January 2021
Interim Revision January 2024

HYDROGEN

Table of Contents

List of Figures

List of Tables

1.0 SCOPE

This data sheet covers liquefied and gaseous hydrogen storage, and systems for dispensing, end-use equipment, and laboratories.

This data sheet covers skid-mounted, packaged hydrogen electrolyzer systems. Multiple skid-mounted systems can be connected to common headers or a bulk supply.

Although this data sheet covers both hydrogen storage and systems, there are several other data sheets that address other applications:

- Data Sheet 7-50, *Compressed Gases In Portable Cylinders and Bulk Storage*, covers cylinder storage.
- Data Sheet 7-7, *Semiconductor Fabrication Facilities*, covers the use of hydrogen in semiconductor fabrication.
- Data Sheet 7-101, *Fire Protection for Steam Turbines*, describes the use of hydrogen as a coolant in steam turbine-driven alternating current generators and provides additional recommendations.
- Data Sheet 6-10, *Process Furnaces*, describes the necessary protection for special atmosphere furnaces.
- Data Sheet 7-95, *Compressors*.
- Data Sheet 7-54, *Natural Gas and Gas Piping*, provides information on the proper arrangement of piping.
- Data Sheet 7-79, *Fire Protection for Gas Turbines and Electric Generators*
- Data Sheet 7-77, *Testing of Engines and Accessory Equipment*

1.1 Changes

January 2024. Interim revision. The document was updated to include guidance on electrolyzer hydrogen generators in the Construction and Location, and Equipment and Processes sections.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Hydrogen Supply Construction and Location

2.1.1 Construction

2.1.1.1 Store hydrogen in containers designed, constructed, and tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, *Unfired Pressure Vessels*; U.S. Department of Transportation specifications and regulations for portable cylinders; or applicable international or nationally recognized code.

2.1.1.2 Use accessories such as valves, gauges, and regulators that are compatible with hydrogen service, and listed or rated for the pressures and temperatures to which they will be exposed.

2.1.1.3 For liquefied hydrogen bulk supply, provide a remotely actuated safety shutoff valve in the liquid withdrawal lines as close to the container as practical.

2.1.1.3.1 Do not install any connections or gauges in the piping between the shutoff valve and the container.

2.1.1.4 Ensure containers, piping, valves, regulating equipment, and other accessories are accessible and protected against physical damage and tampering.

2.1.1.5 Protect vents, relief outlets and ventilation systems from infiltration by rain or snow.

2.1.1.6 Provide bulk hydrogen supply with substantial noncombustible supports securely anchored on firm, noncombustible material. Protect steel supports over 18 in. (0.46 m) high with a two-hour fire resistance-rated protective coating.

2.1.2 Hydrogen Supply Location

2.1.2.1 Locate bulk hydrogen supply outdoors.

2.1.2.1.1 Where liquid hydrogen can flow toward outdoor exposures, use curbs or other diversion methods to prevent encroachment.

2.1.2.2 Limit gaseous hydrogen cylinders indoors to nominal capacity of 2000 scf (57 m^3), located as close as practical to the point of use. Hydrogen fuel systems on vehicles are not considered to be cylinders.

2.1.2.3 Limit liquid hydrogen Dewars indoors to nominal capacity of 50 gal (189 L), located as close as practical to the point of use.

2.1.2.4 Where hydrogen cylinders or Dewars are located indoors, use gas cabinets, or provide mechanical ventilation in accordance with 2.2.4.

2.1.2.5 Locate the bulk hydrogen supply at least 20 ft (6.1 m) horizontally from the vertical plane below overhead electric power lines.

2.1.2.6 Separate bulk hydrogen supply from exposures in accordance with Tables 2.1.2.6-1 and 2.1.2.6-2.

2.1.2.7 Where bulk storage volume exceeds the limits of Tables 2.1.2.6-1 and 2.1.2.6-2, route the pressure relief to a flare system designed and located in accordance with API 521, Pressure-relieving and Depressuring Systems.

Table 2.1.2.6-1. Minimum Distance from Gaseous Hydrogen Storage to Exposures

	Storage Volume[1], scf (m^3)		
	<5,000 (140)	≤5,000 < 25,000 (≤140 < 710)	≤25,000 ≤150,000 (≤710 ≤ 4,200)
Exposure	*Minimum Separation Distance, ft (m)*		
Fire-resistive building	15 (4.6)	15 (4.6)	20 (6.1)
Noncombustible building	15 (4.6)	15 (4.6)	30 (9.1)
Combustible building	15 (4.6)	20 (6.1)	50 (15)
Ignitable liquids storage	15 (4.6)	15 (4.6)	30 (9.1)
Bulk flammable gas storage	15 (4.6)	15 (4.6)	30 (9.1)
Other hydrogen storage	15 (4.6)	15 (4.6)	30 (9.1)
Oxygen storage	15 (4.6)	15 (4.6)	30 (9.1)
Combustible solids	15 (4.6)	20 (6.1)	50 (15)
Air compressor intakes or HVAC intakes	25 (7.6)	50 (15)	100 (30)
Wall openings	25 (7.6)	50 (15)	100 (30)

Note 1. Volume of gas at 14.7 psig (101 kPa) and 70°F (21°C).

Table 2.1.2.6-2. Minimum Distance from Liquefied Hydrogen Storage to Exposures

	Storage Volume, gal (m^3)		
	<4,500 (<17)	≤4,500 < 9,000 (≤17 < 34)	≤9,000 ≤ 18,000 (≤34 ≤ 68)
Exposure	*Minimum Separation Distance, ft (m)*		
Fire-resistive building	20 (6.1)	50 (15)	120 (37)
Noncombustible building	20 (6.1)	50 (15)	120 (37)
Combustible building	20 (6.1)	50 (15)	120 (37)
Ignitable liquids storage	20 (6.1)	25 (7.6)	40 (12)
Bulk flammable gas storage	20 (6.1)	25 (7.6)	40 (12)
Other hydrogen storage	20 (6.1)	25 (7.6)	40 (12)
Oxygen storage	20 (6.1)	25 (7.6)	40 (12)
Combustible solids	30 (9.1)	50 (15)	65 (20)
Air compressor intakes or HVAC intakes	25 (7.6)	50 (15)	100 (30)
Wall openings	25 (7.6)	50 (15)	100 (30)

2.1.2.8 Hydrogen Generating Equipment

2.1.2.8.1 Locate hydrogen generating equipment outdoors, in a detached building or enclosure, or on the roof as close as practicable to the end-use equipment. Hydrogen generating equipment enclosures include prefabricated containers not designed for occupancy.

2.1.2.8.2 Locate hydrogen generating equipment based on the internal storage, with separation in accordance with Table 2.1.2.6-1.

2.1.2.8.3 Locate transformers in accordance with the separation distance in Data Sheet 5-4, *Transformers*, or Table 2.1.2.6-1, whichever is greater, based on non-combustible wall/building.

2.1.2.8.4 Construct the electrolyzer enclosure using lightweight construction or explosion venting panels designed to fail at 20 psf (98 Kg/m^2) or less, or at the required wind resistance pressure.

2.1.2.8.5 Provide dedicated drain lines for hydrogen dryer water to prevent hydrogen from flowing back into the building or enclosure.

2.1.2.8.6 Prevent water infiltration into the electrolyzer enclosure due to rain, snow or flooding.

2.1.3 Indoor Hydrogen Dispensing Location and Construction

2.1.3.1 Locate the bulk hydrogen supply outdoors in accordance with 2.1.2.6.

2.1.3.2 Provide administrative controls so that no more than 2000 scf (57 m^3) of hydrogen capacity is located in the dispensing area during dispensing operations. Include empty or partially-filled containers/vehicle fuel systems when calculating hydrogen capacity in the dispensing area.

2.1.3.3 Locate the hydrogen dispenser inside a room or building of minimum volume as determined in Table 2.1.3.3 based on the maximum hydrogen flow rate for a severed supply line (see 2.2.3.3 regarding restrictive flow orifices). Further discussion on the flow rates and volume thresholds in Table 2.1.3.3 is provided in Section 3.1.4.

