



GASEOUS HYDROGEN INSTALLATIONS

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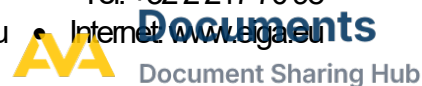
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Prepared by AHG-I.23 of Industrial Gases Council

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Amendments from 15/06

Section	Change
1, 2	Editorial and reference updates
3	Addition of standard definitions
4	Update and addition of hydrogen properties and safety information
5.1, 5.2	Update to references
5.3 – 5.11	Major update to all section to reflect current practices
6.1	Update to use and reference of safety distances
7-15	Major update to all sections to reflect current practices, addition of updated references

NOTE Technical changes from the previous edition are underlined

1 Introduction

Industrial gases companies produce large quantities of hydrogen each year in Europe, and there are in existence national and company standards which make reference to safety in production, distribution and use of hydrogen.

This publication has been prepared for the guidance of designers and operators of gaseous hydrogen stations. It is considered that it reflects the best practices currently available. Its application will achieve the primary objective of maintaining and enhancing the safety of gaseous hydrogen station operation.

2 Scope

The publication covers gaseous hydrogen compression, purification, filling into containers and above ground storage installations at industrial consumer sites. It does not include production, transport, distribution or underground storage of hydrogen, nor does it cover any safety aspects in the use and application of the gas in technical or chemical processes. This publication does not cover hydrogen fuelling stations which may be covered by other publications such as ISO 19880-1, Gaseous hydrogen — Fuelling stations — Part 1: General requirements or TUV Code of practice / Guideline 514, Requirements for hydrogen fueling stations [1, 2].¹

This publication describes requirements for new installations designed and constructed after date of publication used for gaseous hydrogen installations. This publication may be used for existing installations however, application of this publication may benefit existing installations or those in the project phase. Furthermore, to the extent that they exist, national laws may supersede the practices included in this publication. All local regulations, tests, safety procedures, or methods are not included in this publication and abnormal or unusual circumstances can warrant additional requirements.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

¹ References are shown by bracketed numbers and are listed in order of appearance in the reference section

4 Properties of hydrogen

Hydrogen is the lightest gas known (specific gravity 0.0695, air = 1) and diffuses rapidly in air. Hydrogen is colourless, odourless and tasteless. Hydrogen is non-toxic, does not support life and may act as an asphyxiant by replacing the oxygen content in a confined space.

Hydrogen is extremely flammable in air (flammability limits 4% to 75% by volume). The energy required to ignite it is extremely small, for example by static electricity or flow friction.

Hydrogen burns in air with a very hot and almost invisible flame, which emits very little radiant heat and, therefore, gives limited warning of its presence.

Hydrogen can diffuse rapidly through materials and systems, which are leak-tight with air or other common gases. Diffusion is more pronounced at elevated temperatures.

Ignition of hydrogen-air flammable mixtures occur with very low energy input, about one-tenth that of a gasoline-air mixture. An invisible spark and / or static charge can cause an ignition.

<u>Minimum spark ignition energy in air</u>	<u>0.000019 joule (19 µJ)</u>
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<u>Minimum spark ignition energy in oxygen</u>	<u>0.000017 joule (17 µJ)</u>
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Hydrogen can burn in two modes. One mode of burning is called deflagration, in which the flame travels through the mixture at subsonic speeds. Another mode of burning is called detonation, in which the flame and accompanying shock wave travels through the mixture at supersonic speed.

A deflagration occurs when an unconfined hydrogen-air mixture is ignited. An unconfined condition means outdoors in a well-ventilated area where there are no obstructions such as buildings or walls. Flame velocity can greatly increase with confinement. A detonation can be built up from an ordinary deflagration that has been ignited in a confined or partly confined mixture.

5 General design features

5.1 Design

Hydrogen systems shall be designed, fabricated and tested in accordance with recognised pressure vessel and piping codes, and, where appropriate, in accordance with statutory requirements for example the Pressure Equipment Directive (PED) 2014/68/EU or Transportable Pressure Equipment Directive (TPED) 2010/35/EU [3, 4].

