STANDARD FOR HYDROGEN PIPING SYSTEMS AT USER LOCATIONS

Doc 261/26

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Prepared by WG-14 Hydrogen Production

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 261, *Standard for Hydrogen Piping Systems at User Locations*, jointly produced by members of the International Harmonisation Council and originally published by the Compressed Gas Association as CGA G-5.4, *Standard for Hydrogen Piping Systems at User Locations*.

This publication is intended as an international harmonised standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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1 Introduction

Hydrogen supply systems and hydrogen use systems usually require piping to connect components and to transfer hydrogen. Selecting the proper type of process piping and using correct installation techniques are necessary for safe transfer and use of hydrogen.

2 Scope

This standard describes the minimum requirements and general principles recommended for piping systems for gaseous and liquid hydrogen. The standard applies to hydrogen piping in a supply system from the hydrogen source to the point of use above ground. Nonregulated below ground piping and piping used on portable bulk delivery equipment is included in this standard. Regulated pipelines (for example PHMSA jurisdictional pipelines) are excluded from this standard.

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 the provided references.

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.

3.2 Technical Definitions

3.2.1 Authorized personnel

Individual who is knowledgeable in the hazards of compressed gases and cryogenic fluids through training and experience and who is approved to perform specific types of duties on a piping system.

3.2.2 Excess flow valves (EFVs)

Safety devices designed to automatically close stopping fluid flow in response to a sudden increase in flow or above a predetermined value, preventing large releases and potential hazards in the event of a pipe rupture or hazardous leak.

3.2.3 Lockout/Tagout (LOTO)

Safety procedure used to ensure that sources of energy (e.g., electrical, chemical, pressure) are properly shut off, isolated, and labeled prior to the start of maintenance work. This condition is maintained during the work and reversed when preparing for restart.

3.2.4 Pipe

Pressure tight cylinder used to convey a fluid or transmit a fluid pressure, ordinarily designated “pipe” in applicable material specifications. Materials designated “tube” or “tubing” in the specifications are treated as pipe when intended for pressure service [1, 2].[1]

3.2.5 Pipeline(s)

Underground or aboveground piping system used to convey gaseous or liquid product from a producing facility,

crossing third-party, or public property (for example, public road) to a customer's use point on their property.

NOTE—This normally necessitates the use of external governmental requirements depending on region. [2, 3, 4, 5, 6]

NOTE—This definition does not include interplant process piping, which is underground or aboveground piping used to convey gaseous product from a producing facility to a customer's use point on their property without crossing a third-party or public property.

3.2.6 Piping components

Mechanical elements suitable for joining or assembly into pressure-tight fluid-containing piping systems. Components include pipe, tubing, hoses, fittings, flanges, gaskets, bolting, isolation valves, regulators, relief valves, pulsation dampeners, and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, inline portions of instruments, separators, and other appurtenances attached to pipe [1, 2].

3.2.7 Piping system

Assemblies of piping and piping components under the same design conditions, designed, installed, and tested in accordance with the applicable piping code used to convey, distribute, mix, separate, discharge, meter, control, or snub fluid flows. Piping also includes pipe-supporting elements, but does not include support structures, such as building frames, bents, foundations, or equipment otherwise excluded [1, 2, 7].

4 Piping system criteria

4.1 Design criteria

Hydrogen piping systems should be designed in accordance with local applicable codes, regulations, and standards, such as the European Pressure Equipment Directive (PED), EN 13480 series, the ASME B31.12, *Hydrogen Piping and Pipelines* [1, 2]. The design should consider the special requirements for hydrogen service. Single wall piping is used for gaseous and liquid hydrogen service when thermal insulation is not required. Double-walled vacuum-insulated piping is recommended for liquid hydrogen service to avoid liquid vaporization and liquid air formation on the outside of the pipe.

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

- adequately meet the process conditions required such as flow and pressure;
- meet safety, integrity, and leak tightness requirements; and

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

- allow for safe maintenance by providing positive isolation of parts of the system (e.g., double block and bleeds), vents to fully depressurize the system that prevent trapped pressure (e.g., behind a check valve, and purging activities for inerting or commissioning.

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 4.2.2). 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.

