc. around the base so as to provide a seal between the support and the base;

3) there are no obvious signs of deterioration of the hydrogen generator;

h) indications on the necessity and minimum frequency for the examination in g) above by the user and the requirements for the periodic inspection of the hydrogen generator by a qualified service agent.

In-text safety instructions shall refer to, or incorporate, safety precautions from the front cover and from the safety section of the manual. Potentially hazardous situations described in the manual shall require that additional precautionary safety statements be created.

6.3.4 Operating manual

6.3.4.1 General

The operating manual shall detail proper procedures for start-up and use of the hydrogen generator. Particular attention should be given to the safety measures provided and to the improper methods of operation that are anticipated.

The operation manual shall include a section on the hazards related to the use of the hydrogen generator. As a minimum, the hazards related to the presence of hydrogen and the hazards related to the use of purge gases (if used) shall be covered.

Where the operation of equipment can be programmed, detailed information on methods of programming, equipment required, program verification and additional safety procedures where required shall be provided.

The instructions shall give information concerning airborne noise emissions by the hydrogen generator, either the actual value or a value established on the basis of measurements made on an identical hydrogen generator. If the hydrogen generator is intended to be used in a potentially explosive atmosphere, the instructions shall give all the necessary information as required by the appropriate parts of IEC 60079 for the type(s) of protection used.

In the case of the hydrogen generators that are intended for use by non-professional operators, the wording and layout of the instructions for use, whilst respecting the other essential requirements mentioned above, shall take into account the level of general education and acumen that can reasonably be expected from such operators.

6.3.4.2 Remote monitoring system

If the hydrogen generator is provided with a remote monitoring system, the manufacturer shall supply the procedures to address the changes to this remote monitoring system. The procedures shall address the following points where:

— there is a person in charge at the hydrogen generator location;

— there is no person in charge at the hydrogen generator location.

The procedures shall, as a minimum address the following points:

a) modifying control parameters remotely;

b) certifying an upgrade to the remote monitoring system;

c) upgrading software remotely;

d) certifying a parameter change;

e) changing parameters remotely;

f) uploading parameters;

g) uploading software;

h) qualifying the operation;

i) undoing/reversing all changes;

j) testing and backup documentation.

6.3.5 Maintenance manual

The maintenance manual shall detail proper procedures for adjustment, servicing, preventive inspection, and repair. Recommendations on maintenance and servicing records shall be part of the maintenance manual. Where methods for the verification of proper operation are provided (e.g. software testing programs), the use of such methods shall be detailed.

The maintenance manual shall contain clearly defined, legible and complete information for at least the following:

a) instructions for starting and shutting down the hydrogen generator, which shall pictorially illustrate and locate all components;

b) specifications for the frequency of filter change or cleaning and the dimensional size and type of filter for replacements, which shall contain directions for removal and replacement of filters and pictorially illustrate and locate all components supplied by the manufacturer referred to in the instructions for removal and replacement of filters;

c) recommended methods for periodic cleaning of necessary parts;

d) instructions for lubrication of moving parts, including type, grade and amount of lubricant;

e) instructions for examining the hydrogen generator installation to determine that:

    1) any intake or exhaust openings are clear and free of obstructions;

    2) there are no obvious signs of physical deterioration of the hydrogen generator or its support (i.e. base, frame, cabinet, etc.);

f) periodic examination of the venting system and all functional parts;

g) periodic sampling of CO emissions under equilibrium operating conditions as per 5.4.12.1;

h) a parts list, including information necessary for ordering spare or replacement parts.

The maintenance manual shall also provide an enumeration of all regular and routine maintenance activities to be performed on the hydrogen generator components and indicate the necessity and minimum frequency for these examinations.

The maintenance manual shall specify the periodic inspection of the hydrogen generator that shall be performed by qualified service personnel.

When necessary to avoid risks to health or safety, the manufacturer shall include in the maintenance manual requirements for decommissioning and disposal of the hydrogen generator or its materials and components.