Table 2.1.3.3. RFO Flow Rate and Minimum Room Volume

Maximum Hydrogen Flow Rate[1], lb/min (kg/min)	*Minimum Room Volume, ft^3 (m^3)*
2.2 (1)	710,000 (20,000)
4.4 (2)	1,100,000 (32,000)
6.6 (3)	1,800,000 (51,000)
8.8 (4)	2,400,000 (68,000)

Note 1. Based on severed supply line.

2.1.3.4 If the room or building volume is less than indicated in Table 2.1.3.3, provide the following:

A. A dedicated mechanical emergency exhaust system over the dispensing area in accordance with Section 2.2.4.

B. Damage-limiting construction in accordance with Data Sheet 1-44.

2.1.3.5 Locate the dispenser near an exterior wall with direct access from outdoors and a fire-resistance rating of at least 1 hour extending at least 20 ft (6 m) horizontally and vertically from the dispenser.

2.1.3.6 Provide space separation from the dispensing area to the following exposures:

A. At least 25 ft (7.5 m) from combustible materials and construction, building corners, and hazardous processes.

B. At least 50 ft (15 m) from sprinkler risers and maximum foreseeable loss (MFL) walls. (See Data Sheet 1-22, *Maximum Foreseeable Loss*, for description of MFL walls.)

2.1.3.7 Locate the piping entry above ground and use the shortest indoor route to the dispenser, or at least minimize the length of piping inside the building.

2.1.3.8 Protect hydrogen piping and dispensers against potential accidental impact during maintenance activities or by lift trucks. Possible means of protection include administrative controls, signage, barriers (bollards and guard rails), and piping guards. Administrative controls can include locating the hydrogen piping and dispenser in areas that have less traffic and have minimal risk of impact during normal facility operations and building maintenance work.

2.1.3.9 Provide controls to prevent vehicles or portable containers from being driven away or removed from the dispensing area with the dispenser nozzle still connected. Controls may be administrative measures and/or active devices to prevent starting the lift truck if the transfer hose is still connected.

2.1.4 Indoor Hydrogen Equipment Rooms and Laboratories

2.1.4.1 Construction

2.1.4.1.1 Construct hydrogen equipment rooms and laboratories in accordance with the following:

A. Locate the hydrogen equipment room or laboratory in a noncombustible building along an exterior wall equipped with damage-limiting construction (DLC) in accordance with Data Sheet 1-44.

B. Construct floors, walls, and ceilings of materials that have a minimum two-hour fire-resistance rating.

C. Provide continuous, securely-anchored room walls or partitions from the floor to the ceiling.

D. Provide self-closing inside doors and access openings.

2.1.4.1.2 Provide continuous mechanical ventilation at an average fresh air flow rate of at least 1 cfm/ft^2 (0.30 m^3 per minute per m^2) of floor area.

2.1.4.1.3 Where hydrogen cylinders are not installed in gas cabinets, provide gas detection systems interlocked with emergency ventilation to increase ventilation rate to 2.5 cfm/ft^2 (0.75 m^3 per minute per m^2) of floor area if hydrogen is detected at 25% of the LEL.

2.1.4.1.4 If gases are not installed in gas cabinets, provide a solid, full-height partition wall between gases that are capable of hazardous interactions (i.e., oxygen, chlorine, fluorine, and other oxidizers).

2.1.4.1.4.1 If a solid partition wall is not feasible, use space separation of at least 20 ft (6 m) between incompatible gases.

2.1.4.1.5 Provide a safety shutoff valve in the hydrogen piping interlocked to automatically shut off the flow of hydrogen if hydrogen levels in the equipment room or laboratory reach 25% of the LEL.

2.2 Equipment and Processes

2.2.1 General

2.2.1.1 Implement a process safety program in accordance with Data Sheet 7-43, *Process Safety*, for liquefied hydrogen in stationary bulk storage or where recommended by the applicable occupancy-specific data sheet.

2.2.1.2 Locate hydrogen end-use stationary equipment inside a room or building of minimum volume as determined in Table 2.1.3.3 based on the maximum hydrogen flow rate for a severed supply line, or provide mitigation features in accordance with 2.2.1.3.

2.2.1.3 If the room or building volume is less than that indicated in Table 2.1.3.3, provide the following:

A. A dedicated mechanical emergency exhaust system over the dispensing area in accordance with Section 2.2.4.

B. Damage-limiting construction in accordance with Data Sheet 1-44.

2.2.1.4 Limit cylinders in laboratories, end-use, or dispensing areas to those connected for use.

2.2.1.5 Visually inspect hydrogen cylinders, dispensers, regulators, and accessible portions of gas piping prior to opening cylinder service valve or starting dispensing operations. Check for signs of corrosion, discoloration, condensation, bulging, and physical damage. If any of these conditions exist, lock out/tag out the cylinder, dispenser, and end-use equipment in accordance with established operating and maintenance procedures.

2.2.2 Safety Relief Devices

2.2.2.1 Equip liquefied hydrogen tanks with relief devices on both the inner and outer tank in accordance with the applicable part of Section VIII of the ASME Boiler and Pressure Vessel Code, and sized in accordance with CGA S-1.3, *Pressure Relief Device Standards, Part 3, Stationary Storage Containers for Compressed Gases*, or equivalent international standard.

Liquefied hydrogen tanks will slowly absorb heat from the surrounding environment, causing appreciable quantities of hydrogen to vaporize, which must be vented occasionally, especially during shutdown periods.

2.2.2.2 Equip gaseous hydrogen containers with safety relief devices as required by the ASME Code, sized in accordance with CGA S-1.3 or equivalent international standard.

2.2.2.3 Arrange safety relief devices to discharge upward, unobstructed to the open air. The discharge should not impinge on the container or adjacent structures.

2.2.2.4 Design safety relief devices or piping to prevent moisture accumulation, which could freeze and impair relief device operation.

2.2.2.5 Provide safety relief devices in piping wherever liquid hydrogen could be trapped between closures.

2.2.3 Piping, Tubing, and Fittings

2.2.3.1 Design and install piping, tubing, and fittings in accordance with ASME B 31.12, *Hydrogen Piping and Pipelines*, or equivalent international standard.

2.2.3.2 Install an excess flow valve immediately downstream of the shutoff valve on the hydrogen bulk storage to automatically close in the event of pipe failure.

2.2.3.3 Where hydrogen supply piping enters a building or enclosure, install a restrictive flow orifice (RFO) or other passive flow-restricting means downstream of the excess flow valve and upstream of the piping entry into the building as follows:

A. Size the RFO or other flow restriction to meet the application needs.

B. Verify the RFO limits the flow inside the building or other mitigation techniques are applied in accordance with 2.1.3.4.

C. Maintain piping drawings and flow calculations demonstrating the designated maximum flow rate will not be exceeded at the maximum upstream supply pressure and with flow through 100% of the severed pipe cross-sectional area.

D. Maintain a copy of the piping drawings and flow calculations on site for management-of-change purposes.

2.2.3.4 Where dispensing systems are located in FM 50-year through 500-year earthquake zones (as defined in FM Property Loss Prevention Data Sheet 1-2, *Earthquakes*), provide the following seismic-related safeguards:

A. Perform a seismic loading analysis based on ASCE 7 or other recognized code to ensure supports for piping, dispensers and outdoor equipment have been designed to resist the anticipated seismic loads.

B. Provide support and protection in accordance with Data Sheet 1-11, *Fire Following Earthquake*, where hydrogen supply piping penetrates walls and roofs.

2.2.3.5 Avoid contact of dissimilar metals in liquid hydrogen systems or containers to prevent problems arising from corrosion and differences in contraction and expansion.

2.2.3.6 Do not use threaded joints in liquefied hydrogen piping. Threaded joints with suitable thread sealant are acceptable on gaseous hydrogen piping.

2.2.3.7 Install noncombustible insulation around liquid hydrogen piping having a vapor-tight seal in the outer covering to prevent air condensation and oxygen enrichment within the insulation.

2.2.4 Mechanical Ventilation

2.2.4.1 Where a dedicated mechanical emergency exhaust system is provided, design it as follows:

A. Interlock to require ventilation being in operation prior to startup and continuously during hydrogen dispensing operations.