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

4.2 Piping materials

4.2.1 Metal

Material specifications and thickness requirements for piping and tubing shall conform to EN 13480, ASME B31.12, or locally recognized standards [1, 2]. All material selections in piping design shall include consideration of the static and dynamic loadings in addition to process conditions to determine suitability. Piping, tubing, valves, and fittings for operating temperatures less than –20 °F (–29 °C) shall be fabricated from materials listed in or qualified to the operating temperatures and pressure per ASME B31.12, EN 13480, other locally recognized standards, for the operating temperatures [2, 1].

Most materials experience a degradation of properties when used in hydrogen service. The generic term for this is hydrogen embrittlement, although there are multiple hydrogen damage mechanisms. 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. EIGA Doc 259 - *Safe Operation of Hydrogen, Carbon Monoxide, and Syngas Pipeline Systems,* provides a more detailed discussion of hydrogen embrittlement and attack [10].

Austenitic stainless steels (300 series with >8% nickel) meeting the temperature limits of EN 13480, ASME B31.12, or other locally recognized standards, are recommended for liquid and gaseous hydrogen piping systems [1, 2]. The most stable grade is Type 316/316L. Type 316/316L is relatively immune to hydrogen embrittlement for piping systems and is recommended for systems operating at high pressure or high stress ratios. Other grades such as Type 304/304L are suitable for proven industrial applications generally operating at low stress ratios. When available, austenitic stainless steels should be used in the annealed condition as is generally preferred for workability (e.g., welding, bending, threading).

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 EN 13480, ASME B31.12, or other locally recognized standards may be used for gaseous hydrogen product piping, tubing, valves, and fittings [1, 2]. 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. CGA H-18 is an example of guidelines for the allowable composition of various alloy steels for hydrogen service [10].

For higher temperatures the materials should be compatible with the Nelson curves to avoid high temperature hydrogen attack (HTHA).

In addition, for high temperature applications, the suitability of carbon or low-alloy steel shall be evaluated using the “Nelson curves” 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 [11]. Carbon steels with higher strength levels (as defined in the API RP 941 “Nelson curves”), 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.

4.2.2 Low melting point materials

Low melting point materials (for example, aluminum, copper, brass, and bronze) have reduced strength at elevated temperatures. Their use should be in accordance with EN 13480, ASME B31.12, or other locally recognized standards [1,2]. Solders with a melting point temperature less than 1000 °F (537.8 °C) shall not be used.

A system containing these materials shall be:

- suitably protected against fire exposure in accordance with locally recognized codes, for example NFPA 2, *Hydrogen Technologies Code* [7];
- located so leakage resulting from a failure does not unduly expose personnel, buildings, or structures; and
- 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.

4.2.3 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, or other locally recognized standards [2]. The permeability of the plastic material and overall system integrity shall be reviewed to ensure suitability for the application.

4.2.4 Hoses

Hoses should only be used where rigid piping is not practical such as connecting to trailers or other mobile equipment. Hoses are typically made of low melting point materials or of corrugated metals. The temperature limitations listed in 4.2.2 do not apply.

Hoses should be designed for proper handling (e.g., avoid overbending, stretching, ergonomic issues) and include protection from accidental ruptures and releases (i.e., hose whip protection).

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 and adequate strength. For additional guidance on stainless steel braided hoses, refer to CGA E-9, *Standard for Flexible Stainless Steel Braided Hoses Used in Compressed Gas Service*, or EIGA Doc 42*, Flexible Connections in High Pressure Gas Systems* [12, 13]. For additional guidance on fueling station hoses, refer to ISO 19880-5, *Gaseous hydrogen—Fuelling stations – Part 5: Dispenser hoses and hose assemblies* [14].

4.2.5 Additional recommendations 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 embrittlement. A mechanical non-interchangeability standard has not yet been established for trailer pressure classes greater than 2900 psi (200 bar) where hydrogen piping is connected to delivery equipment. Connectors shall be designed for the range of operating pressures and temperatures. Refer to EIGA TB 51/24, *Hydrogen Interface for Trailer to Hydrogen Refueling Station* [15]. [2]

4.3 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.

4.3.1 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 and in Europe, EN 13480, or other locally recognized standards [2, 1].

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 2.54 cm (1 in) nominal, either pipe thread or tube fitting inlet and outlet connections should be used. For 2.54 cm (1 in) 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, *Standard for Hydrogen Vent Systems*, or EIGA Doc 211, *Hydrogen Vent Systems for Customer Applications* [17, 18].

