SAFETY IN STORAGE, HANDLING AND DISTRIBUTION OF LIQUID HYDROGEN

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Prepared by WG-6 Cryogenic vessels

Disclaimer

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Amendments from 06/02

Section	Change
	Editorial to align style with EIGA Style Manual
3	New section on definitions
4.5	Section expanded to cover steel properties
5.1.2	Removal of Table 2
5.1.7	Vent stack design details added
5.5.2.4	Vaporiser inspection requirements added
8	New reference section added
Appendix A	Appendix A removed as redundant

Note: Technical changes from the previous edition are underlined

1 Introduction

Because of the growth in the availability and use of liquid hydrogen in Europe, the European Industrial Gases Association (EIGA) has recognised the need for a publication addressing safety in storage, handling and distribution of liquid hydrogen.

This EIGA publication is intended as guidance for companies directly associated with the installation of liquid hydrogen storage at the user's premises and the distribution of liquid hydrogen by road, rail and sea transport.

Because of the properties of liquid hydrogen, specific precautions shall be taken and these are described in this publication.

2 Scope and purpose

2.1 Scope

A liquid hydrogen storage installation on a user's premises is defined for the purpose of this publication as the installed liquid storage tank. This publication applies to the layout, design and operation of fixed storages and the transportation of liquid hydrogen in bulk form by tankers or tank containers, by road, sea and rail, to fixed storages at user's premises. Portable containers, such as pallet tanks and liquid cylinders, are excluded from the scope of this publication.

2.2 Purpose

To provide recommendations on the storage, handling and distribution of liquid hydrogen.

3 Definitions

For the purpose of this publication the following definitions apply.

3.1 Publications 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 and need not

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.

4 Properties and effects of hydrogen

4.1 General

Liquid hydrogen has the UN number 1966.

Liquid hydrogen is accompanied by a certain amount of gaseous hydrogen. For this reason, it is necessary to consider properties of both liquid and gaseous hydrogen. Some common properties of hydrogen are summarised in Table 1.

4.2 Physical properties

Hydrogen is the least dense of all gases. At standard temperature and pressure, the density of gaseous hydrogen is one fourteenth that of air. Due to its low density, gaseous hydrogen will rise and diffuse rapidly in the air. Hydrogen can therefore collect in the roof spaces of buildings. Hydrogen can diffuse rapidly through certain porous materials or systems with small openings that would normally be gastight compared to air.

At ambient temperature, gaseous hydrogen, contrarily to most other gases, is heated by throttled expansion. The temperature rise is only small and this alone cannot cause self-ignition.

The thermal conductivity of hydrogen is typically higher than that of other gases. This influences combustion behaviour, for example burning velocity.

4.3 Chemical properties

Hydrogen is not significantly reactive. Hydrogen is not corrosive but depending on temperature, pressure and other conditions it can cause embrittlement of certain steels.

From the chemical point of view, hydrogen is a reducing agent. Hydrogen is flammable and therefore presents a possible explosion hazard.

Hydrogen is easily ignited; its minimum ignition energy is very low (19μJ). In practice hydrogen venting or leaking to atmosphere, particularly from a pressure source can ignite due to electrostatic or self-igniting impurities in the hydrogen.

Hydrogen burns with a hot flame. Burning hydrogen produces no soot. Therefore, the flame is pale, colourless and almost invisible in daylight. The heat radiated by a hydrogen flame is relatively low (only 10 percent that of propane). Therefore, a hydrogen flame gives little warning of its presence either by sight or heat.

The range of flammability both in air and oxygen is wide (4-75%). Confined mixtures of hydrogen and air or oxygen explode very strongly and can detonate (typical explosivity range in air is 16-56%). An unconfined gas cloud explosion of hydrogen is very unlikely to occur and to date such a detonation has not been observed.

Hydrogen flames, especially those emanating from a high-pressure source, are extremely difficult to extinguish. The preferred method of extinguishing a hydrogen flame is to shut off the flow.

4.4 Biological effects

Hydrogen is colourless (transparent), odourless and tasteless and therefore not detectable by the human senses. Hydrogen is not toxic but can act as an asphyxiant by displacing the oxygen in the surrounding air.

Breathing a pure hydrogen atmosphere will produce immediate loss of consciousness and almost immediate death. The amount of hydrogen necessary to produce dangerous oxygen deficiency is significantly higher than the lower flammability limit. Therefore, the primary risk of hydrogen is not asphyxiation but fire and explosion.

Liquid hydrogen has specific effects on the human body (see below).

4.5 Properties and effects of liquid hydrogen

Liquid hydrogen is colourless and odourless. Its density is one fourteenth that of water. Liquid hydrogen is extremely cold -and except for helium- has the lowest boiling point of all gases.

Hydrogen consists of ortho-hydrogen and para-hydrogen. These forms have differences in physical but not in chemical properties. At the temperature of liquid hydrogen ortho-hydrogen tends to convert into para-hydrogen. This conversion liberates heat that encourages evaporation. However, commercial liquid hydrogen mainly consists of para-hydrogen.