Compliance with applicable regional or national environmental codes and standards should be verified and methods for recycling should be considered. Guidance on recycling is provided in Annex C.

Annex A
(informative)

Significant hazards and hazardous situations dealt with in this International Standard

The significant hazards and hazardous situations dealt with in this International Standard are described in Table A.1.

Table A.1 — Significant hazards and hazardous situations dealt with in this International Standard

Significant hazards and hazardous situations	Subclause
□ **Mechanical hazards due to:**	
□ Shape (sharp surfaces)	4.4
□ Relative location (trip/crash hazard)	4.4
□ Mass and stability (potential energy of elements which may move under the effect of gravity)	4.4
□ Mass and velocity (kinetic energy of elements in controlled or uncontrolled motion)	4.4, 4.13
□ Inadequacy of mechanical strength (inadequate specification of material or geometry)	4.4, 4.6, 4.14
□ Fluids under pressure (overpressurization, ejection of fluids under pressure, vacuum)	4.4, 4.6
□ **Electrical hazards due to:**	
□ Contact of persons with live parts (direct contact)	4.8
□ Contact of persons with parts that have become live under faulty conditions (indirect contact)	4.8
□ Approach to live parts under high voltage	4.8
□ Electrostatic phenomena	4.6, 4.8
□ Electromagnetic phenomena	4.9
□ Heat/chemical effects from short circuits, overloads	4.8
□ Projection of molten particles	4.8
□ **Thermal hazards due to:**	
□ Contact of persons with surfaces at extreme high temperatures	4.4
□ Release of high temperature fluids	4.6
□ Thermal fatigue	4.5, 4.6
□ Equipment overtemperature causing unsafe operation	4.10
□ **Hazards generated by materials and substances:**	
□ Hazards from contact with, or inhalation of, harmful fluids, gases, mists, fumes and dusts.	4.4
□ Fire or explosion hazard due to leak of flammable fluids	4.7
□ Fire or explosion hazard due to internal build-up of flammable mixture	4.7
□ Hazardous situations caused by material deterioration (e.g. corrosion) or accumulation (e.g. fouling)	4.5

Significant hazards and hazardous situations	Subclause
☐ Asphyxiation	4.4
☐ Reactive materials (pyrophoric)	4.4, 4.5
☐ **Hazards generated by malfunctions:**	
☐ Unsafe operation due to failures or inadequacy of software or control logic	4.10
☐ Unsafe operation due to failures of control circuit or protective/safety components	4.10
☐ Unsafe operation due to power outage	4.10
☐ **Hazards generated by neglecting ergonomic principles:**	
☐ Hazards due to inadequate design, location or identification of manual controls	4.10
☐ Hazards due to inadequate design or location of visual display units and warning signs	4.10
☐ Noise	4.4
☐ **Hazards generated by erroneous human intervention:**	
☐ Hazards due to deviation from correct operating	4.10, 6.3
☐ Hazards due to errors of manufacturing/fitting/installation	4.4, 6.3, 4.17
☐ Hazards due to errors of maintenance	6.3, 4.17
☐ Vandalism	4.14
☐ **Environmental Hazards:**	
☐ Unsafe operation in extreme hot/cold environments	4.14, 4.15
☐ Rain, flooding	4.14
☐ Wind	4.14, 4.3
☐ Earthquake	4.4, 4.3
☐ Smoke	4.3
☐ Snow, ice load	4.14
☐ Attack by vermin	4.14
☐ **Pollution:**	
☐ Air pollution	4.4
☐ Water pollution	4.4, 4.5, 4.6
☐ Soil pollution	4.4

Annex B
(informative)

Carburization and material compatibility for hydrogen service

B.1 Carburization

Conventional carburization is a familiar problem with high-temperature alloys in steam reforming furnaces. It is caused by the inward migration of carbon, the source of which is hydrocarbon cracking, resulting in the formation of carbides within the metal matrix. The process is promoted by high temperature, typically above 800 ^{o}C, and leads ultimately to loss of ductility.