B. Provide accessible local and remote manual activation devices, as well as automatic activation by hydrogen gas detectors installed in the dispensing area.

C. Locate intakes at the roof level above the dispenser and arrange them to prevent potential accumulation of hydrogen in any unavoidable “pockets” formed by roof beams or draft curtains.

D. Provide 100% exhaust to outdoors.

E. Provide sufficient exhaust, based on documented airflow modeling, to capture and remove the released hydrogen and also limit the average hydrogen concentration in the exhaust air to no more than the 50% of the LFL (2%) at the maximum flow rate allowed by the RFO (see 2.2.3.3).

2.2.5 Hydrogen Generating Equipment

2.2.5.1 Design, install, and protect primary reformers for hydrogen generation in accordance with Data Sheet 7-72, *Reformer and Cracking Furnaces*.

2.2.5.2 Design, install, and protect special atmosphere generators for process furnaces in accordance with Data Sheet 6-10, *Process Furnaces*.

2.2.5.3 Packaged (Skid-Mounted) Electrolyzers.

2.2.5.3.1 Degrease the oxygen piping and equipment prior to being commissioned.

2.2.5.3.2 Provide FM Approved hydrogen detection in the enclosure interlocked to activate exhaust ventilation, where provided; and electrically isolate the equipment if hydrogen levels exceed 25% of the LEL.

2.2.5.3.3 Purge the electrolyzer equipment with an inert gas prior to every startup to ensure no air has infiltrated the system.

2.2.5.3.4 Include the following items to provide early warning of impending electrolyzer failure:

1. Continuous gas analysis to monitor the purity of the gases
2. Differential pressure between the oxygen and hydrogen outlets
3. Pressure, temperature and flow detection
4. Voltage and amperage monitoring
5. Liquid level detection in the separators.

Trip points for emergency shutdown based on the monitoring systems above will be set by the manufacturer based on the specific electrolyzer technology. Hydrogen concentrations should initiate an emergency shutdown at no greater than 25% of the LEL in the oxygen piping (see Section 3.3).

2.2.6 Vehicle Fuel Dispensing Equipment

2.2.6.1 Use dispensing hoses and break-away devices listed for hydrogen dispensing.

2.2.6.2 Use SAE J2600 compliant fueling connection devices (nozzles and receptacles).

2.2.6.3 Provide the following features in the design and installation of the dispenser:

A. Use packaged dispensing systems listed or marked by a nationally-recognized third party agency, or perform a process hazard analysis on the dispenser design prior to installation.

B. Design the dispensing protocol in accordance with SAE J2601-3 for “fill to target” or “fill to service pressure” methods.

C. Provide hydrogen venting systems in accordance with CGA G-5.5, *Hydrogen Vent Systems*.

2.2.6.4 Provide an emergency shutdown system (ESD) on the hydrogen dispenser in accordance with the following:

A. Install a dedicated safety shut-off valve (SSOV) on the hydrogen supply line in an accessible location to automatically shut down the hydrogen supply upon activation of any sensors recommended in item C. Use an FM Approved valve if available and suitable for the application.

B. Install local and remote e-stops in locations that will be accessible to manually activate the SSOV in event of an emergency during dispensing.

C. Provide sensors to automatically detect hazardous conditions including the following:

1. Hydrogen gas >25% of LEL in or immediately above dispenser cabinet

2. Hydrogen flame in the dispensing area (optical detection)

3. Fire protection system activation in the dispensing area

4. Dispensing system leak

5. Vehicle “pull-away” (with hose still connected)

6. Internal (watchdog) timer timed out

7. Seismic activity in FM 50-year through 500-year earthquake zones as defined in Data Sheet 1-2, *Earthquakes*

D. Use FM Approved hydrogen gas and flame detectors.

E. Conduct proof testing in accordance with a documented procedure to ensure the fueling protocol is satisfied and all dispenser ESD safety functions are performed as designed prior to startup. Document all testing and maintain records for the life of the equipment.

2.2.6.6 Provide controls to prevent vehicles from being driven away or removed from the dispensing area with the dispenser nozzle still connected. Controls may be administrative measures and/or active devices to prevent starting the lift truck if the transfer hose is still connected.

2.3 Operation and Maintenance

2.3.1 Address hydrogen hazards and prevention of accidental hydrogen releases as part of a documented asset integrity program in accordance with DS 9-0, *Asset Integrity*, including the following:

A. Prepare a written asset integrity policy.

B. Establish authority and responsibilities.

C. Organize responders to handle emergencies.

D. Educate and train.

E. Audit and update.

2.3.1.1 Keep asset integrity documentation current and readily accessible at the facility for review and use in management of change, loss prevention audits, hazards assessments, and emergency response.

2.3.1.2 Establish procedures to identify and promptly report equipment failures, leakage, corrosion, operator error, near-miss events, and other abnormal conditions to the appropriate supervisor.

2.3.2 Inspect hydrogen systems annually, including but not limited to testing relief devices, inspecting insulation for damage, and inspecting exposed piping and container surfaces for corrosion, dents, bulges, or discoloration.

2.3.3 Check concentration of alkali in hydrogen electrolyzers at least annually or at intervals recommended by the OEM.

2.3.4 Empty and purge hydrogen containers or piping prior to initiating maintenance operations that involve opening the container or piping, disturbing the normal container attitude, or hot work.

2.3.5 Charge containers with a nitrogen holding charge when a hydrogen container is going to be removed from service for an extended period of time. If liquid hydrogen has been drained, allow for a warm-up period of several days before adding nitrogen. Continue purging until only nitrogen gas can be detected in the exhaust stream. The nitrogen gas should be passed slowly through all valves and lines to purge the piping.

2.3.6 Do not drain liquefied hydrogen to the ground or an enclosed drain. If it becomes necessary to dispose of hydrogen, arrange for the supplier or other qualified contractor to retrieve and dispose of hydrogen in accordance with local regulations.

2.3.7 Inspect all safety devices whenever the container is out of service. Verify the relief valve settings replace the valve if it fails to operate correctly.

2.3.7.1 Replace rupture disks at least annually. If the outer tank rupture disk bursts, the vacuum will be lost and the liquefied hydrogen should be drained and the container purged.

2.3.8 Have hydrogen detectors calibrated by qualified personnel at least quarterly or in accordance with manufacturer's instructions, whichever is more frequent, for the first year of service. The calibration frequency can be extended to 6 months or in accordance with manufacturer's instructions, whichever is shorter, following the first year of service if previous calibrations were within normal adjustment ranges identified by the manufacturer.

2.3.9 Test the performance of all manual and automatic emergency shutoff devices annually, or more frequently if recommended by the device manufacturer or if warranted by facility experience.

2.3.10 Test excess-flow valves and excess flow switches as recommended by the equipment manufacturer.

2.3.11 Replace or recondition all safety devices based on manufacturers' recommendations, as well as when necessary due to damage.

2.3.12 Transport and secure portable containers in an upright position to ensure proper operation of the pressure-relief device. If the container is moved on carriers or dollies, ensure it is securely supported. Have stored containers fastened to racks or posts to ensure stability.

2.3.13 Use non-sparking tools in areas where connections are made or broken, and when any part of the hydrogen piping system is opened to atmosphere.

2.3.14 Dispensers

2.3.14.1 Establish administrative controls and designate responsible supervisory personnel to ensure employees and contractors adhere to all operating and maintenance procedures.

2.3.14.2 Use qualified employees and/or contractors to supervise and perform all operation and maintenance duties for hydrogen storage and dispensing.

2.3.14.3 Establish and adhere to documented operating procedures, including the following:

A. Normal startup and shutdown

B. Supervision during dispensing

C. Emergency shutdown system

D. Roster of personnel trained and authorized on each shift to conduct dispensing and to manually activate the ESD system in emergency situations

2.3.14.4 Adhere to documented preventive maintenance procedures in accordance with facility experience and equipment manufacturers' guidelines.

2.3.14.5 Conduct regular recorded maintenance and inspection of the dispensing system in accordance with to manufacturers' directions and facility experience.