Pressure relief devices shall be provided to prevent over pressure where this can occur.

Equipment and systems shall be earthed and, where necessary, bonded to give protection against the hazards of stray electrical currents, lightning and static electricity.

5.2 Areas with potentially explosive atmosphere

The minimum requirements for the protection of workers potentially at risk from explosive atmosphere are specified in EU Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (ATEX 137) and corresponding national legislation [5]. It requires the employer to carry out an explosion risk assessment of the work and used equipment including a classification / zoning of 'Ex' areas and to ensure that used mechanical and electrical equipment and protective systems are safe to use. Furthermore, the directive requires the employees to train the personnel, implement a work permit system, mark the 'Ex' areas with a sign, etc. For further information concerning the consequences for the EIGA members, see EIGA Doc 134, Potentially Explosive Atmospheres EU Directive 1999/92/EC [6].

5.3 Location

The selection of the plant site and the layout of plant equipment shall consider industrial facilities, residences located in the surrounding area, and the on-site usage of flammable materials. Equipment spacing shall take into consideration the constraints associated with the plant fire protection system, maintenance requirements, and the electrical equipment hazardous classification.

Hydrogen systems may be installed with suitable safety systems in the open air, under canopies or within buildings and shall be located so that they are readily accessible to distribution vehicles, firefighting services and provide easy means for escape of personnel in the event of an emergency.

They should not be located beneath high voltage power lines.

Care shall be exercised with regard to their location relative to sources of fuel, such as pipelines or bulk storage containing other flammable gases or liquids, or other potential hazardous substances which could jeopardise the integrity of the installation.

For typical safety distances see Table 1.

Consideration shall be given to the proximity of other processes or buildings containing process equipment, where there is a potential fire or explosion hazard. Adequate precautions, such as increased separation distances or properly designed protection walls may be necessary in such cases. Safety distances can be reduced for example by the use of adequately designed fire walls. The fire walls shall not restrain the air ventilation of the installation (for example only on two sides of the installation).

Precautions, such as the erection of safety barriers or fences, shall be taken to protect against damage during the manoeuvring of any hydrogen supply unit and by unauthorised tampering.

The area within 3 metres of any hydrogen installation shall be kept free of weeds and vegetation. If weed killers are used, then chemicals which are a potential source of fire danger should not be used.

5.4 Layout

The layout should consider as a minimum:

- user operability;
- maintenance;
- location of vents;
- vehicle access and safe personnel access; and
- safety distances and hazard zones.

Leaks of hydrogen from pipes, vessels and equipment can result in a jet flame if the hydrogen ignites (for example by friction or static). The jet flame length depends on the hydrogen pressure and leak size.

The layout of equipment should consider escape routes and escape paths such that they are not impacted from potential jet fires. This can be achieved if needed using fire walls for example.

The layout of equipment should also consider the possibility of jet flames from potential leaks impinging on other equipment to avoid the escalation of an incident.

5.5 Buildings

Equipment should preferably be located outdoors to ensure good ventilation and allow dispersal of hydrogen from leaks. It is often necessary to locate some equipment in buildings for noise abatement or protection of electrical or sensitive equipment, for example compressors or control panels / analysers.

When locating equipment indoors, ventilation, dispersal of leaks and risks of confining hydrogen shall be considered.

A facility siting study should be carried out to assist siting of buildings and determine the hazard from explosions and fires.

5.5.1 Design and buildings

5.5.1.1 Mitigation for explosion damage

There are two approaches to design of buildings to mitigate against explosion risk:

- conduct explosion (don't restrict pressure wave and route it to a safe location, normally the roof); or
- contain explosion (bunker approach).

National legislation may direct the design approach required.

The preferred design option is normally the conduct potential pressure wave from explosion towards a preferred area where the risk is minimised, by using lightweight non-combustible materials. Explosion relief shall be provided only in exterior walls or roof and should be designed so that if an explosion occurs the pressure will be relieved without creating projectiles.