In general, carburization of an alloy results in low ductility at ambient temperatures. Carbon pick-up will increase the volume of the metal and coefficient of expansion, resulting in strong internal stresses that give rise to premature failure of equipment. Failure is usually by creep rupture and low-cycle fatigue. If carburization is sufficiently severe, it can also affect the elevated temperature creep and rupture characteristics. There seem to be differences in tolerance between the various alloys regarding this issue.

Generally the carburization rate varies with:

— temperature: The rate roughly doubles for every 55 °C increase;

— CO/CO_2 ratio: Reaction kinetics is controlled by the ratio of CO/CO_2 in the gas and by the temperature;

— strongly carburizing conditions: Strongly carburizing conditions are $CO/CH_4/H_2$ flows with a low steam/carbon ratio at intermediate temperatures (usually 450 °C – 850 °C), and an oxide layer with flaws;

— nickel and silicon content: High values are beneficial;

— protective and regenerative oxide films: Cr, Si and Al in the alloy are beneficial;

These rules are general and may not be true for all combinations of material and environment due to the anomalous character of metal reactions.

B.2 Material compatibility for hydrogen service

B.2.1 Components

Components in which gaseous hydrogen or hydrogen-containing fluids are processed, as well as all parts used to seal or interconnect the same, should be resistant to the chemical and physical action of hydrogen at the operating conditions.

B.2.2 Metals and metallic materials

Users of this International Standard should be aware that engineering materials exposed to hydrogen in their service environment may exhibit an increased susceptibility to hydrogen-assisted corrosion via different mechanisms such as hydrogen embrittlement and hydrogen attack.

Hydrogen embrittlement is defined as a process resulting in a decrease of the toughness or ductility of a metal due to the permeation 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 and supersaturates the metal with hydrogen. The second type, environmental hydrogen embrittlement, results from hydrogen being absorbed by solid metals from the service environment.

Atomic hydrogen dissolved within a metal interacts with the intrinsic defects of the metal, typically increasing crack propagation susceptibility and thus degrading such basic properties as ductility and fracture toughness. There are both important material and environmental variables that contribute to hydrogen-assisted fracture in metals. The material microstructure, which may or may not be present due to compositional and processing variations, may affect the resistance of the metal to fracture. Second phases, such as ferrite stringers in austenitic stainless steels, may also have a specific orientation leading to profound anisotropic response in the materials. In general, metals can also be processed to have a wide range of strengths, and the resistance to hydrogen-assisted fracture is known to decrease as the strength of the alloy is increased.

The environmental variables affecting hydrogen-assisted fracture include pressure of hydrogen, temperature, chemical environment and strain rate. In general, the susceptibility to hydrogen-assisted fracture increases as hydrogen pressure increases. The effect of temperature, however, is not as systematic. Some metals such as austenitic stainless steels exhibit a local maximum in hydrogen-assisted fracture susceptibility as a function of temperature. Although not well understood, trace gases mixed with the hydrogen gas can also affect hydrogen-assisted fracture. Moisture, for example, may be detrimental to aluminium alloys since wet oxidation produces high-fugacity hydrogen, while in some steels, moisture is believed to improve resistance to hydrogen-assisted fracture by producing surface films that serve as kinetic barriers to hydrogen uptake. A so-called inverse strain rate effect is generally observed in the presence of hydrogen; in other words, metals are less susceptible to hydrogen-assisted fracture at high strain rates.

At temperatures close to ambient, this phenomenon can affect metals with body-centred cubic crystal lattice structure, e.g. ferritic steels. 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 sub-critical crack growth leading to fracture.

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.

At temperatures above 200 °C, many low-alloyed structural steels may suffer from hydrogen attack. This is a non-reversible degradation of the steel microstructure caused by a chemical reaction between diffusing hydrogen and the carbide particles in the steels that results in the nucleation, growth and merging of methane bubbles along grain boundaries to form fissures.

Hydride embrittlement occurs in metals such as titanium and zirconium and is the process of forming thermodynamically stable and relatively brittle hydride phases within the structure.

