GASEOUS HYDROGEN INSTALLATIONS

AUSTRALIA NEW ZEALAND INDUSTRIAL GAS ASSOCIATION

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GASEOUS HYDROGEN INSTALLATIONS - EIGA Doc 15/21

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Guide to Use

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ANZIGA membership encompasses all the major producers and suppliers in both Australia and New Zealand.

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The following referenced documents are an example of those that should not be relied upon, and their use is cautioned, the local reciprocal legislation must be sought out and followed:

- EU Directives
- Pressure Equipment Directives
- Transportable Pressure Equipment Directives
- ATEX Directives
- ISO standards

Compliance with the relevant Australian and New Zealand requirements is essential. Users should consider:

- Work Health and Safety Legislation
- Occupational Health and Safety Legislation
- Dangerous goods Transport legislation
- National Transport Commission requirements
- Plant Regulations, design regulations requirements
- Australian Standards
- New Zealand Standards

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Amendments from 15/06

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

NOTE Technical changes from the previous edition are underlined

1 Introduction

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

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

2 Scope

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

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

3 Definitions

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

3.1 Publication terminology

3.1.1 Shall

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

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

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

3.1.5 Can

Indicates a possibility or ability.

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

4 Properties of hydrogen

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

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

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

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

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

Minimum spark ignition energy in air	0.000019 joule (19 μJ)
Minimum spark ignition energy in oxygen	0.000017 joule (17 μJ)

Hydrogen can burn in two modes. One mode of burning is called deflagration, in which the flame travels through the mixture at subsonic speeds. Another mode of burning is called detonation, in which the flame and accompanying shock wave travels through the mixture at supersonic speed.

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

5 General design features

5.1 Design

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

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

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

5.2 Areas with potentially explosive atmosphere

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

5.3 Location

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

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

They should not be located beneath high voltage power lines.

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

For typical safety distances see Table 1.

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

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

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

5.4 Layout

The layout should consider as a minimum:

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

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

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

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

5.5 Buildings

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

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

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

5.5.1 Design and buildings

5.5.1.1 Mitigation for explosion damage

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

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

National legislation may direct the design approach required.

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

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

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

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

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

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

5.5.1.2 Mitigation for fire propagation

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

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

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

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

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

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

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

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

5.5.2 Heating, cooling and ventilation

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

- area of openings for natural ventilation (for example m^2 per m^3); and
- forced ventilation shall be used where calculated ventilation cannot be achieved with natural ventilation.

Ventilation design shall consider potential restricted spaces caused by equipment.

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

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

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

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

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

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

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

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

5.6 Pipelines and Discharge Devices

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

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

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

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

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

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

Flare systems may be used where designed as such.

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

5.7 Materials

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

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

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

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

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

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

5.8 Pressure vessels

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

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

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

- Type 1: All metal.

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

- Type 2: Metallic liner, hoop wrapped.

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

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

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

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

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

5.9 Connections

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

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

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

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

The free end of filling hose connections and pig tails, where threaded, shall have a left-hand thread. Filling hoses should be electrically continuous. If not, sufficient grounding shall be provided upstream as well as downstream of the filling hoses. The material of construction shall provide the best possible resistance to permeation. Where outer sleeves are fitted, these shall be suitably pierced to prevent inflation. Each hose shall be strength tested by the manufacturer and a certificate issued to that effect. The hose shall have a means of identifying its date of manufacture, design pressure and design temperature. Safety devices shall be fitted to restrain the hose in the event of failure (anti-whip wire / tether). Hoses shall be regularly inspected based on risk assessment (and national legislation where applicable). Hoses shall be retired from use if signs of wear affecting integrity are found or after a specified time. Records of inspection shall be kept, and inspection frequency adjusted, shorter or longer, accordingly.

5.10 Instruments

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

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

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

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

5.11 Control and safety systems

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

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

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

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

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

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

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

In addition to its function of process system regulation, data reporting and recording, a control system shall provide safety features such as alarm, shutdown, isolation and relief functions, which will ensure the integrity of the facility and its safe operation under all foreseeable conditions.

Safety systems shall be assessed and designed according to suitable standard. The functional requirements, and the safety integrity requirements may be determined from studies such as Hazard and Operability Studies (HAZOP), layers of protection analysis (LOPA) or risk graphs. Such assessments may require implementation of a Safety Instrumented System. A Safety Instrumented System (SIS) performs specific control functions to failsafe or maintain safe operation of a process when unacceptable or dangerous conditions occur.

Application of a SIS may be achieved using standards:

- ISO 13849-1, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design* [17]; or

- EN 61511, *Functional safety – Safety instrumented systems for the process industry sector* [18].

EN 61511 is associated with the EN 61508 series of standards on *Functional safety* [18, 19].

6 Hazard zones

Hydrogen systems shall be surrounded by hazard zones where additional specific precautions are required to mitigate risks. Hazard zones are sized by considering safety distances which determine the size of areas of potential risk should a leak or release of hydrogen occur.

6.1 Safety distances

Further information on safety distances and methodology for their calculation are given in EIGA Doc 75, *Determination of Safety Distances* [20]. The distances are measured from those points in plan view at which, in the course of operation, an escape of hydrogen may occur. Where equipment is installed within buildings, the distances to outside types of exposure are measured from the openings, for example windows, doors etc. Historically recommended safety distances are given in Table 1 for information. Where national codes or regulations specify greater distances, these shall apply.

Pipelines that contain valves, flanges, removable connections etc. shall be considered as sources of hydrogen escape only at the points where such connections occur. Distances shall be calculated from the point of release and also consider direction of release from vents or relief devices.

Safety distances may be reduced by the provision of suitable fire-resistant barrier walls. The type and dimensions of the barrier and the distance reduction achieved are determined by the conditions at the source of the hydrogen and the nature of the exposure (for example pressure, pipe size). The location of the wall should also consider jet flame impingement and the potential for rebounding or deflection that may spread a fire.

Activities other than those directly related to the hydrogen operation should be kept remote or separated from hydrogen equipment.

Table 1 – Typical minimum horizontal safety distances for hydrogen stations

Typical type of outdoor exposure	Distance in metres of hydrogen from
1. Open flames and other ignition sources (incl. electrical)	5
2. Site boundary and areas where people are likely to congregate such as car parks, canteens, etc.	8
3. Wooden buildings or structures	8
4. Wall opening in offices, workshops, etc.	5
5. Bulk flammable liquids and LPG storage above ground in accordance with national codes, where they exist, for the particular substance. Otherwise	8
6. Bulk flammable liquid and LPG below ground 6.1 Tank (horizontal distance from shell) 6.2 Vent or connections	 3 5
7. Flammable gas cylinder storage, other than hydrogen	5
8. Gaseous oxygen storage (cylinders)	5
9. Liquid oxygen storage (not greater than 125 000 litre tank capacity)[2)]	8[1)]
10. Non-flammable cryogenic liquid storage, other than oxygen, for example argon, nitrogen[1)]	5[1)]
11. Stocks of combustible material, for example timber	8
12. Air compressor, ventilator intakes, etc.	15

[1)] Where satisfactory arrangements are made to divert liquid spillage away from the hydrogen system, these distances may be reduced.

[2)] For tank capacities greater than 125 000 litres see EIGA Document 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites* [21].

In case of occupied buildings, additional care shall be taken with regards to the pressure energy which can be generated from the ignition of hydrogen. For information concerning the consequences, see EIGA Doc 187 *Guideline for the Location of Occupied Buildings in Industrial Gas Plants* [22].

6.2 Identification of and Access to Hazard Zones

The extent of the hazard zones shall be indicated by permanent notices in the local language, particularly at access points, or by distinctive lines painted on the ground. Notices shall indicate the nature of the hazard, for example:

HYDROGEN – FLAMMABLE GAS

NO SMOKING – NO NAKED FLAMES

Only authorised personnel shall be allowed to enter these zones. These personnel shall be aware of the hazards likely to be encountered and the relevant emergency procedures.