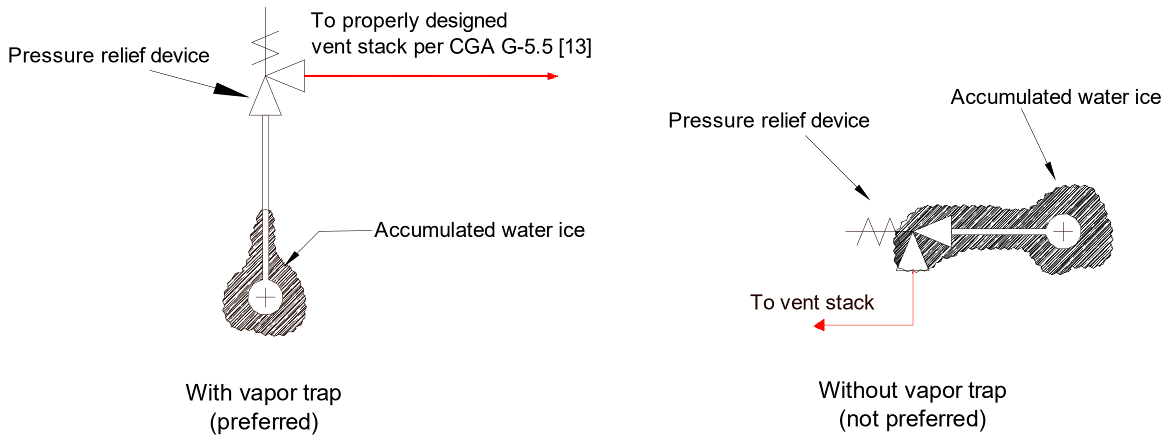


Figure 1—Typical pressure relief device installation—uninsulated cold hydrogen piping

4.3.2 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 4.2.

[2] psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pres-sure or (psid; bar, dif; and kPa, dif) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Met-ric Practice in the Compressed Gas Industry* [16].

4.3.3 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 inlocal fire codes or regulations such as NFPA 2; CSA B51, *Boiler, Pressure Vessel and Pressure Piping Code* in North America [7, 19].

4.3.4 Excess flow valves

Excess flow valves (EFVs) when required, would be located in the system 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 local codes, standards, or regulations, such as NFPA 2 in the United States [7]. When EFVs are used, the system design shall allow for resetting the device. EFVs have historically shown to be problematic due to activation where flow rates are intermittent or have peak flow rates. EFVs are not required where atmospheric monitoring is in place and will activate an outdoor automated shutoff valve with emergency stop (refer to local codes, standards, or regulations, such as NFPA 2 requirements) [7].

4.3.5 Check valves

Check valves prevent reverse flow, which can cause contamination. Swing-type and lift-type check valves are recommended for 2.54 cm (1 in) nominal and larger sizes. Poppet-type check valves are recommended for 2.22 cm (7/8 in) 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.

4.3.6 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 (shatter-proof) 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 no more than 0.8% hydrogen concentration (no greater than 20% of the lower flammable limit) and to shut down the system at 1% hydrogen concentration (no greater than 25% of the lower flammable limit). Flame detectors also should be considered in the event a hydrogen leak is ignited. In outdoor areas where it is difficult to accurately measure hydrogen concentration, flame detectors can be more effective.

4.3.7 Gasket and sealing materials

Plastics and elastomers may be used for internal valve seats and seals.

When plastics and elastomers are used for gasketing, packing, or other sealing elements, the design should incorporate features that minimize the release of hydrogen including consideration of melting during fire exposure, pressure cycling, and temperature cycling/limits. 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. For more details on fueling applications see ISO 19880-7, *Gaseous hydrogen — Fuelling stations Part 7: Rubber O-rings* [20].

For flanged joints, metallic gaskets are preferred and are required for vent system flanges. Graphite compounds may be used with liquid hydrogen or where additional fire resistance is required. Soft elastomers and plastics are not recommended for flange gaskets. Where necessary other joints should be protected to ensure integrity.

The use of O-rings requires careful consideration of not only material compatibility but the design and fabrication of the retaining grooves including tolerancing and surface finishes. Only material and process compatible lubricants should be used on O-rings where required.

4.3.8 Additional requirements

Piping components shall be constructed of materials compatible with hydrogen service and shall have adequate pressure and temperature ratings. Reducing the number of mechanical connections in hydrogen piping system should be part of the system design.