2.3.15 Laboratory Equipment

2.3.15.1 Laboratory-Scale Hydrogen Electrolyzers

2.3.15.1.1 Provide hydrogen detection above a hydrogen electrolyzer or in the exhaust or return air duct, interlocked to deenergize the electrolyzer if hydrogen levels exceed 25% of the LEL.

2.3.15.1.2 If the electrolyzer is not installed under a hood, provide mechanical ventilation in the laboratory in accordance with Section 2.1.4.1.2.

2.3.15.2 Many types of special equipment may be used with liquefied hydrogen for cryogenic experimentation. No one set of recommendations could anticipate all the hazards associated with each type of equipment. There are, however, general safeguards that should be followed.

A. Check equipment for leaks using liquefied helium or liquefied nitrogen before first use.

B. Purge the entire system with inert gas before and after each use with hydrogen. During shutdown periods, maintain equipment above ambient pressure to prevent air from backing into the system.

C. Insulate electrical wiring exposed to liquefied hydrogen temperatures with plastics or rubber that are compatible with liquefied hydrogen temperatures. Examples are TFE plastics or elastomeric rubber or plastic materials. Generally, vinyl insulations will tend to crack at -423°F (-253°C).

D. Do not use electrical or resistive gauges to monitor the liquid content.

2.4 Protection

2.4.1 Ignition Source Control

2.4.1.1 Provide Class I, Div (Zone) 2, Group B electrical equipment in accordance with Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*, located within 15 ft (4.6 m) of gaseous hydrogen storage or equipment.

2.4.1.2 Provide Class I, Div (Zone) 2, Group B electrical equipment in accordance with DS 5-1 within 25 ft (7.6 m) of liquefied hydrogen storage or equipment.

2.4.1.3 Provide Class I, Div (Zone) 1, Group B electrical equipment in accordance with DS 5-1 located within 3 ft (1 m) of a point where connections are regularly made and disconnected.

2.4.2 Automatic Sprinkler Protection

2.4.2.1 Provide ceiling sprinkler protection over hydrogen dispensing areas, hydrogen equipment rooms, and laboratories, and ensure it is adequate for the surrounding occupancy per the appropriate FM data sheet, but not less than HC-2. (For HC-2 design criteria, see Data Sheet 3-26, *Fire Protection Water Demand for Nonstorage Sprinklered Occupancies*.)

2.4.2.2 Provide hose stream allowance and water supply duration in accordance with Data Sheet 3-26 for the applicable occupancy hazard classification.

2.5 Human Element

2.5.1 Training for Hydrogen Dispensing Areas

2.5.1.1 Create a training program for employees who have access to the hydrogen dispensing area, including operators, emergency responders, and maintenance and security personnel. Include at least the following in the training program:

A. The hazards created by hydrogen storage and dispensing

B. Proper operation and shutdown of equipment under normal and emergency procedures

C. Location of all local and remote manual shutoff stations

D. Operator authorization to manually activate ESD when judged appropriate in emergency situations

E. Near-miss reporting procedures

2.5.1.2 Ensure all contractors working in or around the dispensing area have adequate training in hydrogen hazards related to their assigned duties.

2.5.1.3 Train contractors to follow facility procedures for notification and response to hydrogen emergencies.

2.5.2 Emergency Response and Pre-Fire Planning

2.5.2.1 Establish an emergency response plan for accidental hydrogen releases. Include at least the following elements:

A. For general guidelines on establishing and maintaining an emergency response plan see DS 10-1, *Pre-Incident Planning.*

B. Site plan showing the location of all hydrogen dispensers and emergency isolation stations

C. Documented authorization for designated personnel on all shifts to activate the ESD when warranted based on individual judgment

D. Availability of fire protection for cooling exposed hydrogen-powered lift trucks in the refueling area

E. Responder awareness that hydrogen fires are invisible and must not be extinguished until the release source has been shut down

2.5.2.2 Familiarize the facility’s emergency response team members and the local fire service with the location of dispenser installations as well as the emergency response plan.

2.5.2.3 Conduct annual emergency response drills to reinforce the employee and contractor training program and to familiarize the fire service with the site layout and dispensing area arrangements.

2.5.3 Supervision of Hydrogen Supply and Equipment Contractors

2.5.3.1 Develop and implement a program to supervise contractors in accordance with the recommendations in Data Sheet 10-4, *Contractor Management*, including the following:

A. Draft a formal policy statement on contractor supervision, along with procedures for selecting, inducting, and supervising contractors.

B. Assign an employee to be accountable for ensuring the contractor policy and procedures are followed, audited regularly, and updated as necessary.

C. Post the contractor policy and ensure the information is communicated to all employees and contractors involved with the dispensing area.

D. Define and document the work to be completed by the contractor.

E. Specify the codes and standards and other requirements the contractor must comply with in performing the work.

F. Identify any equipment and maintenance activities which remain the responsibility of the facility, and how facility and contractor personnel will interact.

G. Review completed work and records to ensure contract requirements are met.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Indoor Hydrogen Dispensing Hazards

Hydrogen has a very wide flammable range (4% to 75% by volume) and requires very little energy to ignite; a flammable hydrogen-air mixture could be formed under high-pressure release conditions following impact by a heavy object, hose rupture, or as a result of human error. The cloud could subsequently ignite from a weak discharge of static electricity, ordinary electrical equipment, or other ignition source. As discussed below (Section 3.1.4), gas dispersion modeling indicates that such clouds are capable of causing over-pressure damage to the building and its contents. Ignition of an uncontrolled hydrogen release could also result in an almost invisible jet flame capable of igniting nearby combustibles. Manual firefighting becomes very difficult under these conditions.

Accidental releases of hydrogen gas can occur for a number of reasons, including the following:

- Degradation of the storage container
- Incompatible piping materials
- Improper sealing of the nozzle to the container
- Delivery of gas while nozzle is not connected
- Leak in pipe connecting the dispenser with bulk tank (pipes tend to be the weakest point in a hydrogen dispensing system)
- Leak at the connections between dispenser and pipes or bulk container and pipes
- Rupture of pipes due to hydrogen embrittlement

Many safeguards are provided to help prevent accidental hydrogen releases during fueling. As a result, property loss experience with dispensing to HPLTs has been favorable. However, hydrogen dispensing is an inherently hazardous operation; it is critical to ensure that hydrogen dispensing systems located indoors in high-value end-use areas are managed (i.e., designed, installed, and operated) to prevent accidental releases and, if releases do occur, to mitigate potential damage.

3.1.1 Release Prevention and Mitigation Safeguards

The primary defense against fires and explosions involving hydrogen, or any other flammable gas, is to prevent accidental releases from occurring in the first place. Hydrogen release prevention depends primarily on the following:

A. Robust equipment design (lift truck fuel tanks, nozzles, hoses, piping and dispensers)

B. Regular inspection and maintenance of piping, dispensers, and containers

C. Personnel trained to follow proper operating and maintenance procedures at all times

However, even if primary release prevention safeguards are fully implemented, dispenser failures can occur and may result in accidental large releases. For example, releases might be caused by accidental impacts, equipment failure, breaks in supply piping and hoses, failure to follow maintenance or operating procedures, or other human errors. To help mitigate the potential damage should such a release occur, the following additional safeguards are recommended in this data sheet:

- Release-limiting safeguards (Section 3.1.2)
- Damage-limiting building volume (Section 3.1.4)
- Emergency exhaust ventilation (section 3.1.6)

3.1.2 Release-Limiting Safeguards

By limiting both the flow rate and duration of the accidental release, the amount of hydrogen available in a potential fire and/or explosion can be significantly reduced, along with severity of consequences, as compared to a large “uncontrolled” release event.

Two key “release-limiting” safeguards are recommended in this data sheet and are also required by codes: (1) an emergency shutdown system (ESD), and (2) a restrictive flow orifice (RFO). These are illustrated schematically in Figure 3.1.2 and discussed below.