Liquid hydrogen and the cold "boil off' gas, evolving from the liquid, can produce severe burns (similar to thermal burns) upon contact with skin. Delicate tissue, such as those of the eyes can be injured by exposure to the cold gas or splashed liquid in a brief period of time, that would normally be too short to affect the skin of the hands or face. Contact between unprotected parts of the body with uninsulated piping or vessels containing liquid hydrogen can cause the flesh to stick and tear.

Liquid hydrogen and cold "boil off' gas can cause many common materials such as carbon steel, plastic or rubber to become brittle and prone to fracture under stress.

At the temperature of liquid hydrogen all gases, except helium, condense and then solidify. Such solid particles can plug restricted areas such as valves and orifices, which could lead to a failure of, flow and/or pressure increase. Furthermore, condensed or solidified air in liquid hydrogen is a potential explosion hazard.

Liquid hydrogen has a very low heat of vaporisation (related to a volume basis). Therefore, a small heat input for example inserting solids or liquids at room temperature will create a violent evolution of gas and splashing of liquid.

Liquid hydrogen in poorly insulated or uninsulated containers and piping will liquefy the surrounding air. Due to the different boiling points of nitrogen and oxygen condensed air is oxygen-enriched and can cause a fire risk.

Liquid hydrogen, spilled to the atmosphere evaporates rapidly. One litre of liquid hydrogen gives approximately 850 litres of gaseous hydrogen at ambient conditions.

Cold boil-off hydrogen is a little denser than air and may accumulate in pits and trenches, for short periods depending on temperature and quantity. After that hydrogen rises and diffuses rapidly.

Cold boil-off hydrogen condenses the moisture in the air, thus creating a highly visible fog.

4.5.1 Implications for inner vessel design and manufacture

Typically, the inner vessel is manufactured with 300 series austenitic stainless steels. Type 304 SS has shown a tendency to experience hydrogen embrittlement in highly stressed parts like cold formed heads. Pressure vessel heads made of 304 SS should be solution annealed after cold forming in order to reduce the residual stresses.

Note: Annealing could be difficult on large heads.

Care should be taken during fabrication not to leave tool marks or other stress risers on the inner surface of the pressure vessel, which can be propagation sites for hydrogen embrittlement.

It is also recommended to limit the ferrite in the welds

Table 1 Properties of hydrogen and some comparable substances

(Values taken from a number of sources)

	Valid at		Hydrogen[1]	Methane	Propane	Heptane[3]
Boiling point	1.013 bara	K	20.4	111.6	231.1	371.5
Critical temperature		K	33.19	119.6	396.8	540.4
Critical pressure		bara	13.15	46.0	42.4	27.5
Density of liquid	Boiling point	kg/m³	70.8	422.5	580.7	680.4
Heat of vaporisation	Boiling point	kJ/kg	445.6	510.4	427.8	317.0
Density of gas	Boiling point	kg/m³	1.338	1.818	2.419	3.29
Density of gas	1.013 bara 0°C	kg/m³	0.090	0.717	2.011	4.46
Specific heat, C_p	1.013 bara 0°C	kJ/kg K	14.19	2.19	1.56	1.70[5]
Specific heat, C_v	1.013 bara 0°C	kJ/kg K	10.06	1.67	1.35	N/A
Thermal conductivity	1.013 bara 0°C	W/m K	0.1682	0.0305	N/A	0.0188[6]
Diffusion coefficient (in air)	1.013 bara 20°C	cm²/S	0.69	0.22	0.12	0.05
Limits of flammability[2]	1.013 bara 20°C	Vol.-%	4.0-75.0	5.0-15.4	2.1-9.5	1.11-6.7
Auto ignition temperature[2]	1.013 bara	°C	560	595	470	215
Minimum ignition energy[2]	1.013 bara 20°C	mJ	0.019	0.28	0.26	0.22
Theoretical temperature of flame[2]	1.013 bara	°C	2045	1875	2040	2200

1. Normal hydrogen (75% ortho and 25% para)
2. Combustion with air
3. As a representative for gasoline
4. At 0°C
5. Vapour at 25 °C
6. Vapour at 100°C

Conversion: 1bar = 10^5 Pa

5 Customer installations

5.1 Layout and design features

5.1.1 General

Pressure vessels and associated equipment shall be designed, constructed and installed in accordance with appropriate local and national codes,

The installation shall be sited to minimize risk to personnel, local population and property. Consideration should be given to the location of any potentially hazardous processes in the vicinity, which would jeopardise the integrity of the storage installation. This site-specific location shall be analysed in a risk assessment.

5.1.2 Safety distances

Safety distances shall not be less than applicable national regulations and codes and take into account different basic needs including:

- Ensuring protection to people in the vicinity in case of accidental events;
- Ensuring the integrity of the surrounding technical equipment in case of the same accidental events; and
- Allowing access for emergency services when needed.

The determination of safety distances should be based upon experience and a risk assessment including:

- Properties of liquid hydrogen including density, pressure and temperature;
- Design of the pressure vessel and piping configuration;
- Piping and valve sizing commonly used in storage tanks at user's premises;
- Calculation of minor releases from liquid phase piping;
- Weather effects;
- Location and height of vent stack(s);
- Heat flux effects of hydrogen flame; and
- Local overpressure due to flame ignition;

Safety distances shall be measured from:

- Those points, at which in the course of operation an escape of hydrogen can occur including vent stacks, filling connections, flanges or mechanical joints; and
- The outer jacket of the vessel.

