



# **SAFETY IN STORAGE, HANDLING AND DISTRIBUTION OF LIQUID HYDROGEN**

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# SAFETY IN STORAGE, HANDLING AND DISTRIBUTION OF LIQUID HYDROGEN

## KEYWORDS

- FIRE
- HAZARD
- HYDROGEN
- INSPECTION
- LEGISLATION
- PRESSURE VESSEL
- PREVENTION
- SAFETY
- STORAGE
- TRANSPORTATION
- WORK PERMIT
- LIQUID

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## 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 to publish a Code of Practice addressing safety in storage, handling and distribution of Liquid Hydrogen.

This EIGA document is intended as a Code of Practice for the guidance of 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 particular properties of liquid hydrogen, certain precautions must be taken and certain rules must be followed - these are described in this Code of Practice.

## 2 Scope

A liquid hydrogen storage installation on a user's premises is defined for the purpose of this code of practice (COP) as the installed liquid storage tank. This COP applies to the layout, design and operation of such 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 document.

## 3 Properties and Effects of hydrogen

### 3.1 General

Liquid hydrogen has the UN number 1966.

Liquid hydrogen is invariably accompanied by a certain amount of gaseous hydrogen. For this reason it is necessary to consider properties of both liquid and gaseous hydrogen. The most important properties of hydrogen are summarised in table 1.

### 3.2 Physical Properties

Hydrogen is the least dense of all gases. At normal temperature and pressure the density of gaseous hydrogen is one fourteenth that of air. Due to its low density gaseous hydrogen tends to 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, which would normally be gastight with respect to air or other gases.

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 much higher than that of other gases. This influences combustion behaviour (e.g. burning velocity).

### 3.3 Chemical Properties

Hydrogen is not significantly reactive. Hydrogen is not corrosive but depending on temperature, pressure and other conditions it may 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. 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. Confined mixtures of hydrogen and air or oxygen explode very strongly and may detonate. An unconfined gas cloud explosion of hydrogen is very unlikely to occur and up 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 best way of extinguishing is to shut off the flow.

### **3.4 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 special effects on the human body (see below).

### **3.5 Special 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, which encourages evaporation. However, commercial liquid hydrogen mainly consists of para-hydrogen.

Liquid hydrogen and also 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, which 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 (e.g. 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.

## PROPERTIES OF HYDROGEN AND SOME COMPARABLE SUBSTANCE

	Valid at	Hydrogen <sup>1</sup>	Methane	Propane	Heptane <sup>3</sup>
Boiling point	1.013 bar	20.4	111.6	231.1	371.5
Critical temperature		33.19	119.6	396.8	540.4
Critical pressure		13.15	46.0	42.4	27.5
Density of liquid	Boiling point	70.8	422.5	580.7	680 <sup>4</sup>
Heat of vaporisation	Boiling point	445.6	510.4	427.8	317
Density of gas	Boiling point	1.338	1.818	2.419	3.29
Density of gas	1.013 bar 0°C	0.090	0.717	2.011	4.46
Specific heat, C <sub>p</sub>	1.013 bar 0°C	14.19	2.19	1.56	1.70 <sup>5</sup>
Specific heat, C <sub>v</sub>	1.013 bar 0°C	10.06	1.67	1.35	N/A
Thermal conductivity	1.013 bar 0°C	0.1682	0.0305	N/A	0.0188 <sup>6</sup>
Diffusion coefficient (in air)	1.013 bar 20°C	0.69	0.22	0.12	0.05
Limits of flammability <sup>2</sup>	1.013 bar 20°C	4.0-75.0	5.0-15.4	2.1-9.5	1.11-6.7
Auto ignition temperature <sup>2</sup>	1.013 bar	560	595	470	215
Minimum ignition energy <sup>2</sup>	1.013 bar 20°C	0.019	0.28	0.26	0.22
Theoretical temperature of flame <sup>2</sup>	1.013 bar	2045	1875	2040	2200

Conversion: 1bar = 10<sup>5</sup> Pa

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



## 4 Customer Installations

### 4.1 Layout and Design Features

#### 4.1.1 General

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

The installation shall be sited to minimise 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.

#### 4.1.2 Recommended minimum safety distances

The distances shown in Table 2 are recommended minimum safety distances.