Clad welding and welds between dissimilar materials often involve high-alloy materials. During operation at temperatures over 250 °C, hydrogen diffuses in the fusion line between the high-alloy weld and the unalloyed/low-alloy base material. During shutdown, the material temperature drops. The reduced solubility and diffusibility of hydrogen breaks the weld by disbonding.

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

— Carefully identify locations that may be exposed to hydrogen. For example, iron sulphide formed in desulfurization units may catalyse the production of hydrogen, thus locally increasing the susceptibility to hydrogen embrittlement and hydrogen attack.

— Select raw materials with a low susceptibility to hydrogen embrittlement by controlling chemistry (e.g. use of carbide stabilizers), microstructure (e.g. use of austenitic stainless steels), and mechanical properties (e.g. restriction of hardness, preferably below 225 HV, and minimization of residual stresses through heat treatment). Use test methods specified in ISO 11114-4 to select metallic materials resistant to hydrogen embrittlement. The API RP 941 shows the limitations of various types of steel as a function of hydrogen pressure and temperature. The susceptibility to hydrogen embrittlement of some commonly used metals is summarized in ISO/TR 15916.

— Clad welds and welds between dissimilar materials used in hydrogen service should be ultrasonically tested at regular intervals and after uncontrolled shutdowns in which the equipment may have cooled rapidly.

— Minimize the level of applied stress and exposure to fatigue situations.

— 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.

B.2.3 Polymers, elastomers, and other non-metallic materials

Most polymers can be considered suitable for gaseous hydrogen service. Due account should be given to the fact that hydrogen diffuses through these materials much more easily than through metals. Polytetrafluoroethylene (PTFE or Teflon®[2)]) and Polychlorotrifluoroethylene (PCTFE or Kel-F®[3)]) are generally suitable for hydrogen service. Suitability of other materials should be verified. Guidance can be found in ISO/TR 15916 and the NASA document NSS 1740.16. See also ANSI/AGA 3.1 for guidance with regard to gaskets, diaphragms, and other non-metallic parts.

B.3 Additional information

Further guidance on hydrogen-assisted corrosion and control techniques may be found through the following standards and organizations:

B.3.1 International Organization for Standardization

ISO 2626, *Copper — Hydrogen embrittlement test*

ISO 3690, *Welding and allied processes — Determination of hydrogen content in ferritic steel arc weld metal*

ISO 7539-6, *Corrosion of metals and alloys — Stress corrosion testing — Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

ISO 9587, *Metallic and other inorganic coatings — Pretreatments of iron or steel to reduce the risk of hydrogen embrittlement*

ISO 9588, *Metallic and other inorganic coatings — Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement*

2) Teflon® is the trade name of a product supplied by DuPont. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

3) Kel-F® is a registered trade name of 3M Company. In 1996, 3M discontinued manufacturing of Kel-F and today, all PCTFE resin is manufactured by Daikin under the trade name of Neoflon® or by Allied Signal under the trade name of Aclon®. Kel-F is still the most commonly used trade name used to describe PCTFE. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO or IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

ISO 11114-4, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement*

ISO 15330, *Fasteners — Preloading test for the detection of hydrogen embrittlement — Parallel bearing surface method*

ISO 15724, *Metallic and other inorganic coatings — Electrochemical measurement of diffusible hydrogen in steels — Barnacle electrode method*

ISO/TR 15916, *Basic considerations for the safety of hydrogen systems*

B.3.2 American Petroleum Institute

API 934, *Materials and Fabrication Requirements for 2-1/4Cr-1Mo and 3Cr-1Mo Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service*

API 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*

B.3.3 American Society for Testing and Materials

ASTM B577, *Standard Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper*

ASTM B839, *Standard Test Method for Residual Embrittlement in Metallic Coated, Externally Threaded Articles, Fasteners, and Rod — Inclined Wedge Method*