4.3.9 Electrical equipment

Electrical equipment shall be installed, bonded, and grounded in accordance with locally recognized electrical codes and standards, such as NFPA 70® and NFPA 77, *Recommended Practice on Static Electricity* in the United States, or EN IEC 60364-4-41, *Low voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock*, EN IEC 60364-5-54, *Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors*, and IEC TS 60079-32-1, *Explosive atmospheres - Part 32-1: Electrostatic hazards, guidance* in Europe [8, 21, 22, 23, 24].

Lightning protection in accordance with locally recognized codes and standards such as:

- In the United States—NFPA 780, *Standard for the Installation of Lightning Protection Systems* [25];
- In Canada—CSA C22.1 [9]; and
- In Europe—EN IEC 62305 series on lightning protection and EN IEC 60364 (Low-voltage electrical installations) [26, 27].

5 Cleaning

5.1 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* [28]. For additional information, see CGA PS-31, *Cleanliness for Proton Exchange Membranes Hydrogen Piping/Components* [29].

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.

5.2 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 EIGA Doc 33, *Cleaning of Equipment For Oxygen Service* [30].

5.2.1 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.

5.2.2 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.

5.3 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.

5.3.1 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 recleaned 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.

5.3.2 Wipe test

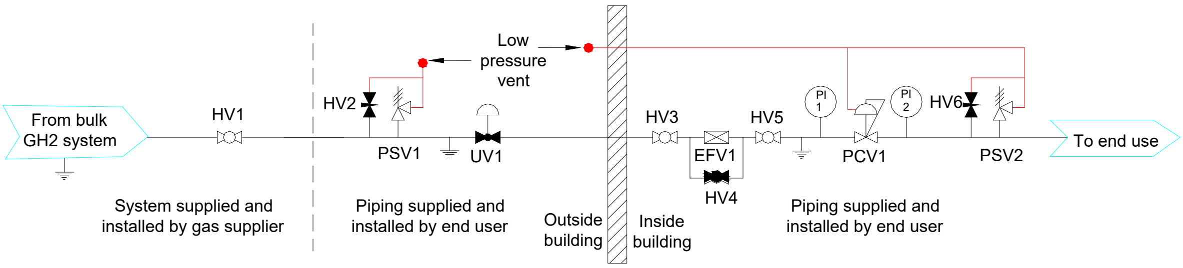
- Wipe tests are an aid to visual inspections and are used to detect contaminants on surfaces that are not accessible for visual inspection. The test surface should be rubbed lightly with clean, white paper or a lint-free cloth, which is then examined under white light. There should be no contaminants and there should be no appreciable discoloration of the wiping media (see 5.3.1).

6 Installation

6.1 General

All piping systems should be installed in accordance with local, state, and national codes and standards (for example, EN 13480, ASME B31.12, CGA H-5, *Standard for Bulk Hydrogen Supply Systems*, EIGA Doc 15, *Gaseous Hydrogen Installations* and EIGA Doc 06, *Safety in Storage, Handling and Distribution of Liquid Hydrogen*) [1, 2, 31, 32, 33]. 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.



Key			
HV1	Source valve	HV5	Isolation valve–downstream EFV1
HV2	PSV1 bleed valve	PI1	PCV1 inlet pressure gauge
PSV1	Final line pressure relief valve	PI2	PCV1 outlet pressure gauge
UV1	Automated shutoff valve	PCV1	Regulator for end use
HV3	Isolation valve–upstream EFV1	HV6	PSV2 bleed valve
HV4	EFV equalization valve	PSV2	Pressure relief valve protecting customer equipment
EFV1	Excess flow valve		Ground connection

Figure 2—Typical gaseous hydrogen piping systems

6.1.1 Joints

Joints may be threaded, flanged, brazed, welded, or made with a suitable mechanical fitting. For leak tightness and fire safety, welding is preferred in joints in piping and tubing, where practical. Cold-worked tubing with mechanical joints (e.g., cone-and-thread) should not be welded, as the material strength reduction is significant (i.e., 50%). Cold-worked tubing is typically used where pressures of greater than 69 000 kPa (10 000 psi) are required. Soft solder joints are not permitted. All leaks that can be detected by an approved leak detection method shall be repaired.

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.

6.1.2 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.