Any work other than that directly connected with operating the station shall be covered by a Safety Work Permit system, see EIGA Doc 40, *Work Permit Systems* [23].

7 Compression

Different types of compressors may be acceptable provided that they have been designed with particular reference to hydrogen service.

Attention shall be given to prevent the ingress of air, for example by low suction pressure trip acting to shut down the compressor, and/or oxygen analyser on the supply hydrogen.

7.1 Flowsheet Description

Appendix 1 shows a flowsheet of a typical hydrogen compressing system using a multistage piston machine.

Hydrogen enters the compressing system through the inlet isolation valve (1). A purge valve (2) fitted with a sealing device (3) shall be provided to allow the system to be purged with nitrogen. A filter (4) should be provided. A pressure indicator/alarm low (5) shall be provided on the suction line. An oxygen analyser (6) should be provided upstream, (see 6.3.2). Analyser response time should be considered when locating analyser sample lines. Pressure protection for the analyser shall be provided where required.

At the outlet of each stage of the compressor (7) a pressure indicator (8) and a temperature indicator (9) should be fitted. Temperature indicators (9) may also be fitted after each cooler (10, 13).

NOTE The inclusion of temperature indicators (9) will be dependent on the condition of the incoming hydrogen and the requirements for the compressed product.

Full flow relief valves (11) shall be installed after each stage. Drain / vent valves (12) may also be provided after each cooler.

The following items may be provided after the final stage:

- After-cooler (13)
- Temperature alarm high (14)
- Separator and drain (15)

NOTE The inclusion of after-cooler, and separator and drain will be dependent on the condition of the incoming hydrogen and the requirements for the compressed product.

A pressure indicator / alarm high (16), a non-return valve (17), a vent / purge valve (18), and an outlet isolation valve (19) shall be installed.

Cooling water systems shall be provided with a pressure alarm low (20) or a flow alarm low (21) located at the inlet or outlet of the compressor cooling system. Additionally, visual flow indicators may be provided.

Where closed circuit water-cooling is used, each cooler should be protected against overpressure on the water side, arising from leakage or failure of the gas side.

If the electric motor (22) is pressurised with nitrogen or air, it shall be equipped with a pressure alarm low (23) to monitor the pressure in the motor casing. If the compressor crank case is pressurised with hydrogen or inert gas, a pressure alarm low (24) shall be provided on the crank case.

Alternatively, item 23 and 24 may be low flow alarms.

7.2 Maintenance

All flammable gases shall be purged with nitrogen before air is admitted. All flammable gas systems shall be purged with an inert gas such as nitrogen before hydrogen or flammable gases are admitted. The purge discharge shall be piped to a safe location. Under no circumstances shall air be purged into an active vent or flare stack

Interconnections between the process gas and inert gas / nitrogen purge systems shall be provided with a positive means to prevent the flow of process gas into the nitrogen purge system, see EIGA Doc 238, *Prevention of Plant Instrument and Utility Gas System Cross Contamination* [24].

NOTE Pre-treatment of the crude hydrogen supply is required to remove oxygen if the stream is intended for subsequent cryogenic processing or if the gas is to be compressed. Otherwise, the effects of oxygen in the stream are to be analysed to ensure that a flammable mixture cannot result from subsequent processing.

NOTE Pre-treatment of the crude hydrogen supply is required to remove chlorides. Wet hydrogen gas laden with chlorides can result in severe corrosion. Even small quantities of chlorides can quickly deactivate deoxo units.

7.2.1 Start-up

When starting a hydrogen compressor, it is important to prevent ingress of air, which could lead to the formation of explosive mixtures within the machine.

It is essential therefore that the particular safety devices mentioned in 6.4 shall be operational. With these conditions satisfied, hydrogen compressors may be started up as any other compressor in accordance with the manufacturer's instructions and the following recommended start-up procedures.

7.2.2 Start-up of new compressors or compressors following maintenance work

Isolate the compressor by closing main isolation valves (1 and 19). Purge air from the compressor by removing sealing device (3) and connect a source of nitrogen to this point. Open purge valve (2) to pressurise the machine with nitrogen. Pressure used will depend on normal duty of machine, usually not less than half design inlet value is recommended, particularly for low suction pressure machines.

Open vent / purge valve (18) and set an adequate purge nitrogen flow. Check that the safety devices under 6.3 are operational. Start the compressor and leave running for approx. ten minutes.

Check the oxygen content of the gas leaving the purge / vent valve (18), when this is less than 1% for a minimum period of two minutes shut down the compressor.

Close purge inlet valve (2) and purge / vent valve (18), disconnect the nitrogen supply and refit blanking device (3). The compressor is now ready for start-up in hydrogen service. This should be done as follows:

1. Open main isolation valve (1). Check that the safety devices under 6.4 are operational.
2. Start the compressor.
3. Open purge / vent valve (19) and analyse vent gas.
4. When analysis is satisfactory, i.e. nitrogen content is reduced to an acceptable value.
5. Close purge / vent valve (18).
6. Open outlet isolation valve (19) to put machine into service.

7.2.3 Restarting of compressors already in hydrogen service

If a positive residual pressure has been maintained within the compressor and its piping systems, for the duration of the stop period, this will prevent air ingress. If in doubt, check for presence of oxygen before re-starting. Check that the safety devices under 6.3 are operational.

Start the compressor.

7.2.4 Shutdown of compressors

Stop the compressor.

If the compressor is to remain in hydrogen service it may be either, left standing connected to the system or, isolated by closing main isolation valves (1 and 19). Residual pressure may be vented down to a safe location via purge / vent valve (18). Care shall be exercised that, during periods of shutdown, a positive residual hydrogen pressure is maintained within the machine, otherwise on restart the purging procedure detailed in 6.2.1 shall be followed.

7.3 Control and Monitoring Equipment

In addition to the instruments and controls normally provided for gas compressing systems, the following specific safeguards for hydrogen shall be considered.

7.3.1 Inlet Pressure

The inlet pressure shall be monitored by a pressure indicator/switch to avoid a vacuum in the inlet line and consequent ingress of air. This pressure switch shall cause the compressor to shut down before the inlet pressure reaches atmospheric pressure.

7.3.2 Oxygen analysis

Where the hydrogen comes from a low-pressure source, or there is a possibility of oxygen contamination, the oxygen content in the hydrogen shall be continuously measured. Should the oxygen content reach a level of 1%, then the compressor shall be automatically shut down.

The location of the oxygen analyser shall consider the analyser response time. The preferred sample location is upstream of the compressor inlet with short, suitably sized sample lines located such that gas analysis can initiate a shut-down before hazardous gas mixtures reach the compressor.

7.3.3 Discharge temperature

The temperature after the final stage, or after cooler, where fitted, shall be monitored by an indicator / alarm, which may be arranged to shut down the compressor at a predetermined maximum temperature.

7.3.4 Discharge Pressure

The pressure after the final stage shall be monitored by an indicator / alarm, which may be arranged, either to shut down the compressor, or initiate alternative actions for example. recycle at a pre-determined maximum pressure, which is below that of the final relief device.

7.3.5 Cooling water

A water pressure / flow alarm should be provided in the cooling water system, which may be arranged to shut down the compressor in case of low pressure or flow.

7.3.6 Purge gas on electrical equipment

Where the motor and auxiliary equipment are pressurised by an inert gas, for example. nitrogen, low pressure / flow shall be indicated by an alarm. This may be arranged to shut down the motor and auxiliaries.

7.3.7 Pressurised crank cases

Where the compressor crankcase is pressurised by hydrogen or inert gas, low pressure / flow shall be indicated by an alarm. This may be arranged to shut down the compressor.