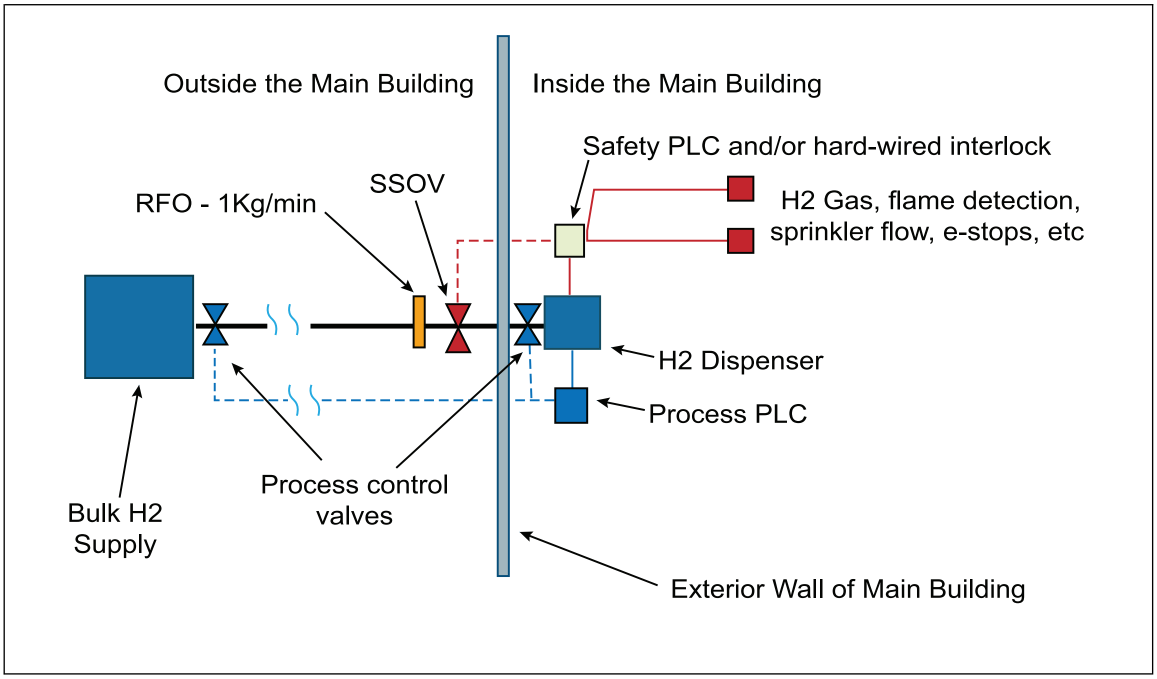


Fig. 3.1.2. Simplified schematic showing hydrogen dispensing system RFO and ESD

3.1.2.1 Emergency Shutdown System (ESD)

The dispenser ESD system recommended in Section 2.2.6.4 is intended to provide the following basic safety shutdown functions:

A. Prompt manual shutdown of the hydrogen supply in case of emergency.

B. Automatic shutdown of the hydrogen supply outside the building prior to or promptly following an accidental hydrogen release during dispensing.

The following are the key components of the ESD system:

- A safety shut-off valve (SSOV) located outside the building and dedicated solely to the above safety functions.
- Hydrogen gas and hydrogen flame detectors in the dispensing area.
- Sensors to detect critical process deviations during dispensing, as determined by a hazards analysis. For example, high pressure or temperature conditions may be critical; a piping leak or hose break may be detected by pressure sensors. ESD sensors are independent of the process control sensors.
- A programmable electronic system (PES, also called a “safety PLC”) and/or “hard-wiring” to activate the SSOV independently of the dispenser PLC.

As long as the ESD performs as intended, the hydrogen supply will be shut down and hydrogen releases will be either prevented or limited to a very short duration. Failure of the ESD system in a large release situation could result in a much longer duration release, a large hydrogen cloud, and much greater damage if an explosion occurs. Therefore, reliable ESD performance is very important in terms of damage mitigation.

3.1.3 Restrictive Flow Orifice (RFO)

A restrictive flow orifice is a fixed, passive device that restricts the flow rate into the building in the event of a break or leak in the inside piping. The maximum flow rate (based on physical limitations imposed by the orifice diameter) is selected to be as low as possible in order to limit the size of a potential hydrogen gas cloud or flame jet that might form following an accidental release, but the flow rate must also be high enough to allow the filling operation to be accomplished efficiently. The maximum allowable flow rate for lift truck hydrogen dispensers is commonly set at 1 kg/minute.

As discussed below (Section 3.1.4), gas dispersion modeling indicates a fire or deflagration could occur even if an RFO is used to inherently limit the maximum possible flow rate as recommended in Table 2.1.3.3; however, the RFO can significantly reduce the total amount of available hydrogen and therefore mitigate the extent of damage as compared to an “uncontrolled” release (without an RFO).

3.1.4 Damage-Limiting Building Volume (DLBV)

Any ESD system, even SIL-rated ones, may fail to shut down the hydrogen flow in a large accidental release situation. Further, even with flow-limiting devices such as RFOs installed, flow rates can still be large enough for some buildings to suffer severe structural damage by over-pressure due to a deflagration. Figure 3.1.4 illustrates this situation for a simulated 1 kg/minute hydrogen release inside an industrial warehouse, resulting in a flammable cloud at the ceiling. (Ignition of the hydrogen cloud is also likely to result in the operation of many ceiling sprinklers).

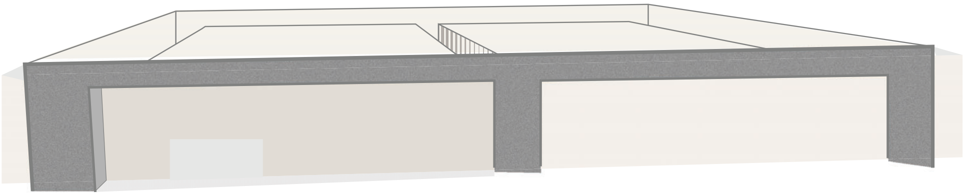
As an additional damage mitigation safeguard in case the ESD fails to shut down the flow of hydrogen, the dispenser is recommended to be located insidea building that is large enough to reduce the explosion overpressure to prevent major structural damage. This approach is the basis for the volume thresholds in Table 2.1.3.3, termed “damage-limiting building volume” (DLBV). These volumes were determined to be large enough to limit the overpressure and extent of damage assuming an RFO controls the flow rate as indicated in the table. Explosion modeling assumptions are described in a paper by Bauwens and Dorofeev (see Section 4.0).

3.1.5 Emergency Exhaust Ventilation

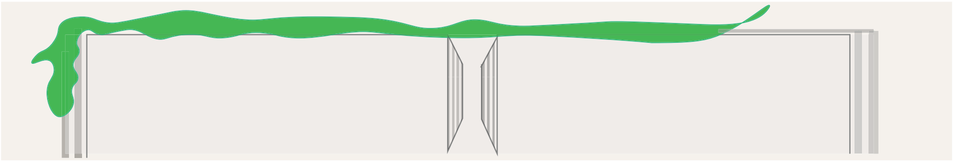
A dedicated emergency exhaust ventilation system is recommended in 2.1.3.4 for locations where damage-limiting building volumes in accordance with Table 2.1.3.3 cannot be achieved. This ventilation can help prevent accumulation of hydrogen and subsequent formation of a flammable cloud at the ceiling level during an accidental release. At the same time, to ensure safe hydrogen concentrations within the ventilation system, the ventilation rate must be sufficient to keep the concentration below the lower flammable limit (4% by volume). Other important factors in the design of the ventilation system are the location and number of exhaust intakes to ensure full capture and removal of the escaped gas.