Piping weld joints shall be installed and inspected in accordance with ASME B31.12, EN 13480, or other locally recognized codes and standards [2, 1].

6.1.3 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, EN 13480, or other locally recognized codes and standards [2, 1].

6.1.4 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, EN 13480, or other locally recognized codes and standards [2, 1]. 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.

6.2 Aboveground installation

6.2.1 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. When installing mechanical joints, any debris from preparing the piping (i.e., cutting that leads metal shavings) shall be cleaned and blown from the lines at the time of installation.

For requirements of electrical continuity of joints, see 6.4.

6.2.2 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 of suitable materials (e.g., stainless steel) shall be installed under uninsulated piping and equipment to collect and vaporize this condensed liquid over the combustible surface to prevent contact. Drip pans may also be used to prevent concrete damage where condensed air can drip from uninsulated portions of the system.

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 5.1 cm (2 in) from electrical cables and any other pipelines shall be maintained. The hydrogen pipeline should be installed above the cables.

6.3 Underground piping system installation

Underground hydrogen piping shall be installed in accordance with local, state, and national codes and standards (for example, NFPA 2) [7].

Piping installed in a trench that is open to the top shall not be considered underground.

NOTE—This section does not apply to regulated pipelines. See EIGA Doc 259 [10].

6.3.1 General requirements

Because of the leak potential, all underground hydrogen piping shall be welded construction with no valves, mechanical joints, or connections installed underground. Where valves maybe necessary they should be installed either above ground or in a valve box suitably designed for hydrogen and maintenance.

Due to the possibility of leaks all underground hydrogen piping shall be welded construction with no valves, mechanical joints, or connections installed underground. If this cannot be avoided, then the number should be limited, and leak points should be installed in a way that provides easy access for inspection, maintenance, and active leak detection (e.g., in valve pits or boxes). Piping should be of all welded construction in accordance with a specification and inspection code such as ASME B31.12, EN 13480, and API Standard 1104*, Welding Pipelines and Related Facilities* [2,1,34].

6.3.2 Cover and backfill

Underground piping should be adequately buried and protected from frost, casual surface construction, shifting due to unstable soil, back-fill damage to the external surface of pipe or the coating, and aboveground loads such as vehicles or equipment moving over the path of the pipeline. For example, a typical minimum depth would be 45.72 cm (18 in).

Where hydrogen piping is buried with other products/service, the hydrogen piping shall be installed above the other piping. Generally piping should be separated from other piping or conduit vertically by at least 15.24 cm (6 in) and horizontally by at least 2 pipe diameters. Electrical conductors should be located at safe separation based on the service and gas line sizes.

Underground piping shall be installed and covered with at least 15.24 cm (6 in) of well compacted bedding material in addition to the cover depth. Caution tape shall be buried in the soil at least 30.48 cm (12 in) above the pipe or other indication of the underground line may be used.

6.3.3 Pipe casings

Pipe casings or load shields, as required by regulations or good practice, should be installed at railroad or road crossings or where unusual aboveground loading can occur. Sleeves can also be used to protect underground piping. Casings or sleeves require careful consideration and special measures to avoid cathodic protection and arcing, which can be caused due to an electrical connection forming between the sleeve and carrier pipe due to settlement, etc. In general, the use of metallic casings or sleeves should be avoided wherever possible. The casing shall be sealed from weather and contaminates and be vented at each end at the top and bottom of the casing. See NACE SP0200, *Steel-Cased Pipeline Practices* [35]. Where required, these vents should be monitored for hydrogen leaks.

6.3.4 Corrosion protection

Underground hydrogen piping in contact with soil or other material that could corrode the piping shall be protected from corrosion using an approved method such as external coatings, cathodic protection, use of a corrosion resistant outer pipe or other method. 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. Additionally ensure adequate current isolation of the corrosion protection (CP) system and piping from induced currents from grounding systems, pipe supports or other support structures or buildings.

For detailed information on corrosion protection see EIGA Doc 259 and the NACE SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* [10, 36]. Nearby high-tension lines can induce Alternating Current (AC) interference, damaging coatings of underground piping and causing AC-induced corrosion.

6.3.5 Lighting strikes

Underground hydrogen piping is vulnerable to damage by lightning strikes or ground fault conditions, which can rupture the pipe material. To reduce the likelihood of one of these occurring, electrical continuity between underground hydrogen piping and aboveground piping or other metal structures should be avoided. Installation of lighting suppressors should be considered at insulating flanges to prevent damage to the insulating flange kit components and gasket.