8 Purification

The purification system consists of equipment to remove oxygen, moisture and other impurities from the hydrogen.

The system may comprise purification vessels, driers, heat exchangers, control and analytical equipment.

8.1 Flowsheet description

Appendix 2 shows a flowsheet of a typical hydrogen purification system. The purification system will depend on the source of hydrogen and the potential impurities.

Impure hydrogen enters the system through the inlet isolation valve (1). A separator (2) removes free droplets of moisture and oil. Removal of vapour phase contaminants, for example ammonia or mercury is achieved in an activated charcoal filter (3). A dust filter (4) prevents adsorbent dust carry-over.

Where necessary a pre-heater (5) is fitted to heat the gas stream before entry into the deoxo catalyser (6). The catalyst temperature is indicated (7). An after cooler (8) and separator (9) reduces the water content in the gas stream before it passes to the adsorption driers (10). The pressure (11) and temperature (12) are indicated. A dust filter (13) removes any carryover of adsorbent dust. The analytical system (14) normally monitors oxygen and moisture content. Additional analytical equipment may be installed according to the specification required.

Product gas leaves the system via an outlet isolation valve (15).

If the presence of mercury is a possibility, provisions for mercury removal shall be installed.

The driers are reactivated by a suitable system.

8.2 Operation

8.2.1 Operating instructions

Detailed operating instructions shall be prepared for each purification system making individual reference to the valves and controls in that system.

8.2.2 Separator and filters

The main aspects of operation with these items are to ensure that separator drains are operated as frequently as necessary to avoid carry-over of free droplets of contaminants.

It is essential that only vapour phase contaminants reach the activated charcoal filter, otherwise rapid breakthrough will occur with subsequent reduction in efficiency of the deoxo catalyst. This may also happen if charcoal dust carries over.

8.2.3 Deoxo catalyser

The deoxo catalyser removes the oxygen present in the feed gas by combining it with some of the feed hydrogen to produce water. The reaction is promoted by a metal-based catalyst, for example platinum, and can be strongly exothermic.

The operating temperature of the reaction is dependent on the quantity of oxygen present in the feed gas. Under certain conditions, for example low gas temperature, or excess moisture, it may be necessary to pre-heat the gas to aid the reaction. The process is normally highly efficient and residual levels of oxygen of less than 1 ppm are achieved. The oxygen content of the gas should be below 2%, due to the upper flammability limit and exothermic reaction. High oxygen content will result in high temperature on catalyst and vessel construction materials.

Temperature indication in the catalyst bed is recommended, with high temperature trip to shut-off the compressor and the supply of gas to the reactor.

The catalyst is very durable and provided there are no contaminants present, for example in the form of oil: mercury, charcoal, etc., it will have a life of several years.

The after cooler and separator reduce the gas temperature and water content of the hydrogen to acceptable levels for the driers. Operating procedures shall consider the cooling water flows and frequency of separator drainage.

8.2.4 Driers

The driers contain an adsorbent desiccant in granular form. The desiccant retains the moisture and before its capacity is reached, it is reactivated by thermal and / or pressure swing methods. The main points of operation of both systems are to ensure that the bed is not overloaded with moisture and design cycle times are maintained.

Particular attention shall be paid in order to avoid over pressure in the reactivation system. This can achieved by relief devices or other design features.

8.3 Control and monitoring equipment

8.3.1 Deoxo catalyser temperature indicator

An increase in oxygen content will result in temperature rise on account of the increased exothermic reaction; therefore the temperature should be monitored by an indicating instrument. This instrument should be connected to an alarm and/or a shutdown system.

8.3.2 Purity analysers

Where oxygen contamination is possible, a feed analyser should be linked to an alarm and a shutdown trip. The product quality should be checked by means of appropriate analytical instruments to ensure the correct operation of the purification system.

9 Filling stations

A hydrogen filling station is any installation where gaseous hydrogen is transferred, under pressure from a compression system and / or bulk hydrogen storage into single cylinders, cylinders manifolded into bundles, or tubes / cylinders which form a fixed load on a road or rail vehicle (a Multi Element Gas Container [MEGC] according to the *European Agreement concerning the International Carriage of Dangerous Goods by Road* (ADR) [25]). As per the scope of this publication, this does not cover hydrogen fuelling stations.

The filling station can comprise fixed storage containers, inter-connecting pipework, filling manifolds, hoses, valves, control system, analysis equipment and vacuum pumps.

Filling stations may be manual (manned) or automatic (unmanned).

Installation of atmospheric analysis (LEL) and associated alarm should be considered in filling areas.

9.1 Flowsheet Description

Appendix 3 shows a flowsheet of a typical hydrogen filling station. Purge connections for inert gas, typically nitrogen, with subsequent hydrogen purge shall be provided for maintenance purposes. Purge connections shall consider cross contamination, see EIGA Doc 238 [24].

9.1.1 Main feeder system

Hydrogen from the compressor / purifier system enters the main header of the filling system.

It passes through a non-return valve (1) and a main isolation valve (2).

A remote operated shut-off valve (3) may be provided so that, in the event of a hazardous occurrence at the filling point, the hydrogen flow may be shut off from the local emergency stops (4). Alternatively, the remote stops may be arranged to shut down the compressors.

An oxygen analyser (5) may be fitted in the main header, if analysis is not provided on the compressor / purification system.

The header can then be sub-divided to feed the various types of filling activities. Each branch should be provided with an isolation valve (6).

9.1.2 Cylinder filling

The cylinder filling flowsheet in Appendix 3 is a generic overview, more detailed information can be found in EIGA Doc 236, *Best Operations Practices for Filling Plants* [26]. EIGA Doc 236 covers the general cylinder filling requirements, this publication will consider the specific hazards related to hydrogen [26].

A pressure indicator or transmitter (7) shall be provided on the main feeder to the cylinder filling area. A high-pressure alarm (8) may also be added. A non-return valve (9) should be provided to ensure, in the event of a rupture at one of the other filling areas, that back-flow does not occur.

Each individual filling manifold shall be provided with an isolation valve (10), a vent/ purge outlet valve (11) and a pressure indicator (12). A vacuum system isolation valve (13) shall also be provided where a vacuum system is used. Individual fill point isolation valves (14) may also be provided.

The vacuum system, where used, may be permanently piped in or may exist as a mobile unit. It shall be provided with adequate relief device(s) (15) to protect the system from the charging pressure of the cylinder filling manifold. Means should also be provided to exclude any backfeed of oil from the vacuum pump into the manifold. Vacuum gauges (16) should be provided.

9.1.3 Bundle trailers

A pressure indicator (17) shall be provided on the main feeder to the filling area. A high-pressure alarm (18) may also be added.

A non-return valve (19) should be provided so as to ensure that, in the event of a rupture at any of the filling areas, back flow does not occur from the containers being filled.

Each individual filling manifold shall be provided with an isolation valve (20), a vent / purge outlet valve (21) and a pressure indicator (22), if one is not provided on the individual units.

A non-return valve (23) should be provided in the hose connection to prevent back flow from the unit in the event of a hose rupture.

A safe means of depressurising / purging the pipe section between the non-return valve (23) and the isolation valve (24) shall be provided. A small-bore vent valve should be installed between the non-return valve (23) and the isolation valve (24). Alternatively, a small hole (1.5 mm maximum diameter) can be drilled in the plug / flap of the non-return valve (23), potential back flow through the drilled non-return valve shall be risk assessed.

This second method would also allow analysis samples to be taken from the unit being filled direct to any analysis instruments connected to the system.

If a vacuum system is required, it shall comply with the requirements stated in 8.2.2.

Care should be exercised to ensure satisfactory earth bonding of the unit being filled. This is particularly essential in the cases of bundle and trailer filling (see 10.6.2).