The safety distances may be reduced if additional protection, is located between the liquid hydrogen installation and the exposure.

Where protective structures such as fire walls are installed, the following limits apply:

- To minimise the consequence of an accidental leakage, the vessel shall not be enveloped or constricted by walls or buildings;
- If the vessel is installed in close proximity to a building or a fire-resistant wall, a minimum distance complying with the requirements of 5.1.2. shall apply;
- Further walls (vessel in 2 or 3-sided zone) shall be avoided when possible to prevent accidental gas confinement if leakage occurs. If not possible to avoid walls, additional safety measures to ensure ventilation shall be provided; and
- If proximity to more than one wall cannot be avoided, the above safety distances should be increased, or the wall structure should be strengthened to withstand an increased overpressure.

Methods to determine safety distances is given in EIGA Doc 75, *Determination of safety distances* and guidance in NFPA 55[1] *Compressed Gases and Cryogenic Fluids Code* [1,2]

5.1.3 Location of installation

All liquid hydrogen storage installations at user's premises shall be situated outdoors. Liquid hydrogen installations shall not be located inside buildings. For underground installations, additional requirements should be considered, see EIGA Doc 171, *Storage of hydrogen in systems located underground* [3].

The storage tank shall be located so that it is readily accessible to mobile supply equipment at ground level and to authorised personnel. Suitable roadways or other means of access for emergency equipment, such as fire department equipment, shall be provided.

The installation shall not be located beneath or near electric power cables, piping containing all classes of flammable and combustible liquids, piping containing other flammable gases, or piping containing oxidising materials.

Dykes, diversion kerbs or grading shall be used to ensure that liquid leakage from adjacent combustible liquid or liquid oxygen storages installed at a higher level than the liquid hydrogen storage, is prevented from accumulating within 15 m of the liquid hydrogen storage.

The slope of the ground shall be such as to provide normal surface water drainage.

Fencing is required to prevent access of unauthorised persons, where other means are not provided. On controlled sites with sufficient supervision, fencing is optional.

Where fencing is provided the minimum clearance between the fence and the installation shall be 0.8m to allow free access to and escape from the enclosure. Fencing shall not impede ventilation of the installation.

Timber or other combustible materials shall not be used for fencing. The height of the fencing shall be at least 1.8 m.

Means of escape in the case of emergency shall be provided. In cases where personnel could be trapped inside compounds there shall not be less than two separate outward opening exits, remote from each other, strategically placed in relation to the degree of hazard considered. All exits shall be unlocked during all entry into the area.

All gates shall be outward opening and wide enough to provide for an easy access and exit of personnel.

- Main gate shall be at least 1.2 metre wide; and

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

- Emergency exit gate shall be at least 0.8metre wide

Gates shall be locked during normal unmanned operation.

Consideration should be given to the provision of an additional emergency exit where the size of fenced area or equipment location necessitates this. A risk assessment could be required.

Any firebreak walls or partitions shall be made of brick, concrete or any other suitable non-combustible material of 120 minutes rating.

Barriers or bollards, to eliminate vehicular impact, shall suitably protect the installation.

5.1.4 Liquid transfer area

The liquid transfer area should be designated a "NO PARKING" area.

A road tanker or tank container; when in position for filling from or discharging to the installation shall be in the open and not be in a walled enclosure from which the escape of liquid or cold vapour is restricted. Tankers shall have unimpeded access to and exit from the installation at all times.

A concrete foundation shall be located adjacent to the fill coupling of the installation. The fill coupling of the installation shall be located within the area of the tank plinth. The area of non-combustible surfacing provided under the liquid mobile supply equipment shall have a width not less than the full width of the delivery vehicle and a length not less than 2.5 metre in the direction of the vehicle axis.

The liquid transfer area shall be clearly defined and transfer of liquid shall only take place within the user's premises.

5.1.5 Electrical equipment and installation

The installation and operation of electrical systems in hydrogen installations shall be in accordance with Directive 2014/34/EU, *relating to equipment and protective systems intended for use in potentially explosive atmospheres* [4].

During operation, sparks, electrical arcs, or high temperatures likely to cause ignition shall be precluded.

Lighting shall be provided for night deliveries as required.

All equipment used and installed within the boundary of the installation shall be in accordance with the requirements of the hazardous area classification.

All systems shall be bonded to give protection against the hazards of electrical currents and static electricity in accordance with national codes/regulations, with a resistance to earth of less than 25 ohms. Major items of equipment such as the stationary tank, vaporizers and vent stack shall be bonded directly to the earth point and not rely upon the piping as a means to earth.

Electrostatic charges can occur when mechanical separation or abrasion of similar or different substances takes place and also when a gas, containing droplets or dust particles, flows past the surface of a solid, for example, valve openings, hose or pipe connections. If accumulated, electric charges are released suddenly, the resulting electric spark can be sufficiently strong to ignite hydrogen.

In order to prevent the accumulation of such charges they shall be allowed to dissipate to earth.

All delivery vehicles shall be earthed prior to commencement of the discharge procedure.