ASTM B849, *Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement*

ASTM B850, *Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement*

ASTM E1681, *Standard Test Method for Determining a Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials*

ASTM F326, *Standard Test Method for Electronic Measurement for Hydrogen Embrittlement from Cadmium-Electroplating Processes*

ASTM F519, *Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments*

ASTM F1459, *Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (HGE)*

ASTM F1624, *Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique*

ASTM F1940, *Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners*

ASTM F2078, *Standard Terminology Relating to Hydrogen Embrittlement Testing*

ASTM G129, *Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking*

ASTM G142, *Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both*

ASTM G146, *Standard Practice for Evaluation of Disbonding of Bimetallic Stainless Alloy/Steel Plate for Use in High-Pressure, High-Temperature Refinery Hydrogen Service*

ASTM G148, *Standard Practice for Evaluation of Hydrogen Uptake, Permeation, and Transport in Metals by an Electrochemical Technique*

B.3.4 American Society of Mechanical Engineers

ASME *Boiler and Pressure Vessel Code*

ANSI/ASME B31.1, *Power piping*

ANSI/ASME B31.3, *Process Piping*

B.3.5 American Welding Society

ANSI/AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

B.3.6 British Standards Institution

BS 17089, *Method of measurement of hydrogen permeation and determination of hydrogen uptake and transport in metals by an electrochemical technique*

B.3.7 National Association of Corrosion Engineers

NACE TM0177, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments*

NACE TM0284, *Standard Test Method — Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

B.3.8 Society of Automotive Engineers

SAE/AMS 2451/4, *Plating, Brush, Cadmium Corrosion Protective, Low Hydrogen Embrittlement*

SAE/AMS 2759/9, *Hydrogen Embrittlement Relief (Baking) of Steel Parts*

SAE/USCAR 5-1, *Avoidance of Hydrogen Embrittlement of Steel*

Annex C
(informative)

Recycling of hydrogen generators

C.1 General

Recycling of a hydrogen generator's hardware depends on issues such as materials selection, hardware accessibility, and ease of materials separation.

C.2 System components and material types

The hydrogen generator's processes will generally take place within metallic vessels, commonly made of corrosion-resistant, high alloy nickel chromium steel, which house the catalysts, commonly precious-metal-based. The catalyst composition will be determined by the specific processing operation, however from a recycling standpoint we can say that when the economics of catalyst metals recovery is sufficiently attractive, there will be an incentive to recover the catalyst from inside the vessel for the purpose of extracting and recycling the metal. High-temperature ceramic insulation made from alumina, silica, and/or zirconia is typically installed internal to the steel vessel. Zinc oxide sorbent, used to remove sulfur from the fuel, is converted to zinc sulfide and accumulated in the unit until it can be removed and disposed of. Activated carbon may also be used to remove sulfur from the fuel stream. Hydrogen-selective permeable metal membranes of Pd, PdAg and other Pd alloys contained within a steel vessel are an alternative to the use of discrete components for desulfurization, water-gas shift, and selective oxidation.

C.3 Recycling engineering and environmental issues

For ease in materials recycling, vessels should be designed to enable removal of precious metals and ease in material separation. It is expected that the steel components will be recycled using existing recycling technology. Access to catalyst contained within the vessels should be possible if catalyst recycling is planned. Currently, nickel catalyst with a metal content of more than 20 % or precious metal catalyst can be economically recycled using existing processes.

Annex D
(informative)

Considerations for the installation of hydrogen generators

D.1 General

Hydrogen generators should be installed, adjusted, operated and maintained in accordance to the product's installation and maintenance manuals.

D.2 Flue gas vent system

The flue gas vent pipe exhausts should be located outdoors in a safe location, away from user areas, ignition sources, air intakes, building openings and overhangs and in accordance with applicable regional or national standards.

The flue gas vent pipe should be properly supported and should be provided with a rain cap or other feature that would not limit or obstruct the gas flow from venting vertically upward.

A means, such as drainage, should be provided to prevent water, ice and other debris from accumulating inside the flue gas vent pipe or obstructing the flue gas vent pipe.

