



STANDARD FOR HYDROGEN PIPING SYSTEMS AT USER LOCATIONS

AIGA 087/14

Based on CGA G-5.4–2012
Fifth Edition

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1 Introduction

This standard is one of a series prepared by the Compressed Gas Association, Inc. (CGA) to provide information on the transportation, handling, and storage of hydrogen.

The industrial gases companies have engaged through the International Harmonization Council (IHC), comprised of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA), in a process of developing harmonized safety practices and this publication is one of them.

Furthermore, to the extent that they exist, national laws supersede the suggested practices listed in this publication. It should not be assumed that every local standard, test, safety procedure, or method is contained in these recommendations or that abnormal or unusual circumstances may not warrant additional requirements or procedures.

2 Scope

This standard describes the specifications and general principles recommended for piping systems for gaseous (Type I) or liquid (Type II) hydrogen. The standard addresses both low and high pressure hydrogen piping systems onsite from the point where hydrogen enters the distribution piping (the battery limits of the hydrogen storage system) to the point of use. For the purposes of this standard, high pressure is defined as gaseous hydrogen at service pressures equal to or greater than 3000 psig (20 680 kPa).^{1,2}

The information in this standard is general in nature and is intended for designers, fabricators, installers, users, and maintainers of hydrogen piping systems as well as for safety personnel, fire departments, building inspectors, and emergency personnel. Basic information on the properties, storage, and handling of hydrogen can be found in CGA G-5, *Hydrogen*; CGA G-5.3, *Commodity Specification for Hydrogen*; National Fire Protection Association (NFPA) 52, *Vehicular Gaseous Fuel Systems Code*; NFPA 55, *Compressed Gases and Cryogenic Fluids Code*; and the CGA *Handbook of Compressed Gases* [2, 3, 4, 5, 6].

3 Piping system criteria

3.1 Design criteria

Hydrogen piping systems should be designed in accordance with the American Society of Mechanical Engineers (ASME) B31.12, *Hydrogen Piping and Pipelines*, other applicable codes and regulations, and the special requirements for hydrogen service [7]. Single wall piping is used for gaseous hydrogen service and for liquid hydrogen service when thermal insulation is not required. Vacuum-insulated piping is recommended for liquid hydrogen service.

Piping systems shall be designed to take into consideration the following:

- a) fully depressurize the system for maintenance (for example, to avoid pressure trapped behind check valves);
- b) isolate the system for maintenance, (for example, double block and bleed, positive isolation); and
- c) purge the system with an inert gas before maintenance and with hydrogen after maintenance.

Piping, tubing, fittings, valves, accessory equipment, gaskets, and thread sealants shall be suitable for hydrogen service at the pressures and temperatures encountered and shall maintain their integrity under elevated temperatures during fire conditions (see 3.2.2). Selection of piping joints shall consider the potential for leaks, mechanical strength, material, and fire safety acceptability. The piping and accessory equipment shall be suitably cleaned for the level of service for which the hydrogen is intended.

¹ kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Metric Practice Guide for the Compressed Gas Industry* [1].

² References are shown by bracketed numbers and are listed in order of appearance in the reference section.

All electrical equipment and electrical grounding apparatus shall comply with NFPA 70, *National Electrical Code*[®], or Canadian Standards Association (CSA) C22.1, *Canadian Electrical Code*, Part I, as applicable [8, 9]. The piping system shall be bonded and grounded to dissipate static electricity.

3.2 Piping materials

3.2.1 Metal

Material specifications and thickness requirements for piping and tubing shall conform to ASME B31.12 [7]. Piping, tubing, valves, and fittings for operating temperatures less than -20 °F (-29 °C) shall be fabricated from materials listed in ASME B31.12 for the operating temperature or shall meet impact test requirements when tested at the minimum operating temperature the system is subjected to when in service [7].

Many engineering alloys experience a degradation of properties when used in high pressure hydrogen service. The generic term for this is hydrogen embrittlement. The effects can range from a reduction in tensile strength and ductility to a marked increase in the rate of fatigue crack growth. Elevated temperatures also can be problematic, promoting hydrogen attack in carbon and low-alloy steels. AIGA 033, *Hydrogen Pipeline Systems*, provides a more detailed discussion of hydrogen embrittlement and attack [10].

Austenitic (300 series) stainless steels meeting the temperature limits of ASME B31.12 are recommended for liquid and gaseous hydrogen product piping, tubing, valves, and fittings [7]. The most stable grade is Type 316/316L. Type 316/316L is relatively immune to hydrogen embrittlement when exposed to high pressure hydrogen and is preferred over other grades such as Type 304L and Type 321. When available, austenitic stainless steels should be used in the annealed condition.