Buildings in which hydrogen systems are installed shall be of single storey construction, be designed for the purpose and be well ventilated, especially at high points.

This total relieving area may consist of any one or a combination of the following:

- area open to the outside;
- walls of light non-combustible material;
- outward swing doors in exterior walls;
- lightly fastened hatch covers; and
- light roof design.

For more info see NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, or EN14491, *Dust explosion venting protective systems* [7, 8].

A conservative approach can be to use a total relieving area not less than either the area of the roof or the area of one of the longest sides.

5.5.1.2 Mitigation for fire propagation

Where firewalls are used within buildings to contain potential fires from hydrogen systems, they should not be structural / or loadbearing unless they are specifically designed for this purpose.

Buildings used for hydrogen operation shall be of fire-resistant construction as determined by national codes or regulations. Provision of means of escape shall comply with Section 11.

Doors that do not have direct access to the outside shall be of fire-resistant construction and shall be self-closing.

The degree of enclosure should be the minimum consistent with providing a reasonable working environment in relation to local weather conditions and local constraints such as noise limitations.

Adequate measures shall be taken to ensure that hydrogen cannot penetrate into service ducts, conduit, staircases and passages that connect to locations that are designated as safe areas, i.e. outside the hazard zone (see [Section 5](#)).

Lighting shall be provided of adequate intensity for all buildings and working areas so that, at all times operations can be carried out in safety. The lighting equipment shall be suitable for use in hydrogen areas, (see [Section 10](#)).

Ceiling design shall not permit hydrogen accumulation. Suspended ceilings are not recommended.

Roof areas of buildings shall be designed to eliminate all pockets that can collect hydrogen unless specifically installed with Lower Explosive Limit (LEL) detection to detect leaks.

5.5.2 Heating, cooling and ventilation

Ventilation of buildings shall be provided to maintain atmospheres below LEL in the case of minor leaks. Natural ventilation is preferred and should be designed to achieve a certain number of air changes per hour (typically in the range of 6-12 room air changes per hour depending on the size of the room). Ventilation design should consider:

- area of openings for natural ventilation (for example m² per m³); and
- forced ventilation shall be used where calculated ventilation cannot be achieved with natural ventilation.

Ventilation design shall consider potential restricted spaces caused by equipment.

For further information on ventilation design see ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*, BS 5925, *Code of Practice for Ventilation Principles and Designing for Natural Ventilation*, API RP500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*, API RP505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2* [9, 10, 11, 12].

The building should have good low and high-level natural ventilation to the open air. Outlet opening shall be located at the highest point of the room in exterior walls or roof.

Natural ventilation is preferred where possible. Restricting areas or sensitive instruments may require forced ventilation for example to dissipate heat, this is normally continuous operating.

Forced ventilation may be installed as response to emergency situations such as significant leaks. The forced ventilation is typically triggered by atmospheric monitor (for example 25% of LEL). Regular maintenance and testing of ventilation shall be performed including calibration of any atmospheric monitors.

Building ventilation shall be able to dissipate the heat load of equipment in the summer.

Where air is used for heating or cooling, it is preferable to use a once-through system where air is passed through building to heat or cool as required. Consider the location of vent inlets and outlets and situate away from potential hazards. Atmospheric monitoring of vent inlet and / or outlet of air should be considered to monitor for risk of contamination.

Where heating or air conditioning is required, it should preferably be by indirect media such as steam, hot / cold water or warm / cold air. Where recirculatory systems are used, consideration shall be given to the possibility of hydrogen contamination and adequate precautions shall be taken. The heat sources, such as natural gas / LPG boilers, shall be located remotely from the buildings considering the distances in Table 1. Where an electrical source for heating is used, it shall comply with the requirement for electrical equipment outlined in [Section 10](#).

Electrical heating may be used but shall be in compliance with the electrical area classification, refer to Section 10. Direct open-flame building heaters shall not be used.