D.3 Product delivery piping

D.3.1 Presentation of hazardous hydrogen release

The product delivery piping should be installed such as to prevent the occurrence of a hydrogen release that develops into a hazardous situation. For that purpose:

— the product delivery piping should not be installed in or through conduits that could disperse hydrogen releases to ignition sources, e.g. a circulating air duct, clothes chute, chimney or gas vent, ventilating duct, dumbwaiter or elevator shaft;

— portions of product delivery piping installed in concealed locations should not be located in solid partitions and solid walls, except when installed in a ventilated chase or casing, and should not have unions, tubing fittings, right or left couplings, bushings, compression couplings or swing joints made by combinations of fittings; exceptions are the joining of tubing by brazing and the use of fittings specifically tested and certified for use in concealed locations.

D.3.2 Mechanical protection

The product delivery piping should be protected against physical damage. Means should be provided to prevent excessive stressing of the product delivery piping, e.g. where there is heavy vehicular traffic or where soil conditions are unstable and settling of piping or foundation walls could occur. For that purpose:

— where product delivery piping is subject to excessive moisture or corrosive substances, the piping should be protected in an adequate manner; when dissimilar metals are joined underground, an insulating coupling or fitting should be used; the piping should not be laid in contact with cinders; uncoated threaded or socket welded joints should not be used in piping in contact with soil or where internal or external crevice corrosion is known to occur;

- product delivery piping installed underground should not penetrate the outer foundation or basement of a building, and should be installed with sufficient clearance from other underground structures to avoid contact therewith, to allow maintenance, and to protect against damage from proximity to other structures;
- in concealed locations, where piping is installed through holes or notches in wood studs, joists, rafters or similar members, the pipe should be protected by adequate means such as shield plates;
- product delivery piping in solid floors should be laid in channels in the floor and covered in a manner to allow access to the piping with a minimum amount of damage to the installation and to avoid accumulation of flammable gases (e.g. by using safety grating); as an alternative to installation in channels, the piping should be installed in a tightly sealing metallic or plastic casing ventilated outdoors;
- product delivery piping installed above ground, outdoors, should be securely supported and located where it will be protected from physical damage; piping passing through an exterior wall should be adequately protected, e.g. by encasing it in a protective piping sleeve; it should also be protected against corrosion by coating or wrapping it in an inert material;
- product delivery piping passing through interior concrete or masonry walls should be protected against differential settlement.

D.3.3 Marking

The product delivery piping should be marked "HYDROGEN" at intervals not exceeding 3 m. Letters of such marking should be in a distinguishable colour. Piping should be marked a minimum of one time in each room or space through which it extends.

Bibliography

[1] ISO 2626, *Copper — Hydrogen embrittlement test*

[2] ISO 3690, *Welding and allied processes — Determination of hydrogen content in ferritic steel arc weld metal*

[3] ISO 3864 (all parts), *Graphical symbols — Safety colours and safety signs*

[4] ISO 7000, *Graphical symbols for use on equipment — Index and synopsis*

[5] ISO 7539-6, *Corrosion of metals and alloys — Stress corrosion testing — Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

[6] ISO 9587, *Metallic and other inorganic coatings — Pretreatments of iron or steel to reduce the risk of hydrogen embrittlement*

[7] ISO 9588, *Metallic and other inorganic coatings — Post-coating treatments of iron or steel to reduce the risk of hydrogen embrittlement*

[8] ISO 11114-4, *Transportable gas cylinders — Compatibility of cylinder and valve materials with gas contents — Part 4: Test methods for selecting metallic materials resistant to hydrogen embrittlement*

[9] ISO 15330, *Fasteners — Preloading test for the detection of hydrogen embrittlement — Parallel bearing surface method*

[10] ISO 15724, *Metallic and other inorganic coatings — Electrochemical measurement of diffusible hydrogen in steels — Barnacle electrode method*

[11] ISO/TR 15916:2004, *Basic considerations for the safety of hydrogen systems*