Carbon steel usually is limited to gas service at operating temperatures equal to or greater than -20 °F (-29 °C). Carbon steels meeting the temperature limits of ASME B31.12 may be used for gaseous hydrogen product piping, tubing, valves, and fittings [7]. For high pressure applications, carbon steel shall be used with caution. Carbon steels with high-carbon content and high-strength, low-alloy carbon steels are susceptible to embrittlement and crack propagation. The use of carbon or alloy steels requires control of tensile strength, heat treatment, microstructure, and surface finish as well as initial and periodic examination for inclusions and crack-like defects when in cyclic service. AIGA 033 and EIGA Doc 100/03, *Hydrogen cylinders and transport vessels*, are examples of guidelines for the allowable composition of various alloy steels for hydrogen service [10, 11].

For high temperature applications, the suitability of carbon or low-alloy steel shall be evaluated using the "Nelson charts" in American Petroleum Institute (API) RP 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants* for resistance to embrittlement [12]. Carbon steels with higher strength levels (as defined in the API RP 941 "Nelson charts"), high-carbon, and low-alloy content are more susceptible to hydrogen embrittlement, and their use should be thoroughly investigated.

Piping, tubing, valves, and fittings made of gray, ductile, or malleable cast iron shall not be used in hydrogen service.

3.2.2 Low melting point materials

Low melting point materials (for example, aluminum, copper, brass, bronze, and solders with a melting point temperature less than 1000 °F (537.8 °C)) have reduced strength at elevated temperatures. Their use should be in accordance with ASME B31.12 [7].

A system containing these materials shall be:

- suitably protected against fire exposure in accordance with NFPA 55 [5];
- located so leakage resulting from a failure does not unduly expose personnel, buildings, or structures; or
- located so leakage can be readily controlled by operation of an accessible, remotely located valve(s).

Aluminum and copper alloys are relatively immune to hydrogen embrittlement, but are not used frequently in high pressure service because of their low strength levels.

3.2.3 Plastic

Plastic piping and tubing shall not be used in hydrogen service except when used under controlled conditions for low-flow and low pressure laboratory applications and in accordance with ASME [B31.12](#) [7]. The permeability of the plastic material shall be reviewed to ensure suitability for the application.

3.2.4 Additional requirements for high pressure service

Seamless pipes and tubes are preferred. Unannealed welded pipes are susceptible to hydrogen embrittlement crack propagation (from welding flaws) at the weld and weld heat-affected zone (HAZ) and therefore are not recommended for high pressure hydrogen service.

When using flexible metal hoses, care should be taken to avoid high velocities and materials susceptible to hydrogen cracking.

3.3 System components

The preferred material for high pressure hydrogen service parts is austenitic (300 series) stainless steel. All nonmetallic materials in contact with hydrogen gas shall be reviewed for hydrogen embrittlement resistance at service conditions. Materials that are not compatible with hydrogen shall not be used.

3.3.1 Pressure relief devices

Pressure relief devices (PRDs) shall be provided in hydrogen piping systems to relieve pressures that can exceed the maximum allowable working pressure of the system. PRDs shall be included in liquid hydrogen piping to protect sections of piping where liquid or cold vapor can become trapped between valves or closures. The guidelines for PRDs for piping systems are provided in ASME [B31.12](#) [7].

PRD construction should conform to the following:

- Metal parts may be austenitic (300 series) stainless steel, carbon steel, or bronze; and
- For sizes less than 1 in (2.5 cm) nominal, either pipe thread or tube fitting inlet and outlet connections should be used. For 1 in (2.5 cm) nominal and larger, flanged inlet and outlet connections are recommended.

PRDs on liquid lines or cold gas piping should be installed with a thermal trap similar to that shown in Figure 1.

The discharge from PRDs shall be designed, installed, operated, and maintained in accordance with CGA G-5.5, Hydrogen Vent Systems [13].

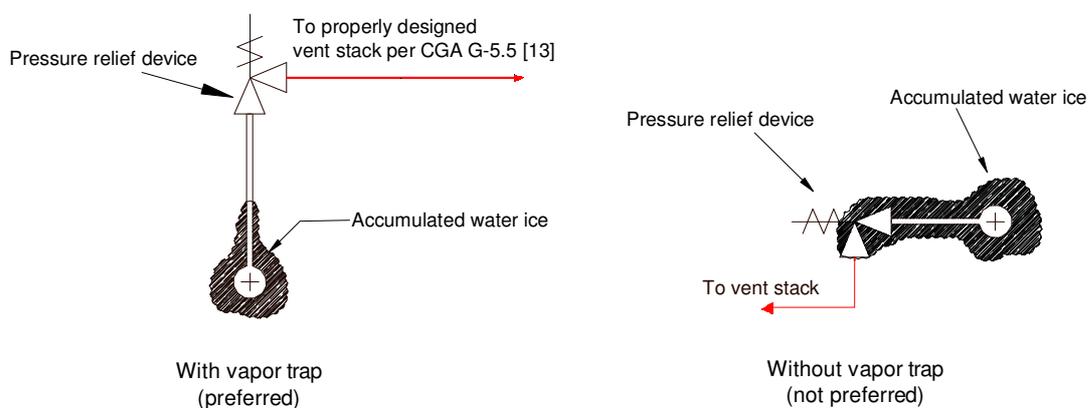


Figure 1—Typical pressure relief device installation – uninsulated cold hydrogen piping

3.3.2 Isolation valves

Isolation valves with lockout capabilities are used to isolate portions of the piping system for routine maintenance and in emergencies. An isolation valve shall be installed at an accessible location in a hydrogen pipeline so hydrogen flow can be shut off when necessary. Isolation valves shall be constructed of the materials listed in 3.2.