6.3.6 Drawings and documentation

Final “as built” drawings of underground piping shall be maintained by the owner/operator of the piping system.

6.4 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. Pipework itself should not be used as a grounding rod and each piece of equipment should be grounded.

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, CSA C22.1, IEC 60079-14, *Explosive atmospheres - Part 14: Electrical installation design, selection and installation of equipment, including initial inspection*, or locally recognized codes and standards, as appropriate, for information on bonding for static electricity and lightning protection [21, 25, 9, 37].

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®, or applicable local codes and standards [8]. Buried ground plates may be used in shallow soil conditions. See NFPA 70®, CSA C22.1, or locally recognized codes and standards for specifications on grounding electrode systems [7, 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.

7 System startup

7.1 General

Hydrogen piping generally comprises part of a hydrogen supply system or equipment for the use of hydrogen, such as a fuel cell electrical vehicle (FCEV) dispensing system. The system shall be started up in accordance with its specifications or applicable standards, such as CGA H-5, EIGA Doc 15 and EIGA Doc 06 for hydrogen supply systems [31, 32, 33]. Specific requirements for hydrogen piping shall be in accordance with this standard.

7.2 Safety

Only authorized personnel should be allowed near the piping system during commissioning. The person re-sponsible for the coordination and control of the commissioning shall ensure that the customer and all personnel be properly briefed and pressure hazards during testing have been accounted for. Normally a commissioning program and procedure should be prepared and discussed with all concerned individuals before commissioning starts. All gas supplier and customer standing orders and safety instructions shall be observed.

7.3 Inspection

Piping systems and components installed in the system should be compared to design specifications (e.g.,process and instrumentation diagram [P&ID], bill of materials [BOM]) to ensure the components meet size, material, pressure rating, orientation, correct sequence, and proper identification. The system should be inspected for good workmanship and all inspections completed prior to introducing any pressurized media.

7.4 Testing

Before initial operation of a new system or new fabricated sections, the piping system shall be leak tested to show integrity and leak tightness in accordance with the applicable sections of ASME B31.12, EN 13480, or applicable sections in locally recognized codes and standards [2, 1].

The piping may be hydrostatically or pneumatically pressure tested for integrity. Hydrostatic or pneumatic pressure testing shall be performed per the local requirements.

Piping should be pneumatically leak tested. Pneumatic leak testing shall use 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.

An additional leak check shall be conducted when in hydrogen service with 100% hydrogen using an approved leak detection method. For vacuum-jacketed lines the vacuum integrity should be checked, for example, visual inspection for frosted spots.

ASME B31.12 and EN 13480 contain a guide for the preparation of the required test records [2, 1].

7.5 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.

7.6 Final commissioning to operations

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.

The methods used to identify valves and piping by color coding, painting, or labeling shall be in accordance with local regulations, for example, 29 CFR 1910.6(a), which points to ASME A13.1, *Scheme for the Identification of Piping Systems* [38, 39]. In Canada, the requirements under the *Workplace Hazardous Materials Information System* (WHMIS) regulations of the applicable province or territory apply [40].

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. For more details on designing, operating, and maintaining a hydrogen supply system, see CGA H-5 [31].

8 Maintenance and repair

In order to ensure a safe operating system, hydrogen piping must be maintained by authorized personnel following established procedures for such work. Examples include following a work permit system, hot work, lockout/ tagout, management of change and should be included with authorized personnel training. These practices are also included in 29 CFR Part 1910 *Occupational Safety and Health Standards*, CGA H-5, EIGA Doc 250 *Standard Procedures for Hydrogen supply Systems*, EIGA Doc 259, CGA P-88, *Guideline for the Maintenance of Bulk Delivery Equipment Containing Class 2 Hazardous Materials,* and EIGA Doc 51, *Management of Change* and can be referred to for additional information [38, 31, 41, 10, 42, 43].

8.1 Inspection

Each owner/operator of a piping system shall establish preventative maintenance and mechanical integrity inspection procedures for piping systems, including regular inspections in accordance with operating experience, manufacturer recommendations, company procedures, or applicable regulations. Some equipment may need more frequent inspection than others and be considered at the component level. For example, inspections of the primary piping, piping components, and equipment used for the transfer of products (e.g. hoses, connections, grounding equipment) should be considered at each transfer operation in addition to periodic maintenance.