5.6 Pipelines and Discharge Devices

Pipelines for hydrogen shall be clearly marked by means of colour coding and / or labels.

Isolation valves shall be provided so that the hydrogen source can be shut off safely in the event of an emergency. Flammable gas piping entering or exiting a process building should be able to be isolated outside the building such as with a block and bleed system.

The design of hydrogen vent lines shall minimise the risk associated with potential ignition (detonation vs deflagration) considering the length to diameter ratio. The mechanical design shall be able to withstand ignition inside the vent line unless ignition within the vent is prevented for example by means of a nitrogen purge or flame arrester.

Flows from vents and safety relief equipment shall be piped to a safe location where they do not generate a hazard for persons or neighbouring structures, away from personnel areas, electrical lines and other ignition sources, air intakes, building openings and overhangs. Copper alloys or stainless steel are preferred materials to minimise the possibility of ignition due to atmospheric corrosion particles.

Vents are typically piped individually. Where vents are manifolded together, design shall consider potential for mis-directed flow, dead-ends and multiple vents operating simultaneously. Vents shall not discharge where accumulation of hydrogen can occur, such as below the eaves of buildings. Hazard zones around vents shall be assessed as well as proximity to other vents (for example oxygen).

Vent design and location should consider the potential for unintentional ignition (radiant heat, flame size, inert gas purge).

Flare systems may be used where designed as such.

Where it is necessary to run hydrogen pipelines in the same duct or trench used for electrical cables, then all joints in the hydrogen pipelines in the duct / trench shall be welded or brazed. A minimum separation distance from electrical cables and any other pipelines shall be determined from risk assessment or local standards / regulations. The hydrogen pipeline should be run at a higher elevation than other pipelines.

5.7 Materials

All materials used shall be suitable for hydrogen service and for the pressures and temperatures involved.

Failure mechanisms such as hydrogen embrittlement, high temperature attack and stress corrosion cracking are not normally present in gaseous hydrogen stations but may need to be considered depending on service temperatures, pressures and environments. Due consideration shall be given when selecting ferrous materials for hydrogen service.

Cast iron pipe and fittings shall not be used. The use of any casting is not recommended due to the permeability of hydrogen and the possibility of porosity in the casting.

Pipes and fittings shall be designed according to PED together with recognised standards such as EN13480, *Metallic industrial piping*, ASME B31.3, *Process Piping*, or ASME B31.12, *Hydrogen Piping and Pipelines* [3, 13, 14, 15].

Where ammonia is likely to be present as an impurity, or as an atmospheric contaminant, copper and copper / tin / zinc base alloys shall not be used for pipe or fittings since these materials are susceptible to attack by ammonia. Consideration should also be given to the possibility of other contaminants being present and adequate precautions be taken.

Material selection and design shall consider (where required) fatigue mechanisms such as movement (particularly for flexible connections) and cycling pressure service.

5.8 **Pressure vessels**

Vessels for the storage of hydrogen shall be designed, fabricated and inspected in accordance with a recognised pressure vessel code.

Vessels used in the processing of hydrogen and subject to cycling pressures, such as a hydrogen pressure swing adsorbers (PSA), are subject to fatigue loading by cyclic pressures. Such vessels shall be designed and constructed in accordance with recognised pressure vessel codes and fatigue design rules. Refer to EIGA Doc 210, *Hydrogen Pressure Swing Adsorber (PSA) Mechanical Integrity Requirements* for further guidance regarding design and fabrication, failure mechanisms and in-service inspection and cyclic monitoring [16].

Cylinder are also used for storage and transport of hydrogen. There are four types of cylinders that may be used:

- Type 1: All metal.

Traditional, all metal cylinder, common for pressures up to 200 or 300 bar.

- Type 2: Metallic liner, hoop wrapped.

A metal cylinder liner (typically aluminium), that is wrapped with carbon fibre (and fibreglass resin) over the cylindrical part of the cylinder.