Driving belts and pulleys of pumps shall be of conductive material.

Care shall also be taken in the choice of material for clothing and protective wear since most synthetic materials readily generate static charges. The use of flame retardant clothing is required.

To ensure that the requirements for the prevention of the build-up of static electricity on equipment are met, the system shall be tested to ensure compliance with the bonding requirement.

5.1.6 Tank foundation and supports

Where liquid hydrogen storage tanks are required to be elevated the tank supports shall be non-combustible structures, and capable of withstanding damage by cryogenic liquid spillage.

The tank foundation shall be designed to withstand the weight of the tank, its contents and other possible loads such those due to wind, snow and earthquakes.

The plinth on which the equipment is installed shall be made of concrete or any other suitable non-flammable material.

5.1.7 Hydrogen vents

All vents, including those of pressure relief devices, thermal relief valves and purge valves shall be connected to a vent stack.

The vent stack shall be arranged to discharge in a safe place in the open air to prevent impingement of escaping gas on to personnel or any structure. The vent stack shall not discharge where accumulation of hydrogen can occur, such as below the eaves of buildings.

Consideration shall be given to the prevention of accumulation of water, including that from condensation, in the vent stack outlet. Prevention of water into relief devices shall be provided through water traps and or sloping of piping.

The position of the vent stack(s) shall be taken into account in the siting of the installation and reflected in the areas classification drawing.

The vent stack(s) shall be dedicated to the installation and not connected to other vent stacks that could back feed into the hydrogen stack(s).

The height of the vent stack outlet should be either 7 metres above ground level or 3 metres above the top of the tank whichever is the greater for protection of the operating personnel and equipment.

The sum of design flows of all vent devices which can open at the same time into the common vent system results in a maximum pressure drop. The maximum pressure drop shall be taken into account for choosing the pressure relief device and defining the set pressure. This maximum pressure drop should not exceed 10% of the lowest set pressure of all the relief valves which can open at the same time and shall not exceed the maximum back pressure specified for any of these relief valves.

For non-spring-loaded relief devices, the back pressure of the vent system shall be taken into account when sizing the device.

5.1.8 Vapour clouds

When siting an installation, site specific consideration shall be given to the possibility of the movement of vapour clouds, originating from spillage or venting; in addition, wind direction and the topography shall be taken into account.

5.1.9 Piping, fittings, valves, regulator

Piping, fittings, gaskets, thread sealant, valves, regulators and other accessories shall be suitable for liquid or gaseous hydrogen service as applicable and for the pressures and temperatures involved. Consideration shall be given to the thermal expansion and contraction of piping systems when exposed to temperature fluctuations of ambient to liquid hydrogen temperature.

Joints in piping and tubing should be welded, brazed, flanged or screwed. Electrical continuity shall be maintained throughout the system.

Means shall be provided to minimise exposure of personnel to piping operating at low temperatures and to prevent air condensate from contacting piping, structural members and surfaces not suitable for cryogenic temperatures.

Uninsulated piping and equipment, which operates at below air condensation temperature, shall not be installed above asphalt surfaces or other combustible materials in order to prevent contact of liquid air with such materials. Drip pans may be installed under uninsulated piping and equipment to retain and vaporise condensed liquid air.

Where it is necessary to run gaseous hydrogen pipelines in the same duct or trench used for electrical cables, then all joints in the hydrogen pipelines in the ducted/trenched section shall be welded or brazed. The hydrogen pipeline should be run at a higher elevation than other pipelines.

Where ammonia or chlorine are likely to be present 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 be attacked by these contaminants. Consideration should also be given to the possibility of other contaminants being present and adequate precautions be taken.

5.1.10 Back flow

A check valve shall be fitted prior to the battery limits to avoid back flow into the hydrogen system.

5.1.11 Instruments and cabinets

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. Certain instruments can use detection systems, which are not normally compatible with safety precautions, required for hydrogen, for example, gas chromatographs, flame ionisation detectors. It is essential that adequate precautions shall be taken to limit quantities of hydrogen, within analysis instruments, to acceptable limits, for example, by inert gas purging and venting to the outside.

Cabinets or housings containing hydrogen control equipment shall be designed to prevent any accumulation of hydrogen gas by providing both high and low ventilation.

5.1.12 Liquid hydrogen vaporisers

Interconnecting piping shall be sufficiently flexible to provide for the effect of expansion and contraction due to temperature changes.

The vaporiser and its piping shall be protected with a relief device to prevent over pressure due to trapped liquid; commonly referred to a thermal relief valve.

The vaporiser shall be adequately sized for the maximum flow requirement specified by the customer. Low temperature protection shall be installed to ensure that cold gas temperature exiting the vaporiser cannot:

- Cause damage to pipework and equipment downstream; and
- Affect the customer's process.

See EIGA Doc 133, *Cryogenic vaporisation systems - Prevention of brittle fracture of equipment and piping*, [5] for further information.

5.2 Access to the Installation

5.2.1 Personnel

The installation shall be so designed that authorised persons shall have unimpeded access to and exit from the operating area of the installation at all times.

Access to the installation shall be forbidden to all unauthorised persons. Warning notices shall support this.