Regular maintenance shall include checks for physical damage, tampering, leak tightness, vent system operation, equipment identification, warning signs, alarm operation, and all other safety related devices or features. Hoses shall be inspected at every use, following CGA P-82, *Standard for Maintenance of Transfer Hoses* [44].

In addition, the integrity and functionality of the grounding system, cathodic protection systems where used, any insulation, and pipe support structures should be verified.

Inspections should also include periodic verification of training, service instructions, maintenance procedures, and repair records.

8.2 Maintenance

Systems shall be purged with an inert gas to eliminate hydrogen before opening the system to atmosphere. Maintenance shall be performed by authorized personnel. The maintenance program shall include safety precautions and instructions for servicing all equipment and piping systems as detailed in the standards above.

Prior to performing work on any piping system, sources of energy must be identified and locked and tagged out. Systems shall be purged with an inert gas and/or vented to atmospheric pressure to eliminate flammability and stored energy risk before opening the system to atmosphere or performing work. Piping systems shall be purged to eliminate oxygen/air before hydrogen is readmitted and system recommissioned.

The need for the use of nonsparking tools for any maintenance task should be evaluated using guidance from CGA PS-55, *Position Statement on Use of Nonsparking Tools* [45].

8.3 Repairs and alterations

Repairs, modifications, and additions shall be made in accordance with the latest edition of applicable codes and standards (i.e., ASME B31.12, EN 13480, ASME Post Construction Committee Standards 1 & 2, API 570, *Inspection Repair, Alteration, and Rerating of In-Service Piping systems*, and/or *National Board Inspection Code, Part 3*, *Repairs and Alterations*) [2, 1, 46, 47, 48, 49]. Piping modifications should be retested, and changes follow the management of change (MOC) process.

8.4 Records

- A record of maintenance shall be maintained for at least 3 years but should be maintained for the life of the system.

9 References

Unless otherwise specified, the latest edition shall apply.

[1] EN 13480, *European Industrial Piping Code*, European Committee for Standardization. www.cen.eu

[2] ASME B31.12, *Hydrogen Piping and Pipelines,* American Society of Mechanical Engineers. www.asme.org

[3] *Code of Federal Regulations*, Title 49 (Transportation) Parts 192, U.S. Government Printing Office. www.gpo.gov

[4] EN 1594, *Gas infrastructure: Pipelines for maximum operating pressure over 16 bar - Functional requirements*, European Committee for Standardization. www.cen.eu

[5] EN 12007-1, *Gas infrastructure - Pipelines for maximum operating pressure up to and including 16 bar - Part 1: General functional requirements,* European Committee for Standardization. www.cen.eu

[6] ISO 13623, *Petroleum and natural gas industries — Pipeline transportation systems*, International Organization for Standardization. www.iso.org

[7] NFPA 2, *Hydrogen Technologies Code*, National Fire Protection Association. www.nfpa.org

[8] NFPA 70®, *National Electrical Code*®, National Fire Protection Association. www.nfpa.org

[9] CSA C22.1, *Canadian Electrical Code, Part I*, Canadian Standards Association. www.csa.ca

[10] EIGA Doc 259, *Safe Operation of Hydrogen, Carbon Monoxide, and Syngas Pipeline Systems*, European Industrial Gases Association. www.eiga.eu

NOTE—This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

[11] API RP 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*, American Petroleum Institute. www.api.org

[12] CGA E-9, *Standard for Flexible Stainless Steel Braided Hoses Used in Compressed Gas Service*, Compressed Gas Association, Inc. www.cganet.com

[13] EIGA Doc 42, *Flexible Connections in High Pressure Gas Systems*, European Industrial Gases Association. www.eiga.eu

[14] ISO 19880-5, *Gaseous hydrogen — Fuelling stations, Part 5: Dispenser hoses and hose assemblies*, International Organization for Standardization. www.iso.org

[15] EIGA TB 51/24 - *Hydrogen Interface for Trailer to Hydrogen Refueling Station*, European Industrial Gases Association. www.eiga.eu

[16] CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry*, Compressed Gas Association, Inc. www.cganet.com