[12] ISO/IEC 17000, *Conformity assessment — Vocabulary and general principles*

[13] ISO/IEC Guide 7, *Guidelines for drafting of standards suitable for use for conformity assessment*

[14] ISO/IEC Guide 51, *Safety aspects — Guidelines for their inclusion in standards*

[15] IEC 60079-2, *Electrical apparatus for explosive gas atmospheres — Part 2: Pressurized enclosures "p"*

[16] IEC/TR 60079-20, *Electrical apparatus for explosive gas atmospheres — Part 20: Data for flammable gases and vapours, relating to the use of electrical apparatus*

[17] IEC 60417 (all parts), *Graphical symbols for use on equipment*

[18] IEC 62061, *Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems*

[19] IEC Guide 104, *The preparation of safety publications and the use of basic safety publications and group safety publications*

[20] API 934, *Materials and Fabrication Requirements for 2-1/4Cr-1Mo and 3Cr-1Mo Steel Heavy Wall Pressure Vessels for High Temperature, High Pressure Hydrogen Service*

[21] API 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*

[22] ASTM B577, *Standard Test Methods for Detection of Cuprous Oxide (Hydrogen Embrittlement Susceptibility) in Copper*

[23] ASTM B839, *Standard Test Method for Residual Embrittlement in Metallic Coated, Externally Threaded Articles, Fasteners, and Rod — Inclined Wedge Method*

[24] ASTM B849, *Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement*

[25] ASTM B850, *Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement*

[26] ASTM E1681, *Standard Test Method for Determining a Threshold Stress Intensity Factor for Environment-Assisted Cracking of Metallic Materials*

[27] ASTM F326, *Standard Test Method for Electronic Measurement for Hydrogen Embrittlement from Cadmium-Electroplating Processes*

[28] ASTM F519, *Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments*

[29] ASTM F1459, *Standard Test Method for Determination of the Susceptibility of Metallic Materials to Hydrogen Gas Embrittlement (HGE)*

[30] ASTM F1624, *Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique*

[31] ASTM F1940, *Standard Test Method for Process Control Verification to Prevent Hydrogen Embrittlement in Plated or Coated Fasteners*

[32] ASTM F2078, *Standard Terminology Relating to Hydrogen Embrittlement Testing*

[33] ASTM G129, *Standard Practice for Slow Strain Rate Testing to Evaluate the Susceptibility of Metallic Materials to Environmentally Assisted Cracking*

[34] ASTM G142, *Standard Test Method for Determination of Susceptibility of Metals to Embrittlement in Hydrogen Containing Environments at High Pressure, High Temperature, or Both*

[35] ASTM G146, *Standard Practice for Evaluation of Disbonding of Bimetallic Stainless Alloy/Steel Plate for Use in High-Pressure, High-Temperature Refinery Hydrogen Service*

[36] ASTM G148, *Standard Practice for Evaluation of Hydrogen Uptake, Permeation, and Transport in Metals by an Electrochemical Technique*

[37] ASME *Boiler and Pressure Vessel Code*

[38] ANSI/ASME B31.1, *Power piping*

[39] ANSI/ASME B31.3, *Process Piping*

[40] ANSI/AWS A4.3, *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding*

[41] BS 17089, *Method of measurement of hydrogen permeation and determination of hydrogen uptake and transport in metals by an electrochemical technique*

[42] NACE TM0177, *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments*

[43] NACE TM0284, *Standard Test Method — Evaluation of Pipeline and Pressure Vessel Steels for Resistance to Hydrogen-Induced Cracking*

[44] SAE/AMS 2451/4, *Plating, Brush, Cadmium Corrosion Protective, Low Hydrogen Embrittlement*

[45] SAE/AMS 2759/9, *Hydrogen Embrittlement Relief (Baking) of Steel Parts*

[46] SAE/USCAR 5-1, *Avoidance of Hydrogen Embrittlement of Steel*

ICS 71.020; 71.100.20

Price based on 75 pages