5.2.2 Access to installation controls

Filling connections and equipment controls shall be accessible to the operators.

Connections and equipment controls necessary for filling purposes shall be located in close proximity to each other and in such a way that tank and tanker controls are visible and accessible from the operator's position.

5.2.3 Notices and instructions

Notices shall be in accordance with local national standards and clearly displayed, to be visible at all times on or near the tank, particularly at access points, to indicate:

- LIQUID HYDROGEN
- FLAMMABLE LIQUID
- NO SMOKING
- NO NAKED FLAMES
- AUTHORISED PERSONS ONLY
- DO NOT SPRAY WATER ON VENT STACK

In order to facilitate control of an emergency, a sign shall be displayed at the compound showing:

- Gas supplier's name and local address;
- Gas supplier's local phone number; and
- The phone number of the local emergency service.

All displayed warning signs and labels shall be in accordance with the relevant national regulations and legible from outside the installation fence.

Operating and emergency instructions shall be supplied to the customer before commissioning the installation, see also 3.6.

5.3 Testing and commissioning

5.3.1 Testing of liquid storage installation

Prior to commissioning the following tests shall be carried out by the supplier or their representative in accordance with established procedures.

5.3.2 Pressure test

Where a pneumatic test is specified, dry, oil free nitrogen or helium is the preferred test medium. The pressure in the system shall be increased gradually up to the test pressure specified by the designer of the system. Any defects found during the test shall be rectified in and the system retested.

A responsible person and a representative of the owner shall witness pressure tests. A copy of the signed test certificate shall be kept.

Plant instruments such as gauges not normally fitted during any pressure test shall be fitted prior to pressurizing for leak testing. Leak testing consists of checking for leaks at joints and is normally carried out a pressure below that of design pressure.

5.3.3 Purging

5.3.3.1 Inert gas purge

Following the pressure test and prior to the introduction of hydrogen into any part of the system, oxygen shall be eliminated from the system.

This can be achieved by purging, pressurizing and venting with an inert gas (helium or nitrogen) and shall be followed by a check to ensure that any residual oxygen is less than 0.5%. Evacuation may be used only for piping systems.

5.3.3.2 Hydrogen purge

If helium is used as the inert purge gas to remove the oxygen, cold hydrogen gas may be used as the secondary purge gas to eliminate the helium.

If nitrogen or another inert gas is used as the purge gas to remove oxygen, use warm hydrogen gas as the secondary purge gas to eliminate the nitrogen followed by cold hydrogen gas to cool the system.

Purging procedures shall be prepared, making reference to valves and equipment to ensure that all parts of the system are safe for the introduction of hydrogen.

5.3.4 Pressure relief devices

Pressure relief devices shall be arranged to discharge through the vent stack, unobstructed to atmosphere and in such a manner as to prevent impingement of escaping liquid or gas upon the tank, adjacent structures or personnel. All vents shall be piped away to the vent stack as noted in 4.1.7.

Pressure relief devices or vent piping shall be designed or located so that moisture cannot collect and freeze in a manner, which would interfere with operation of the device.

Pressure relief devices shall be provided to prevent over pressure, including situations where liquid can be trapped.

If a diverter valve is installed to accommodate two pressure relief devices operating, either simultaneously or alternatively, then the size of the valve, regardless of the position of the actuating device shall be such that the vessel is adequately protected. The diverter valve should be provided with a position indicator, if appropriate, showing which relief devices are "on line".

For the capacity of pressure relief devices refer to EIGA Doc 24, *Vacuum insulated cryogenic storage tank systems pressure protection devices* [6].

A secondary relief device shall be installed together with the primary relief device of the tank.

The design of the installation shall allow the periodic testing of the pressure relief devices.

5.3.5 Commissioning

Commissioning shall only be carried out by authorized and trained personnel and in accordance with a written procedure.

5.4 Decommissioning and removal of tank

Decommissioning shall only be carried out by authorized and trained personnel and in accordance with a written procedure. Prior to dismantling the system or removing the tank the entire installation shall be purged into inert gas service (25% of the lower flammability limit or 1% H2).

5.5 Operations and maintenance

5.5.1 Operation of the installation

Operation of the installation shall be undertaken following the guidelines, training and risk assessment procedure in accordance with Directive 1999/92/EC *on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres* [7].

5.5.1.1 Operating personnel

Only authorized persons shall be allowed to operate the installation. Operating instructions shall be supplied to the user's personnel; these instructions shall define the safe operating limits. Instructions shall be written and presented in a clear and concise format in the national language.

The supplier of either the hydrogen or the tank shall, for the convenience of the operator, colour code or identify by other means the hand wheels of those valves which are to be shut in an emergency.

5.5.1.2 Operating malfunction or emergency

Any operating malfunction or emergency concerning the installation shall be referred to the hydrogen supplier.

The customer shall not modify the supplier’s equipment.

Any proposed modification to a customer owned installation or any attached system should be discussed with the hydrogen supplier.

5.5.2 Periodic inspection and maintenance

5.5.2.1 Site

On a scheduled basis, authorized persons shall ensure that the system is maintained in a proper condition and that safety distances are respected.