3.3.3 Emergency isolation valves

Emergency isolation valves (EIVs) normally are located on product lines to provide a readily accessible manual or automatic means to stop hydrogen flow in the event of an emergency. EIVs are used on systems where branch or multiple distribution lines feed different facilities. They are located outside each building to permit emergency isolation of the system. EIVs shall be capable of full closure to ensure no gas or liquid leakage. EIVs should have a metal-to-metal seat or a metal-to-metal back up of a soft-seated valve for positive shutoff. EIVs may be operated remotely or locally (at the valve) and shall have fail-close operation. Automatic EIVs may be actuated by being spring-loaded, pneumatically operated, or normally closed by electrical operation. Requirements for remote shutoff valves on liquid hydrogen tanks are given in Title 29 of the U.S. *Code of Federal Regulations* (29 CFR) Part 1910.103; NFPA 55; CSA B51; and the applicable provincial or territorial fire codes, as appropriate [15, 5, 13].

3.3.4 Excess flow valves

Excess flow valves (EFVs) for gaseous hydrogen service are self-actuated devices that shut off flow when the built-in sensing mechanism detects that a preset maximum flow rate has been reached. The EFV is used to provide an immediate hydrogen shutoff in the event of failure of the piping system or equipment. EFVs are available with either manual or automatic reset. EFV selection shall be based on the specific requirements of the equipment or facility being protected. Requirements to include EFVs in hydrogen delivery piping are found in NFPA 55 [5].

3.3.5 Check valves

Check valves prevent reverse flow, which can cause contamination. Swing-type and lift-type check valves are recommended for 1 in (2.54 cm) nominal and larger sizes. Poppet-type check valves are recommended for 7/8 in (2.22 cm) nominal and smaller sizes. Swing-type and lift-type check valve seats may be metal-to-metal or metal-to-soft material. Polytetrafluoroethylene (PTFE, commonly known as Teflon[®]) or polychlorotrifluoroethylene (PCTFE, commonly known as Kel-F[®] or Neoflon[®]) are soft seat materials often used for both warm and cold service.

3.3.6 Instrumentation

Valves, gauges, regulators, and other accessories shall be suitable for hydrogen service and for the pressures and temperatures that are encountered. Regulators should be nonventing or have vents that are piped to a safe location.

Instruments and pressure gauges shall be located to reduce hazards to personnel from leakage or failure. The use of safety glass and blow-out plugs on pressure gauges is recommended. In-line restricting devices may be used to reduce flow to gauges.

Hydrogen gas detectors may be installed to sound an alarm or activate shutdown if gas leakage is detected. Sensors should be installed at locations most likely to have an accumulation of hydrogen in the event of a leak. Sensors should be installed at or above the height of the hydrogen system. The detectors should be set to alarm at 1% hydrogen concentration (25% of the lower flammable limit) and to shut down the system at 2% hydrogen concentration (50% of the lower flammable limit). Fire detectors also should be considered in the event a hydrogen leak is ignited.

3.3.7 Gasket and sealing materials

Plastics and elastomers may be used for internal valve seats and seals. Plastics and nonmetallic materials that maintain their integrity at elevated temperatures may be used for flange and valve packing and/or gaskets.

Metallic gaskets are preferred for high pressure service. Graphite compounds also may be used with liquid hydrogen.

When plastics and elastomers are used for gasketing, packing, or other sealing elements, the design should incorporate features that minimize the release of hydrogen if the seal were to melt during a fire. These features can include metal-to-metal or fire-resistant back-up seals. Alternatively, the design can restrict flow with close clearances between metal parts or a tortuous flow path (such as stem threads).

Plastics such as PCTFE, PTFE, and polyamide (commonly known as Nylon[®]) are commonly used. Elastomers such as Buna-N (commonly known as Nitrile), chloroprene rubber (commonly known as Neoprene), fluorocarbon rubber (commonly known as Viton[®]), and other suitable compounds also may be used for hydrogen gas service depending on the service temperature. At lower temperatures, these elastomers become brittle and therefore shall not be used. Certain elastomers, especially low-durometer compounds, can fail during rapid depressurization by explosive decompression. Only virgin stock material may be used. Recycled or reprocessed material should not be used for hydrogen service.