9.1.4 Analysis

Product analysis may be provided by:

- portable instruments;

- fixed instruments at each filling location / manifold;
- one central analysis room; or
- a combination of the above.

For all types of product analysis safety features shall include:

- a pressure reducing valve (25) to reduce charging pressure down to an acceptable instrument system pressure;
- a safety relief valve (26) to protect personnel and instruments in the event of a pressure reducing device failure; and
- Suitable analytical instruments (27) and systems for use with hydrogen (see 7.3).

Pre-fill analysis of trailers should be considered for incoming road trailers, this can prevent purity issues where the trailers are contaminated and can improve safety by preventing formation of flammable mixtures if a trailer is contaminated with oxygen.

9.2 Operating instructions

Detailed operating instructions shall be prepared for each filling station making individual reference to the valves and controls in that system.

The following guidelines should be used in the preparation of the detailed filling instructions.

9.2.1 Cylinder and bundle filling

For detailed information on cylinder and bundle filling see EIGA Doc 236 [26].

Before filling hydrogen cylinders and bundles, check grounding connection of pallet / bundle.

9.2.2 Trailer filling

Connect trailer to fill point ensuring that it is; properly secured and that anti-tow away procedures are implemented.

For further information on anti-tow away procedures, see EIGA Doc 63, *Prevention of Tow-Away Incidents* [27].

Position the trailer for filling. Leave sufficient clearance on both sides to allow personnel passage and opening of the rear compartment doors.

Where applicable, inspect the trailer for any damage to the process equipment including tubes, valves, manifold, rupture disks, and gauges.

Check that the trailer has the proper markings, labels, and placards, and that the retest date is current.

Connect earthing lead to trailer. Connect filling hose(s).

Open the isolation valve a small amount and open vent / purge valve in order to purge hose and also to allow analysis of residual gas.

Close vent / purge valve. Open main isolation valve to fill container(s). Check container valves and connections for leaks during filling.

NOTE Checking for leaks is typically achieved by operator inspecting for audible leaks.

When containers have reached their charging pressure (allowing for temperature correction) close main isolation valve and container valves.

NOTE To avoid dead ending the compressor (where a buffer storage is not provided) it may be necessary to put online a new bank of containers prior to closing isolation valve on the containers being filled.

Analyse product purity, if required. Record analysis and filling pressure, if required. Vent filling hose Disconnect filling hose and earthing lead, where fitted. Check valves and manifold for leaks.

Ensure trailer is ready for movement in accordance with the anti-tow away procedures.

10 Storage installations at consumer sites

A gaseous hydrogen storage system is an installation in which hydrogen, or mixtures containing hydrogen are stored and discharged to the consumer distribution piping. The system includes stationary vessels, pressure regulators, safety relief devices, manifolds, interconnecting piping and controls. It does not necessarily include storage, systems consisting of bundles or individual cylinders that are taken away for refilling.

The storage system terminates at the point where hydrogen, at nominal service pressure, enters the distributing piping.

10.1 Flowsheet Description

The storage system may comprise of high or low-pressure storage vessels, which may be fixed or mobile, or a combination of both.

There are two types of customer installation:

- fixed storage; or
- trailer / bundle swap.

With fixed storage systems, the vessels are fixed to the installation and recharged in place. For bundle / trailer swap systems. product is replenished on site by swapping / replacing bundles and trailers at the consumer site.

Where low-pressure storage is to be recharged from a high-pressure source, such as a high-pressure cylinder trailer, a pressure reducing system shall be incorporated, set at a pressure not greater than the design pressure of the low-pressure storage vessel(s). This is in addition to any pressure relief devices installed to prevent over-pressure.

The flowsheet in Appendix 4 and the following description applies to a stationary high-pressure storage system, being recharged from a high-pressure cylinder trailer.

Hydrogen from the fixed storage vessel(s) (1) enters the mainline. The storage system shall be provided with a relief valve (2) where the pressure rating of storage system is lower than potential trailer delivery pressure, pressure indicator (3), a manual vent (4) and a storage isolation valve (5).

The hydrogen then enters a pressure reducing station consisting of isolation valves (6) and a pressure regulator (7). This may be a duplicate system, as shown, in order to facilitate maintenance.

A relief valve (8) shall be provided downstream of the pressure reducing station to protect the consumer line and equipment.

A pressure indicator (9) should be provided to indicate pressure in the consumer line.

A non-return valve (10) shall be provided to prevent back flow from the consumer process. The hydrogen then enters the pipeline to the consumer system.

During the recharging operation, hydrogen is fed from the mobile trailer via a flexible hose into the fill connection (11).

A non-return valve (12) shall be provided to prevent storage discharge in the event of a hose failure. This may be incorporated in the fill connection.

A filter (13) may be provided as shown, alternatively filters may be incorporated in the pressure regulators (7) to protect them from solid particles.

A vent valve (14) shall be provided to allow purging of the system, from trailer to inlet isolation valve (15), so that air is prevented from entering the storage system.

The fill line may either be connected directly to the storage vessel(s) / manifold as shown or may be connected to the mainline between valves (5) and (6).

10.2 Operating instructions

10.2.1 Consumer supply

During the commissioning of the installation, the regulator(s) (7) are set to deliver to the consumer, on demand, hydrogen gas at the required pressure. This pressure is indicated by pressure indicator (9).

Dual storage and regulating systems, may be installed for automatic changeover from depleted to full storage vessel(s).

10.2.2 Filling Instructions

Detailed operating instructions shall be prepared for each consumer station making individual reference to the valves and controls in that filling system.

The following guidelines should be used in the preparation of the detailed filling instructions:

1. Present trailer to fill point ensuring that it is secured, and anti tow-away safety procedures are implemented.
2. Connect earthing leads to trailers.
3. Connect filling hose(s).
4. Ensure valve (15) is closed and valve (14) is open, open trailer isolation valve a small amount in order to purge hose.
5. Close valve (14).
6. Leak test hose connections.
7. Fully open trailer isolation valve.
8. Open valve (15) to fill vessel(s).
9. Where trailer arrangements allow, cascade filling is typically used to effect maximum transfer of hydrogen gas to the storage container(s). In this event sequential opening and closing of additional valves, on the trailer, will be required.
10. When storage vessels have reached their charging pressure or pressure equilibrium has been reached, close main isolation valve (15) and trailer valves.

11. Vent fill line via valve (14). Disconnect fill line and earthing lead when fitted.

12. Ensure trailer is ready for movement in accordance with the anti tow-away procedures.

10.3 Additional considerations

In addition to the requirements contained elsewhere in this publication, the following shall also apply to storage installations at consumer sites.

Where the storage installation area is not under the direct control of authorised persons, it shall be contained within a secure, locked enclosure and the key held by an authorised person.

Vessels and hydrogen systems shall be identified in accordance with national or local standards.

Permanently installed vessels shall be provided with non-combustible supports on firm non-combustible foundations.

The installation should be located outside, where inside location is necessary the conditions of 4.3 shall apply. There shall be no restriction of the means of emergency egress from the installation.

The installation shall be readily accessible to delivery vehicles, but also protected from physical damage. Where multiple delivery vehicles are necessary then sufficient distance between trailers shall be provided to allow emergency egress and limit escalation of an incident from one vehicle to and adjacent vehicle.

All controls necessary for the safe transfer of hydrogen shall be clearly visible from the operator position.

11 Electrical equipment and installation

11.1 General

The installation and operation of electrical systems in hydrogen stations shall be in accordance with the regulations, standards or codes of practice of each country.

In particular ATEX Directive 2014/34/EU (see also EIGA Doc 134) shall be taken into account for this application [15, 6].

11.2 Electrical installation

The electrical installation shall be such that, under normal operation, the formation of sparks likely to cause ignition, electrical arcs, or high temperature is precluded. This may be achieved by use of one or more specialised equipment such as intrinsic safety, flame proof enclosures etc.