5.5.2.2 Tank

The periodic inspection or testing of the inner vessel is not considered necessary and should be avoided as long as national regulations allow this. There are sound technical reasons for not exposing the inner vessel to ambient air or to the risk of contamination. Other reasons are listed in EIGA Technical Bulletin TB27, *The Pressure Equipment Directive. Periodic Inspection and Reassessment of Static Cryogenic Vessels for use in the European Union* [8].

When a tank is taken out of service for modification or maintenance, an authorized person should examine the accessible areas of the tank immediately prior to re commissioning.

5.5.2.3 Installation

Periodic and planned maintenance of the installed equipment shall be carried out.

An annual external visual examination shall be carried out to confirm the satisfactory condition of the outer vessel, exposed pipework and controls. A check on the vacuum shall be made if an abnormal pressure increase occurs or other signs of vacuum degradation occur.

5.5.2.4 Vaporisers

The ambient air vaporisers should be inspected on a periodic basis for excessive ice formation. This is commonly carried out during deliveries.

When a water bath or steam heated vaporiser is used the system should be inspected periodically by visual examination of shell and external tube surfaces for signs of damage and excessive frosting. Any defects should be reported to the supplier.

5.5.2.5 Pressure relief devices

Regular visual inspections of the devices shall be carried out during periodic inspections.

A regular test of each relief valve shall be carried out to demonstrate its fitness for a further period of service. Pressure relief valves shall be tested or changed out in accordance with EIGA Doc 24 [6] unless unusual conditions of service dictate more stringent requirements.

Bursting disc elements can deteriorate due to aggressive environments resulting in their relief pressure rating being reduced. It may, therefore, be necessary to replace disc elements in such environments on a more frequent basis.

5.5.2.6 Ancillary equipment

Ancillary equipment other than previously detailed, for example, pressure/temperature gauges, should be maintained in accordance with either manufacturers recommendations or national codes, whichever is the more stringent.

5.6 Customer information

The information or handover package that shall be given to the customer, shall be up to date and specific to the customer installation and shall include the following:

5.6.1 All product specific gas and safety data sheets

5.6.2 Product handling documentation

A document to inform the customer of the safe use of low temperature liquefied gases and dealing with the properties and hazards of liquid hydrogen.

5.6.3 Process and instrumentation diagram (P and ID specific to the installation)

It is important to emphasize that the P&ID is not a typical one normally supplied by the manufacturer of the cryogenic vessel but one representing exactly the vessel installed, for example, and not limited to:

- Dedicated liquid and tank connections to pumping systems; and
- Additional liquid lines.

5.6.4 Operating instructions/user manuals

The operating instructions/user manuals that are required for the safe operation of the plant shall be specific to the specific customer installation.

The system for supplying handover documentation needs to be able to cover:

- Changes at customer installations; and
- New equipment developments.

5.6.5 Emergency action procedure

An emergency action procedure shall always be produced for the customer and is normally included in the user manual.

For most installations, the emergency action should be posted adjacent to the equipment being used.

NOTE: All the above documentation should be given to the customer before the first fill or as near as possible to handover to the customer.

6 Transport and distribution of liquid hydrogen

All these activities shall be in accordance the applicable national and international transport regulations for the mode of transport.

6.1 Road transport

6.1.1 General

This section covers operations involved from the time the vehicle leaves the filling plant until it has completed all deliveries given in the route plan and proceeded to its final destination. For transport by road, the ADR, *European Agreement concerning the International Carriage of Dangerous Goods by Road* [9] applies.

These operations include:

- route planning;
- periodic checking;
- parking of tanker or tank container;
- breakdown;
- product transfer into customer storage;
- emergency procedures; and
- driver training.

6.1.2 Routing, periodic checking, parking and breakdown

6.1.2.1 Routing

The route planning shall be established before any trip is started indicating which roads the tanker or tank container should take. When deciding the route, the following information should be considered:

Vehicles should be routed to customer premises on primary routes, that is on motorways and main trunk roads, wherever possible.

Densely populated areas should be avoided wherever possible, for example, city centres, built-up areas.

The rate of pressure increase within the tanker or tank container should be considered when route planning to ensure that venting of product on the public highway is avoided.

Vehicles shall not be routed through tunnels unless the tunnel is part of an ADR or dangerous goods approved route.

Drivers shall keep to approved designated routes. If they are diverted from the route, i.e. by police or roadworks, then, unless the vehicle returns to the original route within a short period, the driver should notify his home base as soon as it is safe to do so.

The route should indicate where tankers and tank containers can be diverted to if the normal operating condition of the vessel deteriorates or there is a need to reduce excessive tank pressure.

NOTE : Venting of the tanker or tank container is not normally permitted on the public highway.

6.1.2.2 Periodic checking

These checks are over and above the legal statutory requirements to be performed by the driver.

The vehicle shall undergo a full pre-departure check and a trip report shall be prepared unless one has been raised previously, for example, tank container by sea.

The vehicle should be checked periodically throughout the duration of the trip.

During the period the vehicle is moving the driver should be able to monitor the vessel pressure.

If abnormal operating conditions are detected the driver should inform the monitoring centre as soon as possible, for example, excessive pressure rise in the transport or external icing of the transport.