The values given take into account different basic needs:

- To ensure protection to people in the vicinity in case of accidental events.
- To ensure the integrity of the surrounding technical equipment in case of the same accidental events.
- To allow easy and quick access for emergency services when needed.

Their determination was based upon:

- Hydrogen cloud dispersion models. These models take into account:
  - 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 a hydrogen flame.
- Local overpressure due to flame ignition.

These distances are measured from:

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

The distances given in table 2 can be reduced if additional protection (e.g. water spray curtain) is located between the liquid hydrogen installation and the exposure. Such protection may be used for items no. 2, 3, 5, 6, 10, 14.

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

- To minimise the consequence of an accidental leakage, the vessel should 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, the minimum distance of 2.5 metres should apply.
- Further walls (vessel in 2 or 3 sided zone) should be avoided as much as possible to prevent accidental gas confinement, if leakage occurs.

- 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.

Recommended minimum safety distances for Liquid Hydrogen storage

	ITEMS	DISTANCE (M)
1	90 min fire resistive walls	2.5
2	Technical and unoccupied buildings	10
3	Occupied buildings	20
4	Air compressor intakes, air conditioning	20
5	Any combustible liquids	10
6	Any combustible solids	10
7	Other LH2 fixed storage	1.5
8	Other LH2 tanker	3
9	Liquid oxygen storage	6
10	Flammable gas storage	8
11	Open flame, smoking, welding	10
12	Place of public assembly	20
13	Public establishments	60
14	Railroads, roads, property boundaries	10
15	Overhead power lines	10

#### 4.1.3 Location of installation

All liquid hydrogen storage installations at user's premises shall be situated in the open air. Liquid hydrogen installations shall not be located inside buildings. For underground installations additional requirements should be considered.

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 apparatus, 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 discouraged from accumulating within 15 metres 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.

Timber or other readily combustible materials shall not be used for fencing. The height of the fencing should be at least 2m.

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

- The main gate should be at least 1.2m wide
- The emergency exit gate should be at least 0.8m wide

Gates shall be locked during normal operation.

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

Any firebreak walls or partitions shall be made of brick, concrete or any other suitable non-combustible material of 90 minutes rating.

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

#### **4.1.4 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 should have easy access to and exit from the installation at all times.

A suitable concrete hard standing 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 liquid transfer shall be clearly defined and transfer of liquid shall only take place within the user's premises.

#### **4.1.5 Electrical equipment and installation**

The installation and operation of electrical systems in hydrogen installations (inside the distance given in Table 2, item 15) shall be in accordance with the National Regulations, Standards and Codes of Practice and especially with the last amendment of the Directive 79/196/EEC on the approximation of the laws of the Member States concerning electrical equipment for use in potentially explosive atmospheres employing certain types of protection, Official Journal L43, 20.Febr. 1979 as applicable. Normal electrical installations (not explosion-proof) should be outside the distance given in Table 2, item 15.

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

Adequate lighting shall be provided for night deliveries as appropriate.

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

All systems shall be bonded and effectively earthed to give protection against the hazards of electrical currents and static electricity (see 3.1.5.6) in accordance with National Codes/Regulations, with a resistance to earth of less than 10 ohms.

Major items of equipment such as the tank 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, e.g. 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 must 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 etc, 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.

To ensure that the requirements for the prevention of the build up of static electricity on equipment are met, a competent person prior to commissioning shall carry out an inspection.

#### **4.1.6 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 applied by wind, snow, etc.

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

#### **4.1.7 Hydrogen Vents**

All vents, including those of safety relief devices 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 so as 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.

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, which 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.

#### **4.1.8 Vapour Clouds**

When siting an installation, due 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.

#### **4.1.9 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.

#### **4.1.10 Back Flow**

A device shall be fitted after the hydrogen vaporiser to avoid back flow into the hydrogen system.

#### **4.1.11 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. 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 safety precautions, required for Hydrogen, e.g. 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, e.g. 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.

#### **4.1.12 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 adequately protected with suitable relief devices as required.

The vaporiser shall be adequately sized for the maximum flow requirement specified by the customer. Where necessary a device should be installed to ensure that cold gas temperature exiting the vaporiser cannot:

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

## **4.2 Access to the Installation**

### **4.2.1 Personnel**

The installation shall be so designed that authorised persons shall have easy 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.