The type of equipment to be used is dependent on the zone classification (Zone 0, Zone 1 or Zone 2 according to ATEX Directive) [15]. Factors to be considered in determining zone classification include the:

- possibility of discharge of hydrogen in sufficient quantity to produce an explosive atmosphere;
- duration of potentially explosive atmosphere; and
- degree and effectiveness of natural ventilation (diluting the potentially explosive atmosphere).

Electrical equipment shall be earthed and be placed, if possible, in the low parts of the plant.

Where physical barriers are used to separate different classified zones, ensure adequate separation of the zones, for example seal conduits and equipment drives shafts, and ensure other potential leak paths (drains, channels etc.) are sealed. Seals should be periodically inspected and maintained.

11.3 System earthing

All systems shall be earth bonded, where necessary, and effectively earthed to give protection against the hazards of stray electrical currents, static electricity (see 10.6) and lightning protection (see 10.7), in accordance with national codes / regulations.

If the electrical equipment is located in a safe area, i.e. outside the hazard zone (see 5), normal electrical equipment can be used, for example motors.

All non-permanent components (bundle, trailer etc) shall be earthed at all times when connected to a permanent flammable gas system.

11.4 Instruction

Employees shall be trained (and receive refresher training) and instructed in the use of equipment and on the dangers of using unauthorised and / or defective electrical equipment. These instructions shall include advice on hazards, which may arise. Records shall be kept.

11.5 Inspection

An inspection shall be carried out periodically by a competent person. Records of these inspections shall be kept. Modifications shall only be carried out by competent persons and shall be recorded. Local regulations may define required inspection frequency.

11.6 Static electricity

11.6.1 Background

Static electricity is an imbalance of electric charges within or on the surface of a material. The charge remains until it is able to move away by means of an electric current or electrical discharge. Static electricity is named in contrast with current electricity, which flows through wires or other conductors and transmits energy.

A static electric charge can be created whenever two surfaces contact and rub, and at least one of the surfaces has a high resistance to electric current (and is therefore an electrical insulator).

Electrostatic charges can also occur when a gas, containing droplets or dust particles, flows past the surface of a solid, for example valve openings, hose or pipe connections.

If accumulation of electric charges is released suddenly, the resulting electric spark can be sufficiently strong to ignite hydrogen.

11.6.2 Precautions against accumulation of static charges

In order to prevent the accumulation of static charges, they shall be allowed to dissipate in a safe manner.

Provisions shall be made at all vehicle loading / unloading stations and product transfer stations for electrical bonding and grounding of the vehicle to prevent statically induced electric discharge. A separate ground cable and clamp shall be provided for each flammable gas trailer or other non-permanent component.

Every non-permanent component such as cylinders or bundles in a flammable gas system shall be grounded at all times when connected to a permanent flammable gas system.

Driving belts and pulleys of compressors, blowers etc. shall be of anti-static and fire-resistant material.

Floors, floor coverings, rubber mats, chairs, steps, etc. shall be of conductive material in order to achieve the electrostatic earthing of persons.

All employees working in hydrogen stations should wear antistatic PPE including shoes to prevent electrostatic build-up.

11.6.3 Inspection of earth resistance

To ensure that the requirements for the prevention of the build-up of static electricity on equipment are met, an inspection shall be carried out by a competent person prior to commissioning. An earth resistance measurement shall be performed, and the results shall be in line with the local guidelines.

Further inspections shall be carried out periodically. Records of these inspections shall be kept. If more restrictive local regulations exist, the facility shall comply with the local regulations.

11.7 Lightning protection

Consideration shall be given to the provision of lightning conductors in accordance with a standard such as EN 62305-3, *Protection against lightning. Physical damage to structures and life hazard* [28]. This may be required by local regulation. Electric resistance shall be designed to meet the local guidelines.

12 Fire protection

12.1 General

The essentials of fire protection are:

- minimise all potential sources of leaks;
- eliminate, as far as possible, all sources of ignition;
- timely identify sources of leaks with detectors; and
- make provision for isolation of hydrogen, means of escape and methods of controlling any fire

Smoking, fires and open flames of any kind shall be prohibited within a defined distance, for example distances defined in Table 1.

Warning notices shall be conspicuously posted in accordance with 5.3.

Due to the high flammability range of hydrogen, presence of air in pipelines shall be avoided. An effective solution is a well-designed nitrogen network, which is used after any maintenance to purge air from the system.

A risk assessment shall be conducted to determine if a fire alarm and detection system should be installed at gaseous hydrogen stations.

As hydrogen flames are difficult to detect (due to invisible flame and low radiant heat), especially in outdoor conditions, conventional flame detection may not be sufficient for fire detection. A more effective fire prevention is a detector system that is able to identify leaks (for example gas or noise detection), either in addition to or instead of a flame detection system. Design and location of detection systems can be optimised with a hazard analysis taking into consideration:

- most probable location of leaks;
- sources of hydrogen due to maloperations;
- areas where hydrogen may collect;
- staffing and personnel location; and

- based on past incidents.

The details of how the system functions shall be established considering the layout of the plant. The alarm / detection system shall be operational prior to start-up of the facility.

Shutdown controls shall be provided that can rapidly put a plant into a state where the hazard to plant personnel or to emergency personnel is minimised in the event of an emergency.

Adequate means of giving alarm, such as audible and / or visible alarms, in the event of a fire shall be provided. These should be clearly marked and suitably located. Alarms signal of detectors should be located adequately so that it can be immediately alert any personnel locally and remotely.

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

The layout of installations and buildings shall provide adequate means of escape in the case of emergency. In cases where personnel could be trapped inside compounds or buildings there shall be not less than two separate outward opening exits, remote from each other, placed in relation to the degree of hazard considered.

Emergency exits shall be kept clear at all times.

The area adjacent to any hydrogen installation should be kept free of dry vegetation and combustible matter. If weed killers are used, chemicals such as sodium chlorate, which are a potential source of fire danger, should not be selected for this purpose.

Water shall be available in adequate volume and pressure for fire protection as determined in consultation with the relevant authorities.

Maintenance or repair work shall only be carried out after the relevant parts of the plant, or area, have been checked and a Safety Work Permit has been issued by a competent person. This is particularly important where such maintenance work introduces an ignition hazard, for example welding. Consideration shall be given to the use of non-sparking tools.

12.2 Firefighting equipment

The location and quantity of firefighting equipment shall be determined based on the size of the hydrogen station, local fire regulations (where applicable) and / or in consultation with the local firefighting department.

The firefighting equipment shall be periodically inspected, and the inspection date recorded.

Personnel shall be trained in the operation of the equipment provided.

12.3 Action in event of fire

Hydrogen fires from high-pressure systems often originate at the point of discharge and the flame will have the characteristic of a torch or jet. Such fires are extremely difficult to extinguish.

The most effective way to fight a hydrogen fire is to shut off the source of hydrogen supply, provided this can be done safely.

Where hydrogen cannot be isolated, hydrogen fires should not be extinguished whilst the flow of leaking hydrogen is continuing, because of the danger of creating an explosion hazard more serious than the fire itself. Surrounding equipment, when necessary, shall be cooled with water jets or sprays during the fire.

Hydrogen flames are almost invisible and have low radiant heat. Hydrogen leaks (and possible fire locations) can be evident from noise. A fire may only be evident from scorching / discolouring of surrounding material or only become visible when dark. Suspected hydrogen fires should not be approached before isolating supply. If it is necessary to approach a suspected hydrogen fire, additional measures shall be used to detect a possible flame for example, a flammable material such as paper or cloth affixed to a rod or an infrared temperature detector.