6.1.2.3 Parking

When parking for meal breaks etc., the vehicle shall be parked in accordance with national legislation, and ADR, and wherever possible use should be made of secure truck parking areas for example, motorway parking areas and always in the open air. If the vehicle is parked for longer periods it should be supervised.

The driver should remain in close proximity to the vehicle and, if possible, within visual contact.

Parking adjacent to obvious potential hazards shall be avoided such as beneath overhead power lines, re-fuelling areas, LPG or liquid oxygen tankers.

Parking within 15 metre of occupied premises or a place where members of the public gather should be avoided.

Vehicles shall not be parked within close proximity to bridges, tunnels or underpasses.

6.1.2.4 Breakdown

In the event of a breakdown on a public highway, other road users should be warned by the use of hazard warning flashers, reflective triangles and flashing amber lights, as required. See also the requirements of ADR [9].

Under no circumstances shall a liquid hydrogen tanker or tank container in service enter enclosed premises for repair unless the premises are specifically built for hydrogen service.

Under no circumstances shall hot work be carried out on a liquid hydrogen tanker or tank container unless purged, inerted, fully authorised and a permit to work issued. It is possible to do this, but specific measures shall be taken to ensure safety of personnel.

If the trailer is not purged, the tractor shall remain attached to the vehicle unless the tractor or tanker is damaged by fire, or for a tractor change. This is in order to be able to remove the tanker from a potentially hazardous situation.

6.1.3 Product transfer into customer storage

Fully authorised, trained and certified personnel shall undertake a transfer operation. This includes in-depth knowledge of written instructions detailing the product transfer operation.

A transfill operation shall not be undertaken during a thunderstorm and shall be stopped if a storm is imminent.

6.1.4 Before unloading

Upon arrival at the customer premises the driver shall:

- Report to the designated customer personnel before any operation is carried out;
- Ensure that the delivery vehicle is grounded (electrically connected to earth) before any other operation is carried out and wheel blocks should be used;
- Visually inspect the hose(s) and couplings to establish the mechanical integrity and ensure that the end fittings are undamaged and not dirty;
- Check the surrounding area to ensure that no safety hazards have been introduced; and
- Ensure that prior to liquid transfer the hose(s) are purged of air with an inert gas and then from contaminants which may freeze at liquid hydrogen temperatures.

6.1.5 Product transfer

Any defect observed by the driver during the transfer operation shall be reported.

Driver(s) shall be in attendance near the operating controls of the tanker or tank container and storage tank during the complete transfer operation.

During transfer, the driver(s) shall wear protective clothing including gloves, eye protection, helmet, flame resistant overalls and protective footwear.

Upon completion of product transfer the delivery hose(s) shall be purged of liquid hydrogen before disconnection.

6.1.6 Emergency procedures

The vehicle shall clearly display an emergency telephone number, which can be used by the emergency services, public or driver for specialist advice as required by ADR [9].

Where there is a need to vent excessive tanker or tank container pressure, refer to the route plan as specified in 6.1.1.

If it is not possible to vent at those areas designated within the route plan (due to rapid pressure increase) park the tanker or tank container in the safest possible place taking into consideration the prevailing wind direction and strength.

All incidents shall be reported in writing.

6.1.7 Driver training

All drivers shall be trained and certified in all aspects related to the distribution and product transfer of liquid hydrogen. This is in addition to the requirements of ADR [9].

- Physical and chemical properties of hydrogen, liquid and gas;

- The general design of equipment including leak tightness, insulation and grounding;
- Tanker and tank container functioning, principle of liquid transfer and different transfer modes;
- Actions to be taken at customer premises;
- Security, driving regulations, dangerous transport regulations, instructions for liquid transfer, instructions for liquid hydrogen handling;
- Instructions in case of accident/breakdown on the road; and
- Reporting requirements.

6.2 Tank container - transport by railway

The carriage of tank containers by rail shall be in accordance with the *International carriage of dangerous goods by rail*, (RID) [10]. Tank containers offered for rail transport shall have the appropriate approval. The national railway authority can impose additional requirements and these should be requested prior to the journey arrangements being made.

The tank container inner vessel pressure condition shall be suitable for the expected journey time plus 24 hours. The nitrogen shield vessel shall be full. A checklist shall be completed to indicate departure condition and a copy carried with the tank container. For more information, see EIGA Doc 184 *Methods to prevent the premature activation of relief devices on transport tanks* [11].

A planned route should be agreed with the national railway authority and where the route crosses a border the journey plan shall be supplied to appropriate persons of other national railway authorities together with other relevant information.

A system shall be agreed whereby any deviation from the specified route plan is notified to all persons concerned.

Segregation from other containers and railway wagons will be under the control of the national railway authority. however, the operator shall inform the authority of the dangers, which could arise so that the tank container can be positioned away from flammable and oxidising substances, being carried on the same train or on other trains parked in marshalling yards.

Prior to the journey, an emergency telephone system should be set up along the planned journey route with a list of specific contacts, for example national railway authority, gas company, emergency services.

A document detailing the initial response to an emergency should be provided to the national railway authority and all other appropriate persons along the planned journey route, for example, the emergency services.