#### 4.2.2 Access to installation controls

Filling connections and equipment controls shall be easily accessible.

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 easily accessible from the operator's position.

#### 4.2.3 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 the following:

- 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
- The phone number of the local emergency service

This information shall also be available at a control point.

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 Section 3.6).

### 4.3 Testing and Commissioning

#### 4.3.1 Testing of liquid storage installation

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

#### 4.3.2 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 a responsible person. Any defects found during the test shall be rectified in an approved manner and the system retested.

A responsible person and a test certificate signed and issued shall witness pressure tests. Such certificates shall be kept for future reference.

Plant instruments, gauges, etc 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).

#### 4.3.3 Purging

- 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.

- Hydrogen purge

If helium is used as the inert purge gas to remove the oxygen, use cold hydrogen gas 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 should be prepared for each installation, making individual reference to valves and equipment to ensure that all parts of the system are safe for the introduction of hydrogen.

#### **4.3.4 Pressure Relief Devices**

Pressure relief devices shall be arranged to discharge 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 3.1.7.

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 proper operation of the device.

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

If a three way 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 three way 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 IGC Code of Practice 24/83.

A secondary relief device such as a bursting disc should be installed together with the primary relief device of the tank.

Consideration shall also be given in the design of the installation to facilitate the periodic testing of the pressure relief devices.

#### **4.3.5 Commissioning**

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

### **4.4 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 (50% of lower explosive limit).

## 4.5 Operations and Maintenance

### 4.5.1 Operation of the Installation

- 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 should, for the convenience of the operator, color code or identify by other means the hand wheels of those valves which are to be shut in an emergency.

- 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.

### 4.5.2 Periodic Inspection and Maintenance

- Site

Authorized persons to ensure that it is maintained in a proper condition and that safety distances are respected should inspect the site regularly.

- 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 IGC Document TN 23/79, Recommendations for the periodic inspection and testing of cryogenic vessels.

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

- Installation

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

An annual external visual examination should 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.

- Vaporizers

In cold weather, the operator should regularly check ambient air vaporizers for excessive ice formation, which may be removed by the use of steam or hot water.

When a water bath or steam heated vaporizer is used the operator should carry out regular visual examination of shell and external tube surfaces for signs of damage, excessive frosting etc. Any defects should be reported to the supplier.

- Pressure Relief Devices



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

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 IGC document 24/83 unless unusual conditions of service dictate more stringent requirements.

Bursting disc elements may 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.

- Ancillary Equipment

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

#### **4.6 Customer Information**

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

##### **4.6.1 All product specific gas and safety data sheets**

##### **4.6.2 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.

##### **4.6.3 Process and instrumentation diagram (P&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 e.g.:

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

##### **4.6.4 Operating Instructions/User Manuals**

The document which is for the safe operation of the plant shall be specific to the particular customer installation; and therefore:

The system for supplying handover documentation needs to be able to cope at short notice with:

- Changes at customer installations
- New equipment developments

##### **4.6.5 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.

## **5 Transport and Distribution of Liquid Hydrogen**

All these activities shall be in accordance with ADR, national and international regulations.

## 5.1 Road Transport - General

This section covers all 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.

These operations include:

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

Tankers and tank containers used for transportation and distribution of liquid hydrogen should take account of the general design considerations given in Appendix 1.

### 5.1.1 Routing, periodic checking, parking and breakdown

- 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, i.e. motorways and main trunk roads, wherever possible.

Densely populated areas should be avoided wherever possible, i.e. 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.

- Periodic Checking

(NOTE) 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 raised, unless one has been raised previously, i.e. tank container by sea.

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

During the periods 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.

- 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 Heavy Goods Vehicle public parking areas, e.g. 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, e.g. beneath overhead power lines, re-fuelling areas, LPG or Liquid Oxygen tankers.

Parking within 15m 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.

- 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.

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.

As long as the trailer is not purged, the tractor must 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 potential dangerous situation.

### **5.1.2 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.

### **5.1.3 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.
- 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.

### **5.1.4 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, overalls and protective footwear.

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

### **5.1.5 Emergency Procedure**

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

Where there is a need to vent excessive tanker or tank container pressure refer to the route plan as specified in paragraph 5.1.1.