The following are guidelines, which should be used for formulating emergency procedures:

- raise the alarm;
- evacuate all persons from the danger area, except those necessary to deal with the emergency;
- summon help and firefighting services;
- wherever possible, and it is safe to do so, turn off valves, preferably remotely if available, to cut off the source of hydrogen supply; and
- always approach any fire from the upwind direction.

CAUTION *Never attempt to fight a fire if it is not safe to do so.*

13 Personnel

13.1 Personal protective equipment

Personal protective equipment (PPE) shall be selected based on the risks assessed with operation of the equipment, see EIGA Doc 136, *Selection of Personal Protective Equipment* [29].

When personnel are involved in hydrogen operation, flame-resistant and anti-static clothing shall be worn as well as conductive footwear, to avoid the build-up of static electricity.

13.2 Personnel training

All personnel engaged in the operation and / or maintenance of hydrogen stations / systems shall have received training suitable for the work on which they are engaged. Competency of training shall be assessed and recorded. See EIGA Doc 23, *Safety Training of Employees*, for more information [30].

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

Training shall include, but is not limited to:

- potential hazards of hydrogen;
- site safety regulations;
- emergency procedures;
- use of firefighting equipment; and
- use of protective clothing/apparatus including breathing sets where appropriate.

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.

14 Commissioning

Before any commissioning activity commences, the system shall be inspected by competent person(s) to verify that the construction and equipment conforms with the design drawings and schedules and a report issued to this effect. Particular attention shall be paid to inspection and checking of safety / pressure relief devices.

14.1 Testing

14.1.1 Pressure testing

A pressure test shall be carried out after manufacturing in accordance with national, international or company codes such as PED [3]. Means of pressure indication suitable for the test pressure shall be installed before the test. Precautions shall be taken to prevent excessive pressure in the system during the test. Following any hydraulic test, the system / equipment shall be drained and thoroughly dried out and checked. Local regulation may require periodic pressure testing after putting into service.

Where a pneumatic test is specified, dry nitrogen is the preferred to air as the test medium and non-destructive testing, for example X-ray in accordance with the design code, shall be performed in advance. The test pressure shall not exceed 1.1 times the design pressure. The pressure in the system shall be increased gradually up to the test pressure. Any defects found during the test shall be rectified in an approved manner.

Testing shall be repeated until satisfactory results are obtained.

Pressure tests shall be witnessed by responsible persons and suitable test certificates, signed and issued. Such certificates shall be kept for future reference.

Instruments, gauges, etc. may be removed during the pressure testing and shall be re-fitted when test is complete. Ensure any relief valves removed for pressure test are replaced.

14.1.2 Leak testing

Leak testing normally occurs at the same time as pressure testing by holding pressure for a stated period of time and checking for leaks (for example with leak detection fluid, see EIGA Doc 78, Leak Detection Fluids with Gas Cylinder Packages). A leak test is normally performed using the same test medium as the pressure test at a lower pressure.

However, due to its molecular size, a leak test with nitrogen may not be sufficient to ensure leak tightness with hydrogen. Two options are available:

- leak test with helium (typically nitrogen / helium mixture) combined with helium leak detection or
- test with hydrogen after leak test with nitrogen, initially test at low pressure and then at increasing pressures, observing for leaks at each point.

14.2 Purging

Following the pressure test and prior to the introduction of hydrogen into any part of the system, oxygen shall be removed from the system to a safe level. Refer to 6.2 for avoidance of cross contamination of purge systems.

This can be achieved by evacuation, purging or pressurising and venting cycles with an inert gas, typically nitrogen, and shall be followed by a check to ensure that any residual oxygen is less than 1 %. If carbon dioxide is used as purge gas, the potential generation of dry ice and static electricity shall be considered. Where detectors are used to measure the oxygen content, they shall be capable of working in an inert atmosphere.

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.

14.3 Start-up

When the above procedures have been satisfactorily completed and all controls and safety devices have been checked, the system is ready for the introduction of hydrogen in accordance with the operating instructions.

When the system is at operating pressure, a further leak test shall be carried out on all joints to ensure tightness under hydrogen conditions. Approved leak detection fluids shall be used, for more information see EIGA Doc 78, *Leak Detection Fluids with Gas Cylinder Packages* [31].

14.4 Operation

Detailed operating instructions containing all necessary technical information in clear form shall be prepared for each system (see 6.2, 7.2, 8.2 and 9.2). These instructions shall be used in the training programme and shall be available to the relevant operating personnel.

Operating personnel shall wear suitable clothing (see 12.1) and where necessary protective equipment.

15 Maintenance and repairs

A systematic approach to the maintenance of hydrogen systems is necessary to ensure safe and correct operation.

A nitrogen network may be used as a safety system in case of failure of electrical power or automated plant control, or in case of fire. This can be achieved by using fail safe pneumatic valves actuated by nitrogen.

Maintenance / repairs procedures should follow normal sound engineering practice, with additional precautions relating to hazard zones. Attention shall be paid to ensure that systems are adequately depressurised, isolated and purged, before any work is undertaken and a Safety Work Permit is issued (see 5.2). The isolation method shall be selected based on a risk analysis considering all aspects of the maintenance, for example confined space, open air, valve leakage etc. Isolation methods include, for example, double block and bleed, physical disconnection etc.

Hydrogen analysis shall be performed, when necessary, using an analyser that is capable of measuring the hydrogen concentration in an inert atmosphere and has been calibrated using the gas used for purging.

NOTE Hydrogen sensors relying on the reaction of hydrogen with oxygen shall not be used for this analysis.

Detailed maintenance programmes should be prepared for each system, making individual reference to items of equipment in the system. The following guidelines may be used.

15.1 Documentation

A documentation system should be set up to include the following information and taking into account the relevant requirements of ATEX Directive 1999/92/EC (see also EIGA Doc 134), including (but not limited to) [5, 6]:

- flowsheets;
- vessel dossiers;
- pressure test certificates;

- operating instructions;
- equipment manufacturers maintenance instructions;
- equipment drawings;
- piping drawings (including any modifications);
- material schedules;
- modification details and approvals; and
- list of recommended spare parts.

Documentation shall be retained for the lifetime of the equipment. Equipment design information should be retained for future reference.

15.2 Records

A suitable system for recording the frequency and extent of all maintenance and periodic tests shall be provided. This should include a means of recording defective or suspect equipment to ensure that prompt and correct action is taken.

Where modifications are made to any part of the system, or to individual items of equipment, these shall be subject to a management of change system, see EIGA Doc 51, *Management of Change* [32].

15.3 Periodic inspection

Periodic inspections shall be established detailing inspections, maintenance tasks and their frequency. The following shall be included as key items:

- periodic inspection
  - Pressure retest of vessels and piping systems:

    Some European countries permit the replacing of the hydraulic test for pressure vessels by an Acoustic Emission Test (AET) and follow up crack detection ultrasonic test (UT) performed at a specified pressure for example between 1.1 to 1.2 times the normal working pressure, but not exceeding 1.1 time design pressure. For more information on cylinder AET see ISO 16148, *Gas cylinders — Refillable seamless steel gas cylinders and tubes — Acoustic emission examination (AT) and follow-up ultrasonic examination (UT) for periodic inspection and testing* [33].
  - Inner inspection of vessels:

    The inner inspection of the vessels shall always be accompanied by or done as a crack detection test (magnetic particle [MP] from the inside or UT done from the outside) of the welds (100% of longitudinal and 100% of tee welds between longitudinal and circumferential welds) to ensure the integrity of the vessel.

    NOTE Some European countries permit the replacing of the statutory internal inspection test for pressure vessels by an ultrasonic crack detection test (UT) of the welds (performed from the outside of the vessel and with the same specification as specified in the design code for new vessels). In this case entering of the vessel can be avoided.
- system checks of leakage;
- safety shut-down system functional check;

- pressure relief device testing;
- control and monitoring equipment testing;
- filter checks;
- electrical system / earthing integrity checks;
- compliance of equipment with ATEX zone requirements;

  NOTE This may be mandatory according to local regulation.