The operator (gas company or contractor) should set up an emergency response team(s) to deal with incidents.

Due to the nature of railway activity it may not be possible to measure inner vessel pressure rise at regular intervals. This requirement should be discussed with the individual national railway authority and suitable agreements made.

A full check of the tank container should be made at the conclusion of the journey. This should be recorded on the checklist. If a further journey by another mode is necessary, the appropriate instructions for that mode should be followed.

6.3 Transportation by inland waterways and sea

The requirements for waterways and sea transport are covered by ADN *The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways*, IMDG *The International Maritime Dangerous Goods Code* and the general guidelines given in EIGA Doc 41, *Guidelines for transport by sea of multiple element gas containers (MEGCS) and portable tanks for gases*, [12,13,14]

It is recommended that a check list be supplied to the shipping line to ensure that performance monitoring of the tanker/tank container is recorded at regular intervals.

Specific instructions should be provided which detail procedures to the following in the event of an emergency, in addition to the requirements of IMO Emergency procedures for ships carrying dangerous goods.

7 Training and protection of personnel

7.1 Training of personnel (gas supplier and customer)

All personnel directly involved in the commissioning, operation and maintenance of liquid hydrogen storage systems shall be informed regarding the hazards associated with hydrogen and trained and qualified as applicable to operate or maintain the equipment.

Training shall be arranged to cover those aspects and potential hazards that the particular operator is likely to encounter.

Training shall cover, but not necessarily be confined to the following subjects for all personnel:

- Properties of liquid and gaseous hydrogen;
- Properties of liquid and gaseous nitrogen (or other purging gas);
- Potential hazards of hydrogen;
- Site safety regulations;
- Emergency procedures;
- Use of firefighting equipment;
- Use of protective clothing/apparatus including breathing sets where applicable; and
- First aid treatment for cryogenic burns.

In addition, individuals shall receive specific training in the activities for which they are employed.

It is recommended that the training is carried out under a formalised system and that records of the training are retained. The training programme should make provision for refresher courses on a periodic basis, or on changes of site personnel.

It is the responsibility of the customers to train their own personnel in accordance with EC Directive 1999/92/EC) [7]

7.2 Permit to work

Before maintenance is carried out on the installation, a written permit to work for the particular type of work such as, but not limited to cold work, hot work, entry of vessel and electrical work shall be issued by an authorised person to the individual(s) carrying out the work see, EIGA Doc 40 *Work permit systems.* [15].

7.2.1 Emergency procedures

Emergency procedures shall be prepared to cover fire or any other hazardous event that can occur.

The following are guidelines that may be used for formulating emergency procedures:

- Raise the alarm;
- Summon help and emergency service;
- Isolate the source of hydrogen, if appropriate and safe to do so;
- Evacuate all persons from the danger area and seal it off;
- Alert the public to possible dangers from vapour clouds and evacuate when necessary; and
- Notify immediately the gas supplier.

7.2.2 Fire protection

Emergency procedures shall be established for each particular installation in consultation with local authorities and periodic drills should be carried out.

Water shall be available in order to keep equipment cool in the event of fire.

7.2.3 Firefighting equipment

The location and quantity of firefighting equipment shall be determined, depending on the size of the hydrogen installation and in consultation with the local authorities/customers.

When water is used to keep equipment cool careful control must be exercised. Water should not be sprayed near relief valve vents or vent stack outlets due to the potential danger of plugging vents with ice.

8 References

Unless otherwise specified the latest edition shall apply.

[1] EIGA Doc 75, *Determination of Safety Distances* www.eiga.eu

[2] NFPA 55 Compressed *Gases and Cryogenic Fluids Code* www.nfpa.org

[3] EIGA Doc 171, *Storage of Hydrogen in Systems Located Underground* www.eiga.eu

[4] DIRECTIVE 2014/34/EU *of The European Parliament and of The Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)* www.europa.eu

[5] EIGA Doc 133, Cryogenic Vaporisation Systems - Prevention of Brittle Fracture of Equipment and Piping, www.eiga.eu

[6] EIGA Doc 24, *Vacuum Insulated Cryogenic Storage Tank Systems Pressure Protection Devices* www.eiga.eu

[7] DIRECTIVE 1999/92/EC of The European Parliament and of The Council of 16 December 1999 *on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (15th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)* www.europa.eu

[8] EIGA Technical Bulletin TB27, *The Pressure Equipment Directive. Periodic Inspection and Reassessment of Static Cryogenic Vessels for use in the European Union* www.eiga.eu

[9] ADR, *European Agreement concerning the International Carriage of Dangerous Goods by Road* www.unece.org

[10] (RID) *International carriage of dangerous goods by rail*, www.otif.org

[11] EIGA Doc 184 *Methods to Prevent the Premature Activation of Relief Devices on Transport Tanks* www.eiga.eu

[12] ADN *The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways* www.unece.org

[13] IMDG *The International Maritime Dangerous Goods Code* www.imo.org

[14] EIGA Doc 41 *Guidelines for Transport by Sea of Multiple Element Gas Containers (MEGCS) and Portable Tanks for Gases* www.eiga.eu

[15] EIGA Doc 40 *Work Permit Systems* www.eiga.eu