Flanged joints on hydrogen vent piping shall have a metal-to-metal seal; a gasket of a material like graphite, that is difficult to ignite; or shall be suitably protected from a fire. Soft elastomers and plastics are not recommended.

3.3.8 Additional requirements

Piping components shall be constructed of materials compatible with hydrogen service and shall have adequate pressure and temperature ratings.

Flexible hoses constructed of nonmetallic materials shall have electrical continuity through the length of hose or shall have a bonding strap along the length of hose. Flexible hoses shall be connected with metal connectors at each end to ensure electrical continuity.

Sections of piping or equipment connected by electrically insulated gasket joints or flexible hoses shall have electrical continuity to the system ground. A bonding strap may be used if required (see NFPA 77, *Static Electricity*; NFPA 780, *Standard for the Installation of Lightning Protection Systems*; and CSA C22.1 Section 10 [16, 17, 9]).

3.4 Electrical equipment

Cabinets or enclosures containing electrical equipment or controls shall be installed in accordance with NFPA 70 [8]. See NFPA 55 and CGA H-5, *Installation Standards for Bulk Hydrogen Supply Systems* for electrical classification areas [5, 18]. The classified areas specified in NFPA 55 can be reduced or eliminated through protection techniques specified in NFPA 70 [5, 8]. One such technique is ventilation or purging of the enclosure with inert gas or air to prevent the accumulation of hydrogen. See NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, for purging requirements [19].

Electrical equipment shall be bonded and grounded in accordance with NFPA 70 Article 250 and NFPA 77 [8, 16]. Lightning protection in accordance with NFPA 780 shall be considered [17]. In Canada, CSA C22.1 applies [9].

4 Cleaning

4.1 General

Piping systems should be cleaned before being placed in hydrogen service. The cleaning procedure selected shall be suitable for the type of contaminant and shall provide the level of cleanliness required by the application. The cleaning procedure should ensure the removal of particles and noncompatible materials to avoid a chemical reaction or mechanical interference in the piping or in systems served by the piping. Effective cleaning can require removal of rust, weld spatter, scale, soil, oil, grease, or other contaminants. See ASTM A380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems* [20]. For additional information, see CGA PS-31, *Cleanliness for Proton Exchange Membranes Hydrogen Piping/Components* [21].

Internal parts of components and assemblies should be cleaned before assembly. Subassemblies should be cleaned after completion of all welding, machining, hydrostatic testing, and other mechanical work. Precautions should be taken to avoid contamination after cleaning.

4.2 Cleaning procedures

Cleaning can be accomplished by one or more of several procedures. General information on cleaning procedures is provided in the remainder of this section. More detailed cleaning information can be found in AIGA 012, *Cleaning Equipment for Oxygen Service* [22].

4.2.1 Mechanical cleaning

Mechanical cleaning can be accomplished by wire brushing, grinding, blast cleaning, or tumbling. These methods remove contaminants such as scale, slag, and weld splatter, which are not removed by steam, water, or chemicals.

After mechanical cleaning, loose particles should be removed by vacuum cleaning, blowing out with oil-free air or oil-free nitrogen, or flushing with a suitable solvent.

After cleaning and removing particles, the piping should be purged with dry, oil-free air or dry, oil-free nitrogen to remove moisture and solvent vapors.

4.2.2 Chemical cleaning

Chemical cleaning procedures use solvents, acids, caustic cleaners, or detergents to remove oxides, dirt, oil, grease, and other organic materials. Selection and use of a cleaning agent is based on the type of contaminant, compatibility with materials, and compliance with the governing agency requirements for environmental impact and toxicity. The use of water soluble cleaners requires rinsing, draining, and drying. The use of solvents shall be followed by the removal of residual liquid and purging of solvent vapor from the piping system.

Solvents are commonly used for chemical cleaning. The solvent cleaning method is accomplished either by flushing (full immersion in a bath) or by swabbing with a clean, white, lint-free cloth until no noticeable soiling of the cloth occurs.

4.3 Inspection tests for cleanliness requirements

After cleaning, the piping and components should be subjected to a visual inspection of accessible surfaces and a wipe test of inaccessible surfaces. Surfaces should be free of excessive contamination, which can cause a chemical reaction, interfere with operation of moving parts, damage critical surfaces, or reduce product purity to below acceptable limits.

4.3.1 Direct visual inspection

A visual internal inspection should be performed under white light or strong daylight conditions to detect the presence of contaminants on surfaces. A surface should be re-cleaned if the following contaminants are detected:

- moisture;
- loose corrosion, scale, or weld spatter;
- dirt, filings, chips, or particles; or
- organic matter such as grease, oil, paint, marker, crayon, and ink.

The following contaminants are not considered objectionable and may remain in the piping if allowed by the system design specifications:

- tightly adherent scale or weld spatter;

- moderate rust film;
- stains or discoloration; and
- certain adherent films used for rust prevention, as approved by the owner.