3.2 Outdoor Bulk Hydrogen Supply Separation Distances

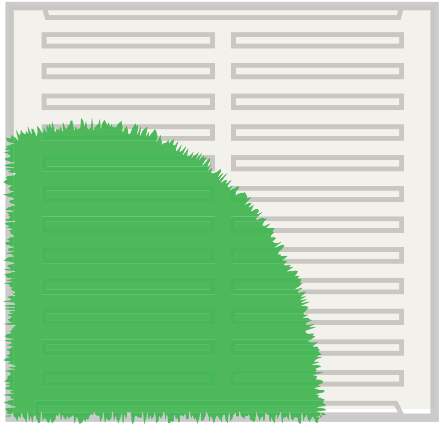
The separation distances consider both thermal radiation and overpressure generated by the unintended release and subsequent ignition of hydrogen generated by a full-bore break of the vessel’s pressure relief device. In general, the thermal radiation criteria generates the more conservative distances, except for the



a. Side view isometric of building



b. Side view - hydrogen cloud at ceiling



c. Plan view - hydrogen cloud

Fig. 3.1.4. CFD simulation of indoor hydrogen releases (Bauwens 2013)

largest liquid storage configurations. The thermal radiation thresholds consider 12 kW/m^2 for combustible construction, 30 kW/m^2 for noncombustible, 35 kW/m^2 for flammable gas/ignitable liquid storage, and 78 kW/m^2 for 1-hour fire-rated construction. For the overpressure criteria, the separation distance considers the distance to significant (50%) damage to light-weight unreinforced concrete block wall construction.

3.3 Flammability Limits of Hydrogen

The hydrogen-oxygen-nitrogen flammability diagram is provided in Figure 3.3 for reference. The LFL of hydrogen does not vary significantly from the generally-accepted 4.66% across all mixtures.

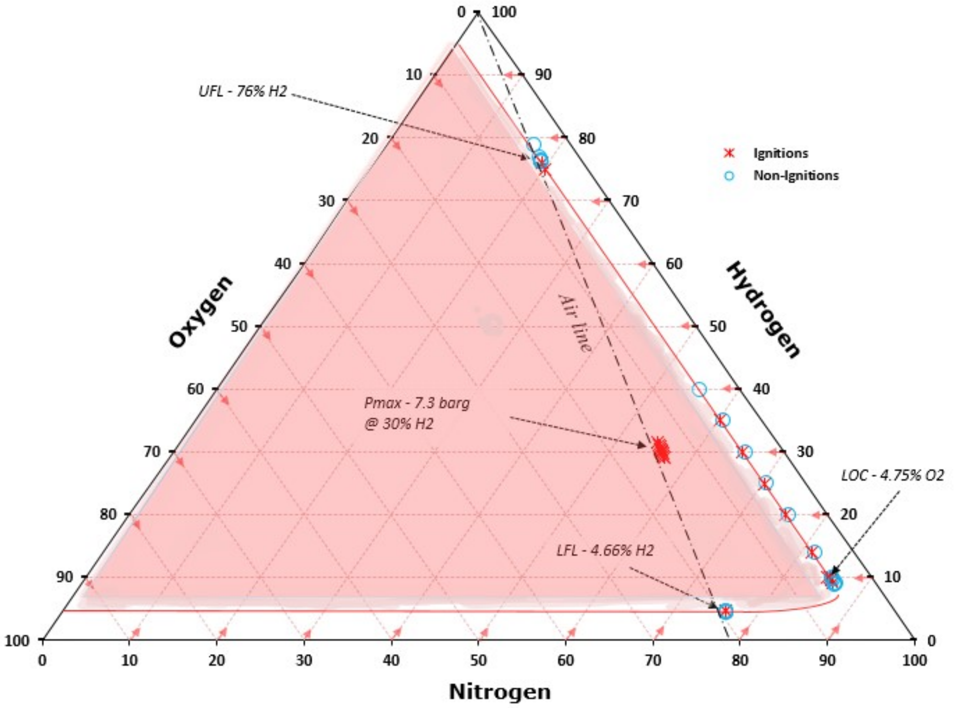


Fig. 3.3. Flammability diagram for hydrogen in air at 1 atm (Figure courtesy of Fauske & Associates www.fauske.com or info@fauske.com)

3.4 Loss History

3.4.1 Recent Loss Experience

In the 10-year period from Jan 1, 2009 through Dec 31, 2018, eleven losses involving hydrogen gas were reported by FM clients (Table 3.4.1-1). Of these, approximately 99% were fires and explosions resulting from hydrogen releases due to piping or equipment failures or misoperation. The overwhelming majority of these losses occurred in non-hazardous chemical plant occupancies (see Table 3.4.1-2). In most losses, property damage contributed approximately 40% of the gross loss cost, while time element/business interruption contributed approximately 60% of gross loss cost. (All loss amounts are indexed to 2019 values.)

Table 3.4.1-1. Losses by Peril, 2009-2018

Peril	*# of Losses*	*% of Loss Cost*	*Total Gross Loss Cost, US$ Million*
Explosion	5	27%	20.8
Fire	5	72%	56.0
Mechanical Breakdown	1	1%	0.8
Total	**11**	**100%**	**77.6**

Table 3.4.1-2. Losses by Occupancy, 2009-2018

Occupancy	*# of Losses*	*% of Loss Cost*	*Total Gross Loss Cost, US$ Million*
Electrical/Electronics	1	2%	1.9
Machine Shop	1	0%	0.1
Non-Haz Chemical Plant	7	94%	73.0
Power Generation Plants	2	4%	3.0
Total	**11**	**100%**	**77.0**

3.4.2 Illustrative Losses

All loss amounts are indexed to 2019 values.

3.4.2.1 Misoperation Causes Compressor Damage

Operators in a non-hazardous chemical plant were restarting a hydrogen compressor following a maintenance shutdown. The operators had written procedures and a checklist for completing the operation. For unknown reasons, the operators closed an equalization valve out of sequence, resulting in pressure differentials within the compressor. The pressure differential caused the machine to become unbalanced, which caused vibrations and pipe failures. The fire began approximately 6 minutes after the compressor was started, and approximately 60 seconds after the equalization valve was closed.

3.4.2.2 Faulty Gas Sensors Fail to Prevent Introduction of Flammable Gas to Equipment

A semiconductor manufacturing facility uses forming gas of 5% hydrogen/95% nitrogen in die and wire bond equipment. A sudden reduction of nitrogen pressure upstream of the forming gas mixer resulted in forming gas with higher concentration of hydrogen than design. Several small fires were detected in multiple production areas and were extinguished by facility personnel with portable fire extinguishers. An investigation identified a faulty relay that controlled the solenoid activating the safety shutoff valve (SSOV) downstream of the mixing chamber upon the detection of a high hydrogen concentration.

4.0 REFERENCES

4.1 FM

Data Sheet 1-2, *Earthquakes*
Data Sheet 1-11, *Fire Following Earthquake*
Data Sheet 1-22, *Maximum Foreseeable Loss*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 3-26, *Water Demand for Nonstorage Sprinklered Occupancies*
Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*
Data Sheet 6-10, *Process Furnaces*
Data Sheet 7-7, *Semiconductor Fabrication Facilities*.
Data Sheet 7-50, *Compressed Gases In Portable Cylinders and Bulk Storage*
Data Sheet 7-54, *Natural Gas and Gas Piping*
Data Sheet 7-72, *Reformer and Cracking Furnaces*
Data Sheet 7-79, *Fire Protection for Gas Turbines and Electric Generators*
Data Sheet 7-95, *Compressors*
Data Sheet 7-101, *Fire Protection for Steam Turbines*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-4, *Contractor Management*

4.2 Other

American Petroleum Institute (API), API 521, *Pressure-relieving and Depressuring Systems*.

American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section VIII. ASME B 31.12, *Hydrogen Piping and Pipelines*.

Bauwens, C.R., and S. B. Dorofeev. “CFD Modeling and Consequence Analysis of an Accidental Hydrogen Release in a Large Scale Facility.” International Conference on Hydrogen Safety, September 9-11, 2013, Brussels.

Compressed Gas Association (CGA). Standard CGA G-5.5, *Hydrogen Vent Systems*.

Compressed Gas Association (CGA). Standard S-1.3, *Pressure Relief Device Standards, Part 3, Stationary Storage Containers for Compressed Gases*.

National Fire Protection Association (NFPA). NFPA 55, *Compressed Gases and Cryogenic Fluids Code*.

Society of Automotive Engineers (SAE). *Compressed Hydrogen Surface Vehicle Fueling Connection Devices*.

APPENDIX A GLOSSARY OF TERMS

Cryogenic laboratory: A separate building or special room used for small-scale experiments or processing involving liquified hydrogen in limited quantities, about 50 gal (200 L).