- compressor maintenance;
- flexible hoses (see 4.8);
- painting;
- notices; and
- pipeline identification.

Some inspections listed above are in addition to any legal requirements.

For further information, see EIGA Doc 190, *Plant Integrity Management* [34].

16 References

Unless otherwise specified, the latest edition shall apply.

[1] ISO 19880-1, *Gaseous hydrogen — Fuelling stations — Part 1: General requirements*, www.iso.org.

[2] TUV Code of practice / Guideline 514, *Requirements for hydrogen fueling stations*, www.vdtuev.de.

[3] Pressure Equipment Directive (2014/68/EU), www.europa.eu.

[4] Transportable Pressure Equipment Directive (2010/35/EU), www.europa.eu

[5] EU Directive 1999/92/EC *on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres*, www.europa.eu.

[6] EIGA Doc 134, *Potentially Explosive Atmospheres EU Directive 1999/92/EC*, www.eiga.eu.

[7] NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, www.nfpa.org.

[8] EN14491, *Dust explosion venting protective systems*, www.cen.eu.

[9] ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*, www.ashrae.org.

[10] BS 5925, *Code of Practice for Ventilation Principles and Designing for Natural Ventilation*, www.bsigroup.com.

[11] API RP 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*, www.apiwebstore.org.

[12] API RP 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2.* www.apiwebstore.org.

[13] EN 13480, *Metallic industrial piping*, www.cen.eu.

[14] ASME B31.3, *Process Piping*, www.asme.org.

[15] ATEX Directive (2014/34/EU), www.europa.eu.

[16] EIGA Doc 210, *Hydrogen Pressure Swing Adsorber (PSA) Mechanical Integrity Requirements*, www.eiga.eu.

[17] ISO 13849-1, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*, www.iso.org.

[18] EN 61511, *Functional safety – Safety instrumented systems for the process industry sector*, www.cen.eu.

[19] EN 61508 series of standards on *Functional safety*www.cen.eu.

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

[21] EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites*, www.eiga.eu.

[22] EIGA Doc 187 *Guideline for the Location of Occupied Buildings in Industrial Gas Plants*, www.eiga.eu.

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

[24] EIGA Doc 238, *Prevention of Plant Instrument and Utility Gas System Cross Contamination*, www.eiga.eu.

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

[26] EIGA Doc 236, *Best Operations Practices for Filling Plants*, www.eiga.eu.

[27] EIGA Doc 63, *Prevention of Tow-Away Incidents*, www.eiga.eu.

[28] EN 62305-3, *Protection against lightning. Physical damage to structures and life hazard*, www.cen.eu.

[29] EIGA Doc 136, *Selection of Personal Protective Equipment*, www.eiga.eu.

[30] EIGA Doc 23, *Safety Training of Employees*, www.eiga.eu.

[31] EIGA Doc 78, *Leak Detection Fluids with Gas Cylinder Packages*, www.eiga.eu

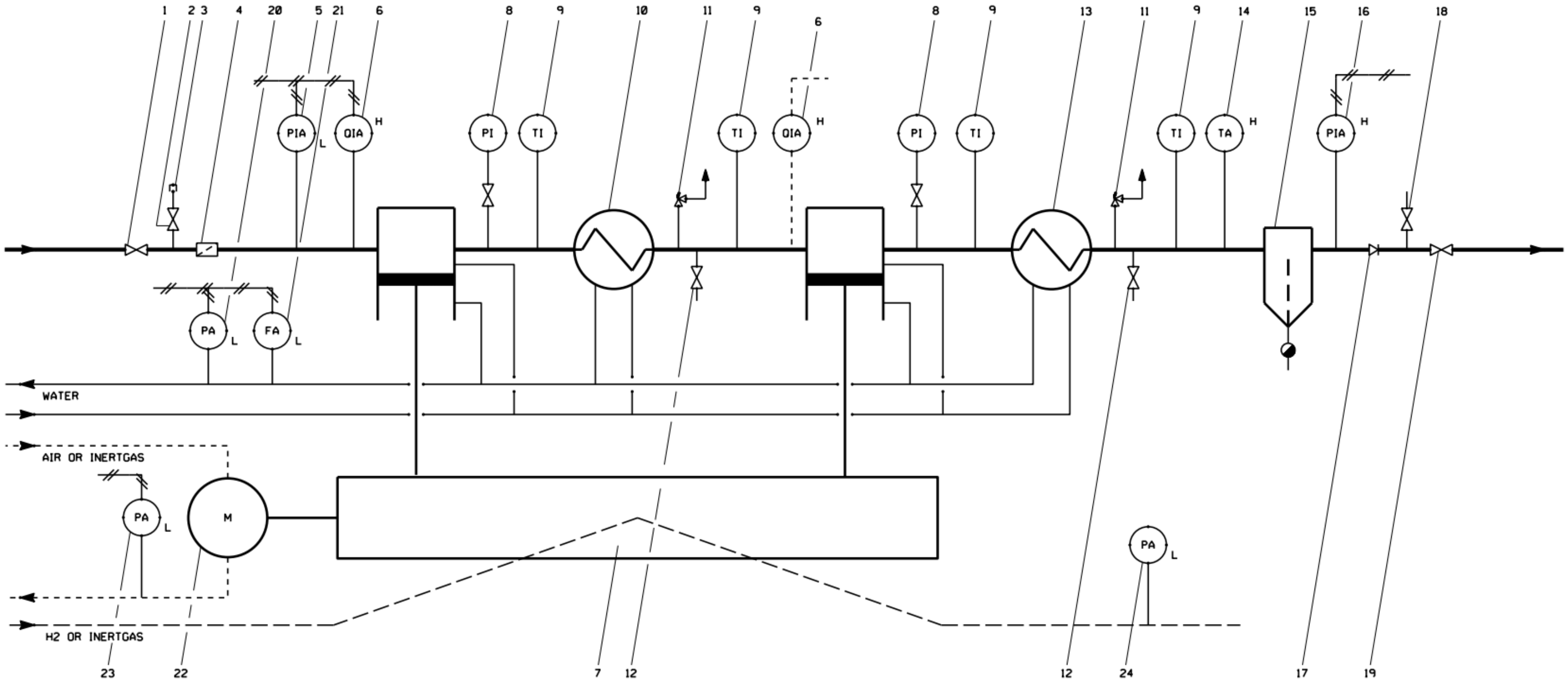
[32] EIGA Doc 51, *Management of Change*, www.eiga.eu.

[33] ISO 16148, *Gas cylinders — Refillable seamless steel gas cylinders and tubes — Acoustic emission examination (AT) and follow-up ultrasonic examination (UT) for periodic inspection and testing*, www.iso.org.