A visual external inspection should be performed on uninsulated liquid hydrogen and cold gaseous hydrogen piping because of the potential for condensing liquid air on these surfaces. A surface should be cleaned of organic contaminants such as grease, oil, paint, marker, crayon, and ink.

4.3.2 Wipe test

Wipe tests are an aid to visual inspections and are used to detect contaminants on surfaces that are not accessible for visual inspection. The test surface should be rubbed lightly with clean, white paper or a lint-free cloth, which is then examined under white light. There should be no contaminants and there should be no appreciable discoloration of the wiping media (see 4.3.1).

5 Installation

5.1 General

All piping systems should be installed in accordance with ASME B31.12 and local, state, and national codes [7]. When installing pipe anchors and supports, consideration shall be given to thermal expansion and contraction of the piping. Piping should be routed as far away as practical from other lines and process equipment containing fluids that are hazardous in a hydrogen environment.

Typical gaseous hydrogen piping systems are shown in Figure 2. In Canada, piping systems and fittings for stationary storage systems shall be approved by the appropriate provincial or territorial pressure vessels authority and carry a Canadian registration number.

5.1.1 Joints

For leak tightness and fire safety, joints in piping and tubing should be welded. Joints may also be threaded, flanged, brazed, or made with a suitable mechanical fitting. Soft solder joints are not permitted. All leaks that can be detected by an approved leak detection method should be repaired as soon as possible. For outdoor systems or indoor systems with a minimum of 6 air changes per hour, repairs are not urgent.

To reduce the potential for leakage, threaded joints may be seal-welded or backbrazed.

For fire safety, flanged joints on hydrogen piping shall be suitably protected. They shall have a metal-to-metal seal or a gasket made from a material that is difficult to ignite such as graphite.

5.1.2 Welded connections in high pressure service

Welded connections are the recommended method for joining pipe/tube, valves, and equipment except when welding would negatively affect the parent material (such as high pressure cold-worked tubing) or when the frequency of internal inspection, maintenance of valves and equipment, or initial blow out of the piping system warrants the use of other mechanical connections.

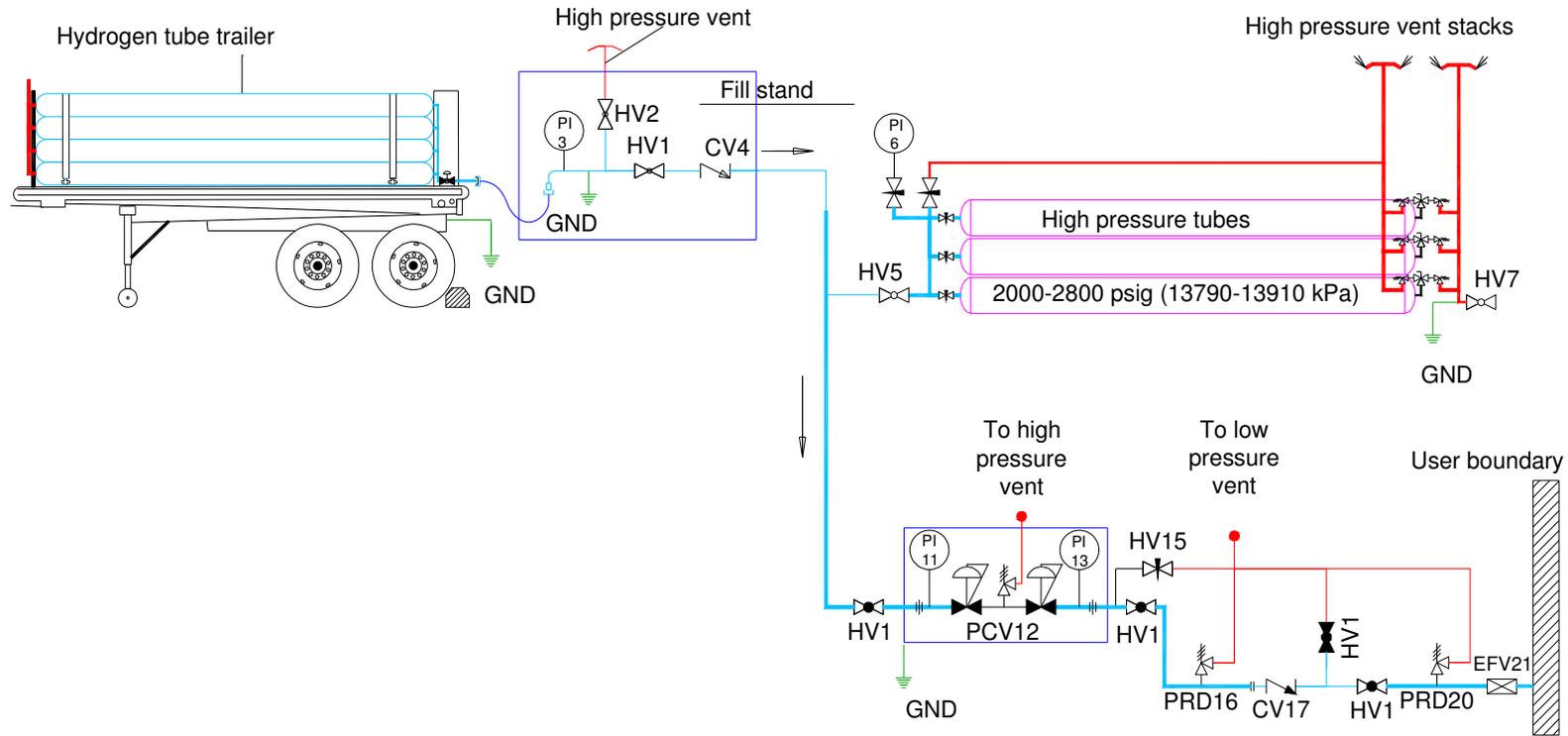
Welding is critical in hydrogen service because of the effect of hydrogen on the weld and weld HAZ. The welding process should produce defect-free welds and weld HAZ that match the mechanical and toughness properties of pipe material being joined. Proper welding procedures should be developed to achieve the desired weld properties for hydrogen service.