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.

### **5.1.6 Driver Training**

All drivers shall be trained and certified in all aspects related to the distribution and product transfer of liquid hydrogen. This includes:

- Physical and chemical properties of hydrogen, liquid and gas.
- The general design of equipment, leak tightness, insulation, grounding, etc.
- 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.
- Reporting requirements.

## **5.2 Tank Container - Transport by Railway**

The carriage of tank containers by Rail shall be in accordance with the "Règlement Concernant le Transport International Ferroviaire des Marchandises Dangereuses" (RID). Tank containers offered for rail transport must have the appropriate approval. The National Railway Authority may 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.

A planned route should be agreed with the National Railway Authority and where the route crosses a border the journey plan must 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, i.e. 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, i.e. 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.

### **5.3 Transportation by Waterways and Sea**

The requirements for waterways and sea transport are covered in the International Maritime Dangerous Goods Code and general guidelines given in IGC Doc 41/89, which should also be applied, to Road Tankers.

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.

## **6 Training and Protection of Personnel**

### **6.1 Training of Personnel (gas supplier and customer)**

All personnel directly involved in the commissioning, operation and maintenance of liquid hydrogen storage systems shall be fully informed regarding the hazards associated with hydrogen and properly trained 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 fire fighting equipment
- Use of protective clothing/apparatus including breathing sets where applicable
- 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 be carried out under a formalised system and that records be kept of the training given and where possible, some indication of the results obtained, in order to show where further training is required.

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 EEC Directive 85/374.

## **6.2 Permit to Work**

Before maintenance is carried out on the installation, a written Permit to Work for the particular type of work (cold work, hot work, entry of vessel, electrical work, etc) shall be issued by an authorised person to the individual(s) carrying out the work.

### **6.2.1 Emergency Procedures -**

Emergency procedures shall be prepared to cover fire or any other hazardous event, which may occur.

The following are guidelines, which 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
- Notify immediately the gas supplier

### **6.2.2 Fire Protection**

Full 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.

### **6.2.3 Fire Fighting Equipment**

The location and quantity of fire fighting 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.

## APPENDIX 1: VEHICLE EQUIPMENT AND DESIGN CONSIDERATIONS

Consideration should be given to the following when designing a tanker or tank container for use in liquid hydrogen service.

### 1. General Design

Electrical equipment including transfer pump motor and lighting of compartments shall be suitable for hydrogen service, e.g. explosion proof or inerted. This does not apply to the automotive electrics.

All enclosures on the tanker or tank container shall be suitably ventilated either by design or operation.

All control equipment shall be adequately protected to minimise the effect of impact damage.

The liquid discharge line shall be equipped with two valves in series, one of which shall be an automatic shut off (fail close).

On uninsulated pipe work operating at liquid hydrogen temperature air can condense. Drip pans should be installed to allow the collection and vaporisation of condensed air.

Drip pan design and location should be such that it prevents condensed air running on to equipment, and minimises the risk of condensed air falling onto asphalt surfaces.

Special care shall be taken to isolate piping which can be cold from equipment not designed for low temperature such as carbon steel, e.g. vehicle chassis or rubber, plastics, e.g. electrical cabling, etc.

The tanker or tank container shall be equipped with an emergency shut off valve, which can be activated from both sides of the vehicle.

### 2. WARNING NOTICES AND PLACARDS

The product in the tanker or tank container shall be clearly identified according to ADR and/or the appropriate national regulations.

All valves and equipment shall be individually tagged according to a specific process and instrumentation diagram (P&ID), which is permanently located on the vehicle.

### 3. ANTI TOWAWAY DEVICES

Each vehicle shall be equipped with an anti-towaway device (see IGC document TN 19/83R).

### 4. HOSE COUPLING

The use of hose coupling adaptors should be avoided at customer sites.

### 5. SAFETY CIRCUITS

The inner vessel should be protected against over pressure by a dual safety relief device system.

All piping circuits in which liquid may be trapped must be equipped with a relieving device of adequate size and pressure rating.

Piping from all vents should be routed into a vent stack, excluding the relief devices mentioned above.

All vehicles must be equipped with a fire extinguisher in accordance with ADR regulation (marginal No10240).