- Type 3: Load sharing metallic liner, fully wrapped.

A metal cylinder liner that is fully wrapped with carbon fibre over the entire cylinder surface, including cylinder end cap. These cylinders can be used for very high pressures for example 700 or 1000 bar.

- Type 4: Non-load sharing plastic liner, fully wrapped.

A plastic cylinder liner that is fully wrapped with carbon fibre over the entire cylinder surface, including cylinder end cap. These cylinders are the lightest cylinder and are often used where low weights are an advantage.

5.9 **Connections**

The use of welded or brazed (soft solder is not recommended) joints is recommended wherever possible. Where breakable joints (threaded, flanged etc.) are considered necessary, these should be kept to a minimum since they are a potential source of leakage. Consideration shall be made of potential leaks at connections due to the permeability of hydrogen at all pressures.

Compression fittings are not recommended on process lines because of the potential for leakage. However they may be used for small bore instrument and sample lines / valves, and also where manufacturing (welding) is problematic, for example in case of high pressure and large wall thicknesses. Where compression fittings are used, fittings shall be suitable for the fluid / pressure and installed as per manufacturer's guidance, including compliance with tightening up procedures.

Electrical continuity shall be maintained throughout the system (see 10.3).

Where flexible connections are required, hoses or pig tails can be used, both shall comply with PED [3]. Pig tails are a preferred solution where practical.

The free end of filling hose connections and pig tails, where threaded, shall have a left-hand thread. Filling hoses should be electrically continuous. If not, sufficient grounding shall be provided upstream

as well as downstream of the filling hoses. The material of construction shall provide the best possible resistance to permeation. Where outer sleeves are fitted, these shall be suitably pierced to prevent inflation. Each hose shall be strength tested by the manufacturer and a certificate issued to that effect. The hose shall have a means of identifying its date of manufacture, design pressure and design temperature. Safety devices shall be fitted to restrain the hose in the event of failure (anti-whip wire / tether). Hoses shall be regularly inspected based on risk assessment (and national legislation where applicable). Hoses shall be retired from use if signs of wear affecting integrity are found or after a specified time. Records of inspection shall be kept, and inspection frequency adjusted, shorter or longer, accordingly.

5.10 Instruments

Instruments and gauges shall be designed and located such that, in the event of a leakage or rupture, and possible subsequent fire, the risk to personnel is minimised. The use of safety glass and blow-out backs on pressure gauges is recommended.

Certain instruments may use detection systems, which are not normally compatible with hydrogen safety precautions, for example gas chromatographs, flame ionisation detectors. In these instances, adequate precautions shall be taken to limit quantities of hydrogen, within analysis instruments, to acceptable limits, for example by flow restriction devices such as excess flow valves or orifice, and inert gas purging and venting to the outside.

All automatic valves shall assume a fail-safe position on loss of power or instrument air / gas that drives the process in a safe direction.

All controls that require regular operator attention shall be ergonomically accessible.

5.11 Control and safety systems

Control systems and instrumentation shall not introduce a hazard, which does not otherwise exist, either to the facility or to personnel.

Electrical control equipment and systems located within hazardous classified areas (see Section 10), and electric operators or positioners used with flammable gas service automatic valves, shall conform to requirements of ATEX Directive 2014/34/EU [15]. Power systems (systems exceeding 24V) require the use of purged or explosion-proof enclosures.

Data acquisition centres and other similar facilities for computerised or advanced electronic control shall be located outside classified areas wherever possible.

Designs shall make provision for alerting operating personnel of undesired events and provide means of taking corrective action. Personnel safety and fire protection emergency alarm systems may include:

- manually activated fire and emergency alarm stations;
- sprinkler and deluge systems;
- atmosphere monitors for buildings and enclosures to warn of potential fire and explosive atmosphere;

NOTE Oxygen monitoring may be required where inert gas (for example nitrogen) is used for purging or instrument air in an enclosure.

- fire and smoke detection alarms; and
- automatic shutdown of hydrogen supply.