Systems that operate at design pressures greater than those allowed by class 2500 flanges as defined by ASME B16.5, *Pipe Flanges and Flanged Fittings*, may alternatively use the welded high pressure piping rules in Chapter IX of ASME B31.3, *Process Piping* [23, 24].

The use of ASME B31.3 Chapter IX is optional and is at the discretion of the system owner [24]. This would require the designer to qualify all welding procedures including such items as: impact tests; hardness checks;

100% radiographic inspection; and a prohibition on the use of backing rings, socket welds, or unreinforced branch connections [7].

Ten percent of piping/tubing weld joints shall have a hardness check after fabrication/installation. Maximum allowable hardness is limited to 22 Rockwell C Hardness (HRC). If hardness exceeds this value, the weld joint shall be heat-treated (annealed).



Item	Description	Function	Item	Description	Function
HV1	Fill valve	Allows products to fill system	PI13	Pressure gauge	Indicates user supply pressure
HV2	Vent valve	Purges fill hose and discharges to high pressure vent	HV14	Isolation valve	Regulator manifold exit valve
PI3	Pressure gauge	Indicates hose pressure	HV15	Purge valve	Purge valve to vent gas pressure
CV4	Check valve	Prevents reverse flow (see 3.3.5)	PRD16	Relief device	User line safety relief device
HV5	Isolation valve	Isolates high pressure cylinders from system	CV17	Check valve	Backflow prevention device from user
PI6	Pressure gauge	Indicates system pressure	HV18	Purge valve	System purge or vent valve
HV7	Drain valve	Vent stack water drain (capped when not in use)	HV19	Isolation valve	User master shutoff valve
HV10	Isolation valve	Regulation manifold supply valve	PRD19	Relief valve	User line relief valve
PI11	Pressure gauge	Supply pressure indication	EFV20	Emergency valve	User excess flow valve (see 5.5)
PCV12	Regulating valve	Regulates supply pressure to user	GND	Ground	System purge or vent valve

Figure 2—Typical gaseous hydrogen piping systems

5.1.3 Brazed connections

Brazed connections shall use a brazing alloy with a melting point greater than 1000 °F (538 °C) and shall be safeguarded for fire protection in accordance with ASME B31.12, Appendix G [7].

5.1.4 Fittings

Mechanical fittings such as cone-and-thread; O-ring seal; face seal; compression fittings; threaded, flanged connections; proprietary; and special joints may be used within the guidelines and limitation of ASME B31.12 [7]. In selecting and applying a fitting, the designer shall consider the possible adverse effects on the joint due to operating conditions such as high pressure, cyclic loading, vibration, shock, and thermal expansion and contraction. Usage of a particular fitting shall be in conformance with the fittings manufacturer's recommendations.

5.2 Aboveground installation

5.2.1 Mechanical joints

In a multi-line pipe rack, mechanical joints in the hydrogen lines should not be located close to the mechanical joints in other fluid lines. Hazardous mixtures can result if simultaneous leaking or failure occurs. Piping should not be exposed to external forces that can cause bowing or bending, which can lead to dangerous conditions or failure. The cleanliness of the piping system and its components shall be maintained throughout the installation.

For requirements of electrical continuity of joints, see 5.5.

5.2.2 Safety features

Means shall be provided to reduce exposure of personnel to uninsulated liquid hydrogen piping and to prevent any condensed liquefied air from contacting piping, structural members, and surfaces not suitable for cryogenic temperatures. To prevent the condensation of air and subsequent oxygen enrichment within the insulation, the insulation shall be either vacuum jacketing or noncombustible material with a vapor-tight outer covering. The outside shield also shall prevent attrition of the insulation due to normal operating conditions.