Ignitable liquid: Any liquid or liquid mixture that is capable of fueling a fire, including flammable liquids, combustible liquids, or any other reference to a liquid that will burn. An ignitable liquid is any liquid that has a fire point.

Separate building: A detached, non-communicating building used exclusively to house a hydrogen system.

Special room: A separate, enclosed area that is part of or attached to another building and is used exclusively for a hydrogen system.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

January 2024. Interim revision. The document was updated to include guidance on electrolyzer hydrogen generators in the Construction and Location, and Equipment and Processes sections.

April 2021. Interim revision. Minor editorial changes were made.

January 2021. This document has been completely revised. The following major changes were made:

A. Updated recommended separation between gaseous and liquefied hydrogen storage and exposures.

B. Incorporated recommendations on indoor dispensing from Data Sheet 7-39, *Lift Trucks*, including equipment, location, protection, maintenance, and support for recommendations.

C. Added recommendation for excess flow valve in bulk hydrogen supply piping.

D. Added recommendations for hydrogen dispensing systems in active seismic areas.

E. Expanded recommendations for mechanical ventilation systems.

F. Updated loss experience.

G. Reorganized the document for ease of use.

January 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM Global’s loss prevention recommendations for ignitable liquid hazards.

September 2010. Equations for calculating overpressure relief devices have been replaced by a reference to the appropriate CGA guidance for sizing.

September 2000. This revision of the document has been reorganized to provide a consistent format. In addition the following technical corrections were made:

- Clarified the pressure at which hydrogen can cause significant embrittlement to some metals.
- Clarified the types of metals that can be used in hydrogen service and proper joining methods.

May 1998. Document reformatted.

June 1984. Dropped NFPA format. Added information on gaseous hydrogen systems, handling hydrogen fires and relief vent sizing criteria.

December 1973. Revised by adopting NFPA 50B, *Liquefied Hydrogen at Consumer Sites*.

November 1967. Initial publication that included only liquefied hydrogen.

APPENDIX C BACKGROUND INFORMATION

Hydrogen is a colorless, odorless, flammable gas. It is the lightest gas known, with a 0.0695 specific gravity (air = 1.0). Its boiling point at atmospheric pressure is -423.2°F (-252.9°C). When liquefied hydrogen converts to gaseous hydrogen at standard conditions, it expands roughly 850 times. Hydrogen diffuses through various size openings 2 to 3.8 times faster than air. In both the liquid and gaseous states, hydrogen may leak because of its low viscosity and low molecular weight. It also disperses easily into the atmosphere. Under the right ambient wind and temperature conditions, a 500 gal (1.89 m^3) outdoor spill of liquid hydrogen will diffuse to a nonexplosive mixture in one minute. If released as a liquid, the initial vapor density will be approximately equal to that of air, but will quickly become lighter than air as its temperature rises.

The flammability range in air is 4%–75% by volume, although pressure, temperature, and water vapor will affect the flammable limits. Table C-1 lists the flammability limits for hydrogen in various oxidants. Minimum ignition energy is 0.017 MJ as compared to 0.28 MJ for methane. Hydrogen has been ignited by the static electricity generated from a high-velocity leak. It burns in air with a pale blue, almost invisible flame. Although the flame temperature of hydrogen burning in air is hotter than that of LP gas, it emits much less radiant heat than a comparable size hydrocarbon flame. The U.S. Bureau of Mines reports the autoignition temperature of atmospheric pressure hydrogen-air mixtures is as low as 932°F (500°C).

Table C-1. Hydrogen Flammability Limits in Various Oxidants at 77°F (25°C) and Atmospheric Pressure

Oxidant	*Lower Explosive Limit*	*Upper Explosive Limit*
Oxygen	4.0	95
Air	4.0	75
Chlorine	4.1	89
Nitrous Oxide	3.0	84
Nitric Oxide	6.6	66

A stoichiometric hydrogen-air mixture burns at a velocity roughly nine times faster than a stoichiometric methane-air mixture. This makes explosion venting of hydrogen explosions more difficult, and increases the likelihood for hydrogen deflagrations in pipes or long thin enclosures will escalate to detonations. Because hydrogen has a high flame velocity, it is difficult to arrest a hydrogen flame. A hydraulic-type arrestor may be possible.

High-pressure (greater than approximately 1,000 psig [7 MPa]) hydrogen can embrittle and significantly weaken structural steel and other metals to the point where they crack and fail at much lower stress levels than normal. Iron-base and nickel-base alloys are particularly susceptible to hydrogen embrittlement. Apparently this embrittlement occurs because the metal surface absorbs hydrogen that penetrates into the crystal lattice.

Handling liquefied hydrogen creates two hazards. First, small amounts of liquids can be converted into large quantities of highly flammable gas; and second, the extremely cold liquid can embrittle unprotected structural metal. If a large-scale leak occurred, a considerable amount of the liquid would flash into vapor. A large leak from a high-pressure gaseous hydrogen container would produce a large vapor cloud. Ignition of the vapor-air mixture would generate considerable heat and, if the quantities were large enough, a pressure pulse. Detonation would be unlikely unless the hydrogen were confined or a strong initiating source such as a detonating charge were present. It is necessary to separate liquid storage tanks from other plant facilities to minimize the possibility of these structures being entrapped in the flame envelope, as well as to minimize exposure to the hydrogen facility.

Hydrogen is liquefied by cooling high-purity gas to its condensation temperature by ultra-low-temperature refrigeration techniques. Because of its extremely low temperature, it is handled in well-insulated tanks and pipes constructed of materials compatible for service at -423°F (-253°C). Liquefied hydrogen is stored and transported in spherical or cylindrical storage tanks (Figs. C-1 and C-2), in tank cars and trailers and, for laboratory applications, in small liquid containers or Dewar flasks (Figs. C-3 and C-4). All are at essentially atmospheric pressure. These vessels are of multiwall construction with insulation or vacuum between the walls. The insulation is designed to minimize heat transfer to the inner tank. There are several types of insulation available for liquefied hydrogen service, the most effective being multilayer or laminated type. This insulation requires a high vacuum for maximum effectiveness and does not necessarily require a thick layer.

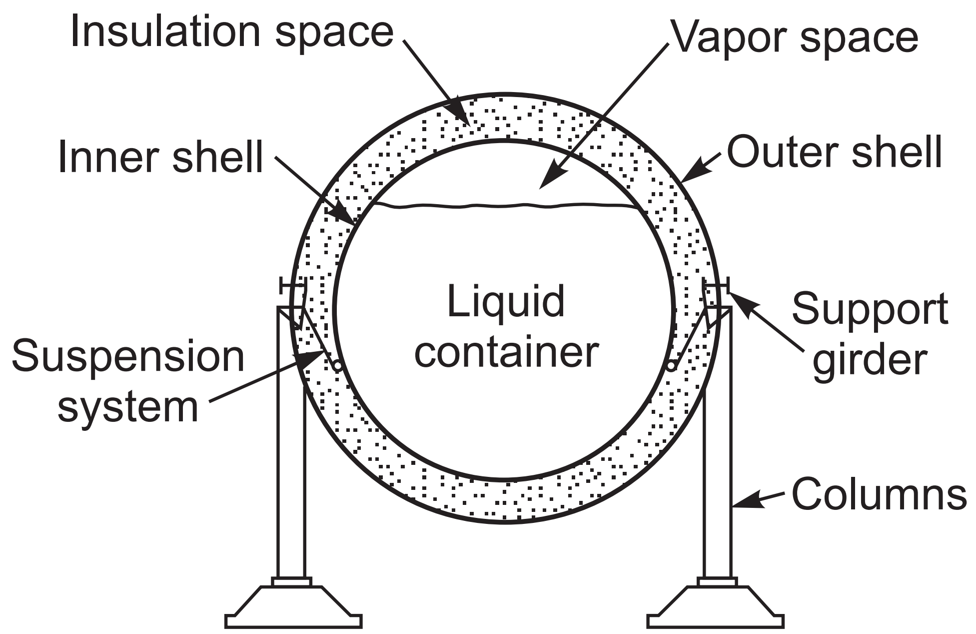


Fig. C-1. Liquid hydrogen storage vessel, inner container suspended from outer shell