[17] CGA G-5.5, *Standard for Hydrogen Vent Systems,* Compressed Gas Association, Inc. www.cganet.com

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[18] EIGA Doc 211, *Hydrogen Vent Systems for Customer Applications*, European Industrial Gases Association. www.eiga.eu

[19] CSA B51, *Boiler, Pressure Vessel, and Pressure Piping Code,* Canadian Standards Association. www.csa.ca

[20] ISO 19880-7, *Gaseous hydrogen — Fuelling stations, Part 7: Rubber O-rings*, International Organization for Standardization. www.iso.org

[21] NFPA 77, *Recommended Practice on Static Electricity,* National Fire Protection Association. www.nfpa.org

[22] EN IEC 60364-4-41, *Low voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock*, International Electrotechnical Commission. www.iec.ch

[23] EN IEC 60364-5-54, *Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors*, International Electrotechnical Commission. www.iec.ch

[24] IEC TS 60079-32-1, *Explosive atmospheres - Part 32-1: Electrostatic hazards, guidance*, International Electrotechnical Commission. www.iec.ch

[25] NFPA 780, *Standard for the Installation of Lightning Protection Systems*, National Fire Protection Association. www.nfpa.org

[26] EN IEC 62305 series, *Lightning Protection Systems*, International Electrotechnical Commission. www.iec.ch

[27] EN IEC 60364 series, *Low-voltage electrical installations*, International Electrotechnical Commission. www.iec.ch

[28] ASTM A380, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems,* ASTM International. www.astm.org

[29] CGA PS-31, *CGA Position Statement on Cleanliness for Proton Exchange Membranes Hydrogen Piping/Components,* Compressed Gas Association, Inc. www.cganet.com

[30] EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* www.eiga.eu

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[31] CGA H-5, *Standard for Bulk Hydrogen Supply Systems* (an American National Standard), Compressed Gas Association, Inc. www.cganet.com

[32] EIGA Doc 15, *Gaseous Hydrogen Installations*, European Industrial Gases Association. www.eiga.eu

[33] EIGA Doc 06, *Safety in Storage, Handling and Distribution of Liquid Hydrogen*, European Industrial Gases Association. www.eiga.eu

[34] API STD 1104, *Standard 1104, Welding Pipelines and Related Facilities*. American Petroleum Institute. www.api.org

[35] NACE SP0200, *Steel-Cased Pipeline Practices*, NACE International. www.onepetro.org

[36] NACE SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*, NACE International. www.onepetro.org

[37] IEC 60079-14, *Explosive atmospheres - Part 14: Electrical installation design, selection and installation of equipment, including initial inspection*, International Electrotechnical Commission. www.iec.ch

[38] *Code of Federal Regulations*, Title 29 (Labor), Superintendent of Documents, U.S. Government Printing Office. www.gpo.gov

[39] ASME A13.1, *Scheme for the Identification of Piping Systems*, American Society of Mechanical Engineers. www.asme.org

[40] *Workplace Hazardous Materials Information System*, Health Canada. www.hc-sc.gc.ca/hecs-sesc/whmis

[41] EIGA Doc 250, *Standard Procedures for Hydrogen Supply Systems,* European Industrial Gases Association. www.eiga.eu

[42] CGA P-88, *Guideline for the Maintenance of Bulk Delivery Equipment Containing Class 2 Hazardous Materials*, Compressed Gas Association, Inc. www.cganet.com

[43] EIGA Doc 51, *Management of Change,* European Industrial Gases Association. www.eiga.eu

[44] CGA P-82, *Standard for Maintenance of Transfer Hoses,* Compressed Gas Association, Inc. www.cganet.com

[45] CGA PS-55, *Position Statement on Use of Nonsparking Tools*, Compressed Gas Association, Inc. www.cganet.com

[46] ASME PCC-1, *Pressure Boundary Bolted Flange Joint Assembly*, American Society of Mechanical Engineers. www.asme.org

[47] ASME PCC-2, *Repair of Pressure Equipment and Piping*, American Society of Mechanical Engineers. www.asme.org

[48] API 570, *Piping Inspection Code: Inspection, Repair, Alteration, and Rerating of In-Service Piping Systems*, American Petroleum Institute. www.api.org

[49] *National Board Inspection Code, Part 3, Repairs and Alterations*, The National Board of Boiler and Pressure Vessel Inspectors. www.nationalboard.org