Uninsulated piping and equipment that can be at the temperature of liquid hydrogen shall not be installed above asphalt surfaces or other combustible materials that are not compatible with the oxygen-enriched liquid resulting from cooling and condensing air. Drip pans may be installed under uninsulated piping and equipment to collect and vaporize this condensed liquid.

Where hydrogen piping is run in the same duct or open trench used for electrical cables, all joints in the pipe in the ducted or trenched section shall be welded. A minimum separation of 2 in (5.1 cm) from electrical cables and any other pipelines shall be maintained. The hydrogen pipeline should be installed above the cables.

5.3 Underground installation

5.3.1 Welded construction requirements

Underground hydrogen piping shall be protected against corrosion. Underground liquid hydrogen piping shall be protected through a corrosion-resistant outer pipe, preferably a vacuum insulation jacket.

Because of the leak potential, all underground hydrogen piping shall be welded construction with no valves, mechanical joints, or connections installed underground. Underground piping shall be buried to a depth in accordance with state and local codes for protection from frost, surface loads, and shifting due to unstable soil. A protective casing shall be provided for pipe routed under railroad tracks and may be required by local codes under roadways or wherever the piping can be subject to physical damage. The casing shall be open at both ends or adequately vented.

5.3.2 Soil tests

Soil shall be tested for corrosiveness to determine the necessity for cathodic protection and/or a corrosion protective coating. Underground piping having cathodic protection should be connected to aboveground piping through an electrically insulated joint to isolate the cathodic protection system. For detailed information on corrosion protection see the National Association of Corrosion Engineers (NACE) SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* [25].

5.4 Electrical installation

Electrical equipment and wiring shall be of the type specified by NFPA 70 and shall be installed in accordance with NFPA 70 [8].

NFPA 70 classifies hydrogen as a Class I, Group B material. Within this classification, there are two divisions of electrically classified hazardous areas, Division 1 and Division 2 [8]. The extent of the electrically classified areas can be found in CGA H-5, NFPA 55, NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, and Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, or CSA C22.1, whichever is more appropriate for the installation [18, 5, 26, 9].

Hydrogen gas can pass through leaks in conduit seals and cables and through the inside passages of stranded wire conductors. Interface connections between the hydrogen and electrical systems shall have additional devices or means to prevent passage of hydrogen gas beyond the additional device. See NFPA 70 Article 501-5(f)(3) or CSA C22.1 Section 18 [8, 9].

5.5 Electrical grounding and bonding

The equipment and piping shall be bonded and grounded to drain static electricity and to carry electrical fault currents to earth ground. This prevents the release of electric sparks, which can ignite hydrogen leaks.

All metallic parts of the installation including the piping, supports, and metallic items within a classified hazardous area shall be at ground potential.

All mechanical joints shall have electrical continuity through the joint or shall be connected with a bonding strap. See NFPA 77, NFPA 780, or CSA C22.1, as appropriate, for information on bonding for static electricity and lightning protection [16, 17, 9].

Vessels and piping in hydrogen systems shall be grounded by conductors with low electrical resistance. These conductors should be attached to ground rods driven in the ground deep enough to penetrate to moist soil. Where soils are light and porous, a grid of wires may be used in conjunction with the ground rods in accordance with NFPA 70 [8]. Buried ground plates may be used in shallow soil conditions. See NFPA 70 Article 250 or CSA C22.1 Section 10 for specifications on grounding electrode systems [8, 9]. Floors, floor coverings, rubber mats, chairs, steps, etc. should be made from conductive material to electrically ground personnel. Because most synthetic materials readily generate static charges, work clothes made of cotton or fire-resistant fabric should be worn.

6 System startup

6.1 Inspection

The grounding system shall be inspected and the electrical resistance to ground measured to ensure compliance with NFPA 70, CSA C22.1, or other more stringent requirements [8, 9].

Piping components installed in the system should be reviewed with design specifications to ensure the components have proper characteristics such as size, material, pressure rating, orientation, correct sequence, and proper identification.

6.2 Testing

Before initial operation and after maintenance, the piping system shall be tested to show structural integrity and leak tightness in accordance with the applicable sections of ASME B31.12 [7]. The piping may be hydrostatically or pneumatically tested. Pneumatic testing with a mixture of at least 10% helium in an inert gas

or 5% to 10% hydrogen in an inert gas. Leak detection on hydrogen systems requires a small molecule gas to be effective. ASME B31.12 contains a guide for the preparation of the required test records [7].

6.3 Purging

Systems shall be purged with an inert gas to eliminate oxygen/air before hydrogen is admitted. Residual oxygen shall be reduced to less than 1%. Purging can be accomplished by sweep purging, evacuation, or repeated pressurizing and venting cycles. Vent and purge connections shall be provided to facilitate purging of the system.