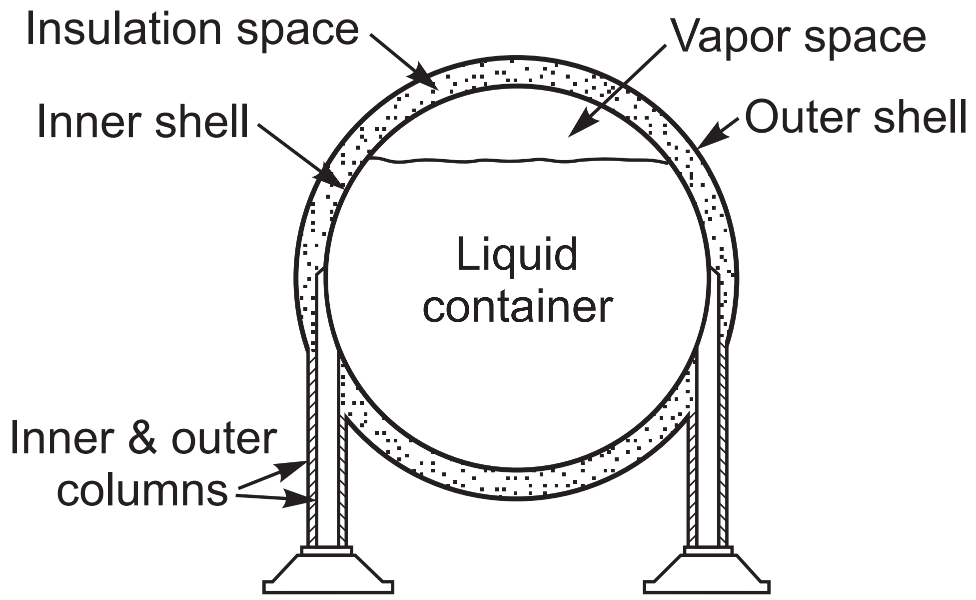


Fig. C-2. Liquid hydrogen storage vessel, inner and outer shells suspended by separate columns

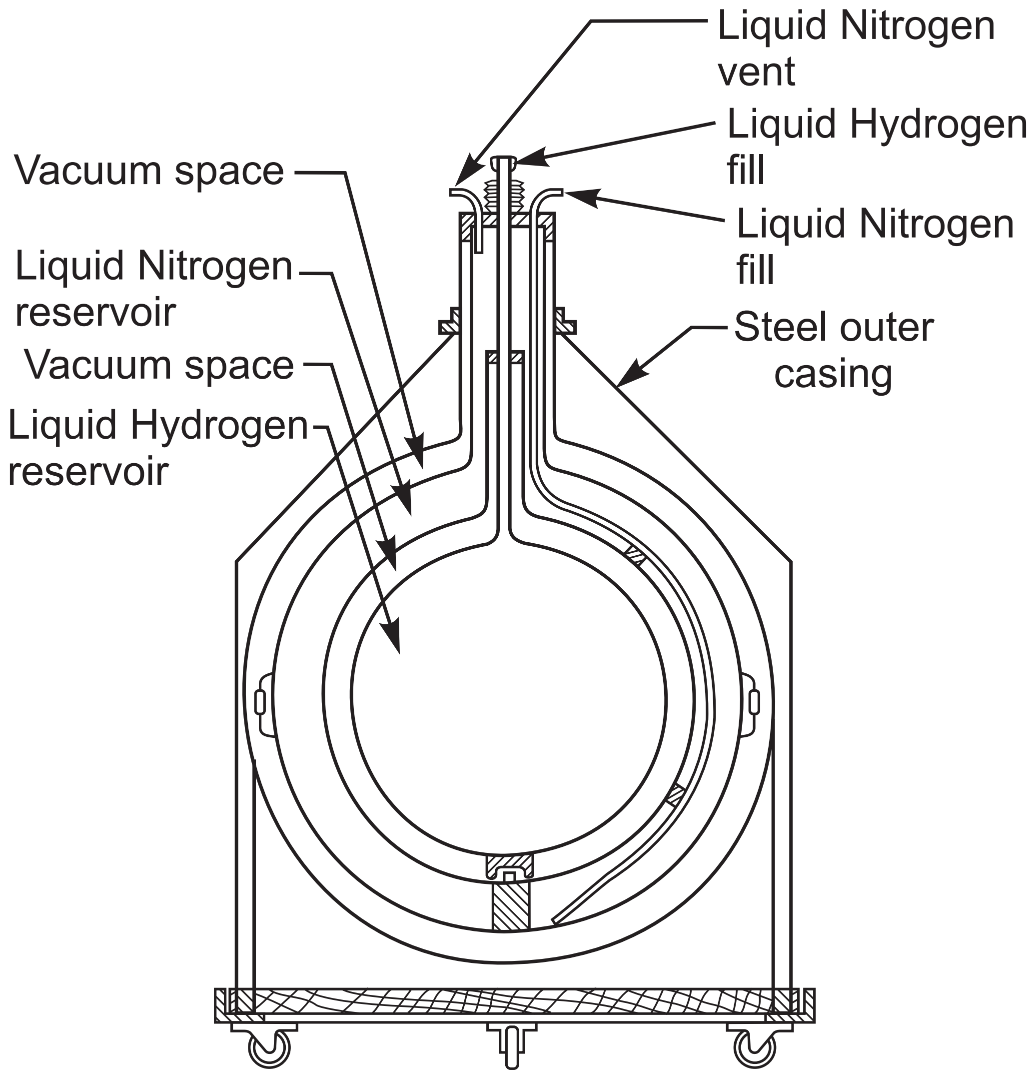


Fig. C-3. Portable liquid hydrogen container insulated with liquid nitrogen

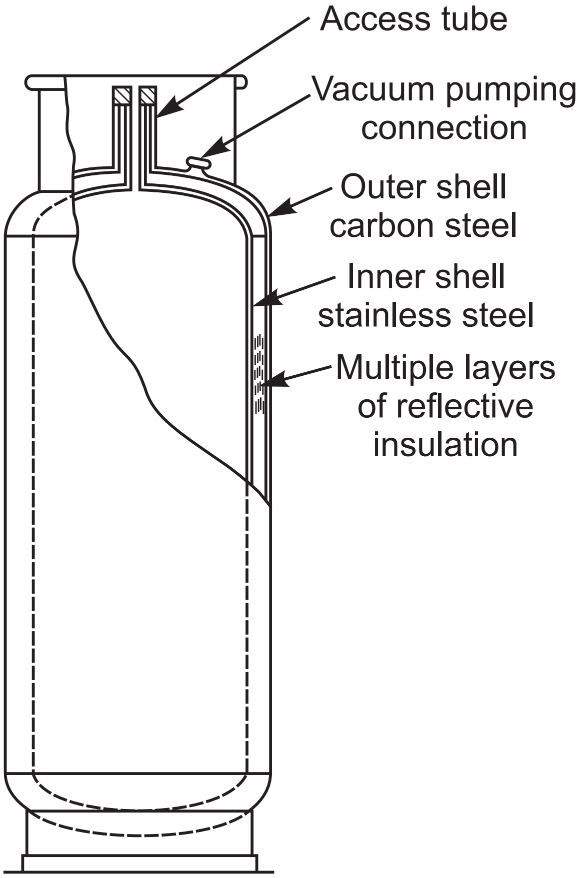


Fig. C-4. Typical Dewar flask, laminar insulated

Dewars use liquid nitrogen for insulation and are available up to 40 gal (150 L). A laminated-insulated cylinder is shown in Fig. C-4. Capacities of this type range from ½ pint (0.25 L) upward. A properly designed Dewar will vaporize 1-¼ of its liquid content per day.

Large volumes of gaseous hydrogen are stored in cylinders or mobile tube trailers. A typical hydrogen cylinder holds 260 ft^3 (7.5 m^3) at 2400 psig (16.6 MPa). Tube trailers have capacities ranging from 25,000 to 180,000 ft^3 (708 to 5100 m^3) and 2400 psig (16.6 MPa) pressure.