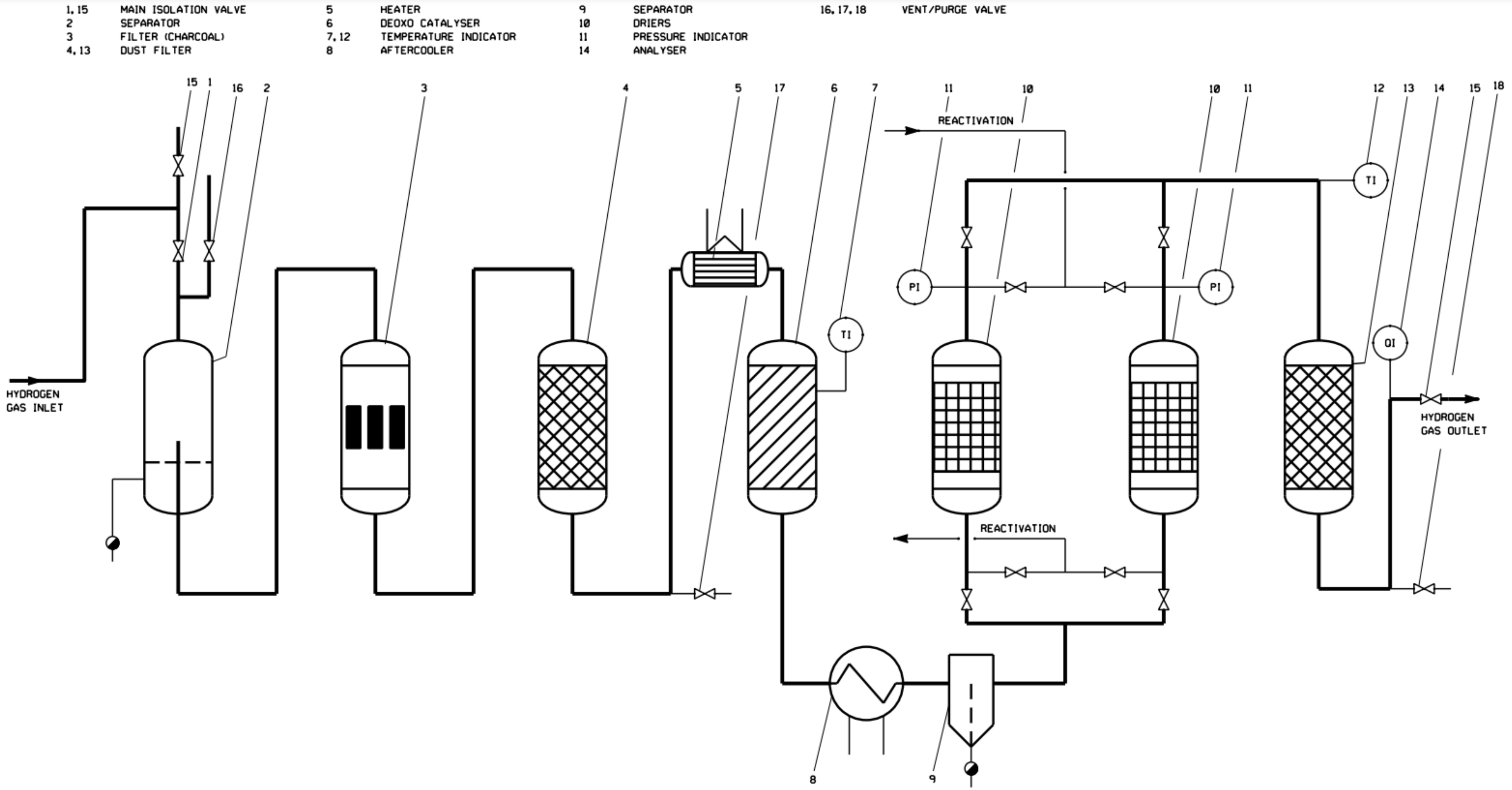
[34] EIGA Doc 190, *Plant Integrity Management*, www.eiga.eu.

Appendix 1: Flowsheet of a typical hydrogen compressing system

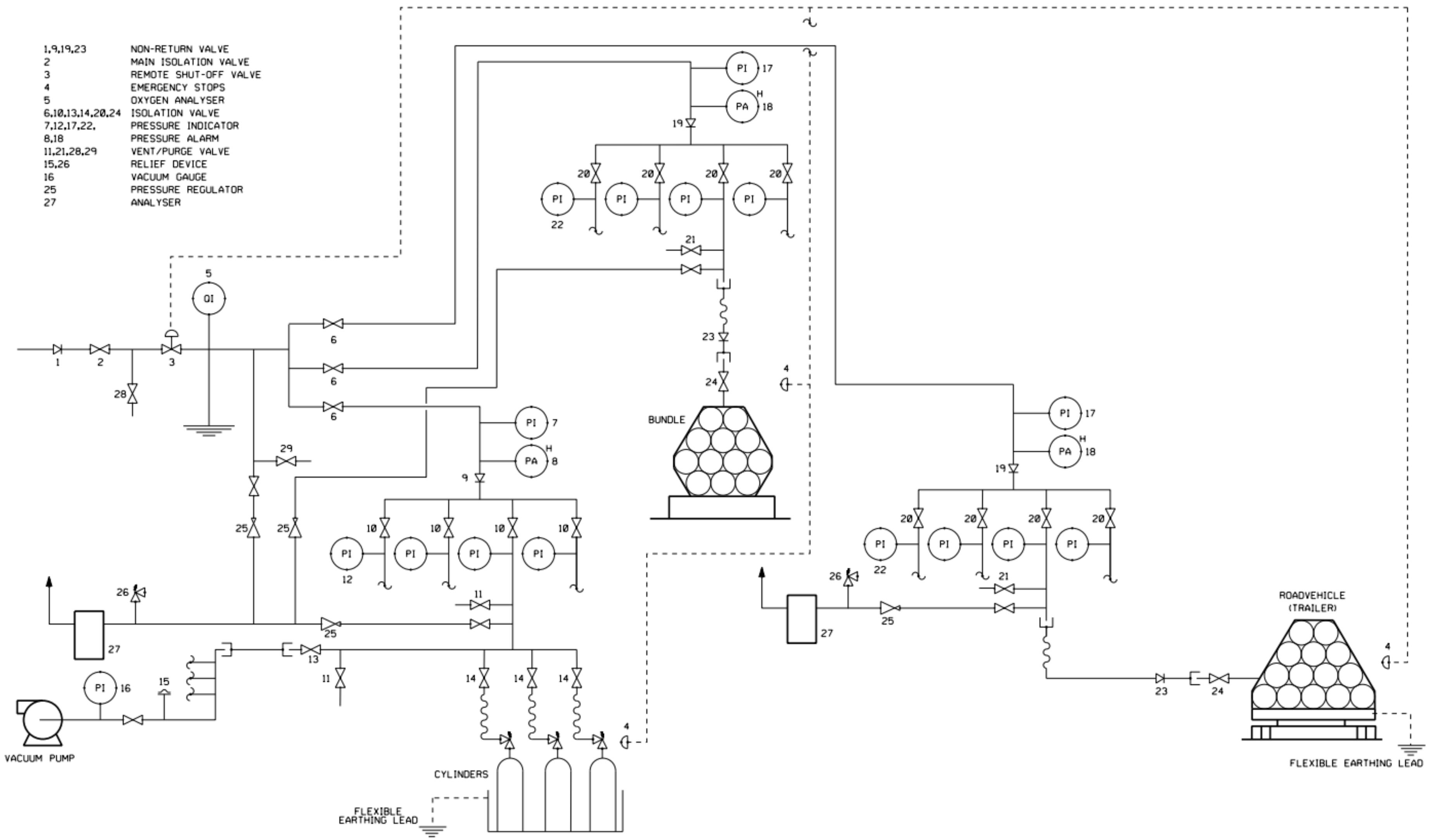
1, 19	MAIN ISOLATION VALVE
2, 18	PURGE VALVE
3	SEALING DEVICE
4	FILTER
5, 16	PRESSURE INDICATOR/ALARM
6	ANALYSER
7	COMPRESSOR
8	PRESSURE INDICATOR
9	TEMPERATURE INDICATOR
10	INTERCOOLER
11	RELIEF VALVE
12	DRAIN VALVE
13	AFTERCOOLER
14	TEMPERATURE ALARM
15	SEPARATOR
17	NON-RETURN VALVE
20	PRESSURE ALARM
21	FLOW ALARM
22	ELECTRIC MOTOR
23, 24	PRESSURE / FLOW ALARM



Appendix 2: Flowsheet of a typical hydrogen purification system



Appendix 3: Flowsheet of a typical hydrogen filling system



Appendix 4: Flowsheet of a typical storage installation at consumer sites