After purging, the inert gas shall be displaced with hydrogen to reduce the inert gas impurities to acceptable levels. A testing and purging procedure should be prepared for each installation to ensure that all parts are completely and safely purged and tested and that personnel are protected against asphyxiation hazards associated with inert gases.

6.4 Operation

The system shall be charged with hydrogen and leak checked at operating pressure and temperature before being put into service. The system should be brought to service pressure and temperature gradually while the operating characteristics are monitored.

In the United States, the methods used to identify valves and piping by color coding, painting, or labeling shall be in accordance with 29 CFR or ASME A13.1, *Scheme for the Identification of Piping Systems* [15, 27]. In Canada, the requirements under the *Workplace Hazardous Materials Information System (WHMIS)* regulations of the applicable province or territory apply [28].

Only authorized and trained personnel shall be allowed to operate a hydrogen system. Legible instructions shall be maintained at operator locations, shall include emergency procedures, and shall identify components to be operated in an emergency.

7 Maintenance and repair

7.1 Inspection

The system and components should be regularly inspected. This should include inspection for physical damage, leak tightness, ground system integrity, vent system operation, equipment identification, warning signs, operator information and training records, scheduled maintenance and retest records, alarm operation, and all other safety related features.

7.2 Grounding system

The grounding system should be visually inspected at least annually and the electrical resistance to ground measured every 1 to 3 years. The actual time interval should be consistent with other inspection and maintenance periods.

7.3 Maintenance

Systems shall be purged with an inert gas to eliminate hydrogen before opening the system to atmosphere. Maintenance shall be performed by qualified, trained personnel. The maintenance program shall include information on safety precautions and instructions for servicing equipment. A spare parts list with ordering instructions should be available. Piping modifications should be retested. Piping systems shall be purged to eliminate oxygen/air before hydrogen is readmitted.

7.4 Records

A permanent record of inspections and repairs shall be maintained. Repairs, modifications, and additions shall be made in accordance with the latest edition of applicable codes and standards.

8 References

Unless otherwise specified, the latest edition shall apply.

- [1] CGA P-11, *Metric Practice Guide for the Compressed Gas Industry*, Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com
- [2] CGA G-5, *Hydrogen*, Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com
- [3] CGA G-5.3, *Commodity Specification for Hydrogen*, Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com
- [4] NFPA 52, *Vehicular Gaseous Fuel Systems Code*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org
- [5] NFPA 55, *Compressed Gases and Cryogenic Fluids Code*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org
- [6] *Handbook of Compressed Gases*, Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com
- [7] ASME B31.12, *Hydrogen Piping and Pipelines*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org
- [8] NFPA 70, *National Electrical Code*[®], National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org
- [9] CSA C22.1, *Canadian Electrical Code, Part I*, Canadian Standards Association, 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada. www.csa.ca
- [10] AIGA 033, *Hydrogen Pipeline Systems*, Asia Industrial Gases Association, www.asiaiga.org
- [11] EIGA Doc 100, *Hydrogen Cylinders and Transport Vessels*, European Industrial Gases Association, Avenue des Arts 3-5, B-1210 Brussels, Belgium. www.eiga.org
- [12] API RP 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*, American Petroleum Institute, 1220 L St., NW, Washington, DC 2004. www.api.org
- [13] CGA G-5.5, *Hydrogen Vent Systems*, Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com
- [14] *Code of Federal Regulations*, Title 29 (Labor), Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. www.gpo.gov
- [15] CSA B51, *Boiler, Pressure Vessel, and Pressure Piping Code*, Canadian Standards Association, 5060 Spectrum Way, Mississauga, ON L4W 5N6, Canada. www.csa.ca
- [16] NFPA 77, *Recommended Practice on Static Electricity*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org
- [17] NFPA 780, *Standard for the Installation of Lightning Protection Systems*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org
- [18] CGA H-5, *Installation Standards for Bulk Hydrogen Supply Systems* Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com
- [19] NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

[20] ASTM A380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems*, ASTM International, 100 Bar Harbor Dr., West Conshohocken, PA 19428. www.astm.org

[21] CGA PS-31, *CGA Position Statement on Cleanliness for Proton Exchange Membranes Hydrogen Piping/Components*, Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly, VA 20151. www.cganet.com

[22] AIGA 012, *Cleaning Equipment for Oxygen Service*, [Asia](http://www.asiaiga.org) Industrial Gases Association, www.asiaiga.org

[23] ASME B16.5, *Pipe Flanges and Flanged Fittings*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[24] ASME B31.3, *Process Piping*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[25] NACE SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*, NACE International, 1440 S. Creek Dr., Houston, TX 77084. www.nace.org

[26] NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269. www.nfpa.org

[27] ASME A13.1, *Scheme for the Identification of Piping Systems*, ASME International, Three Park Ave., New York, NY 10016. www.asme.org

[28] *Workplace Hazardous Materials Information System*, Health Canada, Ottawa, ON K1A 0K9 Canada. www.hc-sc.gc.ca/hecs-sesc/whmis