

Safetygram

Gaseous Hydrogen

Introduction

Hydrogen is a colorless, odorless, tasteless, highly flammable gas. It is also the lightest-weight gas. Since hydrogen is noncorrosive, special materials of construction are not usually required. The American Society of Mechanical Engineers (ASME) code and the American National Standards Institute (ANSI) Pressure Piping code specify vessel and piping design requirements for the pressures and temperatures involved. Applicable Dangerous Goods regulations specify requirements for vessels used for transportation.

Table 1 shows physical properties of gaseous hydrogen. As indicated by the specific gravity, hydrogen gas is much less dense than air and can disperse rapidly or accumulate in the upper sections of enclosed spaces.

Flammability

The wide flammability range, 4% to 75% in air, and the small amount of energy required for ignition necessitate special handling to prevent the inadvertent mixing of hydrogen with air. Sources of ignition such as sparks from electrical equipment, static electricity, open flames, or extremely hot objects should be eliminated.

Hydrogen and air mixtures within the flammable range can explode and may burn with an almost invisible flame.

Manufacture

Hydrogen is produced primarily by the steam reforming of natural gas.

The steam reforming process produces syngas, which is a mixture of hydrogen and carbon monoxide. The product stream is separated into its components and the hydrogen is dried, purified, and compressed into cylinders, pipelines or tubes for transportation.

Uses

Hydrogen is used in manufacturing processes for producing petroleum, steel, chemicals, foods and electronics. Refineries use hydrogen to produce cleaner burning gasoline and low sulfur diesel fuel, helping to reduce air pollution.

In the metallurgical industry, hydrogen is used to reduce metal oxides and prevent oxidation when heat-treating certain metals and alloys. It is also used as a fuel in alternative energy vehicles and may be used when welding and cutting metals. Hydrogen is also used by semiconductor manufacturers, primarily to form reducing atmospheres, and it is used in the chemical industry to synthesize ammonia and methanol.

Health

Hydrogen gas is odorless and nontoxic but may induce suffocation by diluting the concentration of oxygen in air below levels necessary to support life.

The amount of hydrogen gas necessary to produce oxygen-deficient atmospheres is well within the flammable range, making fire and explosion the primary hazards associated with hydrogen and air atmospheres.

Containers

Gaseous hydrogen may be supplied in cylinders or in tubes that are designed and manufactured according to applicable codes and specifications for the pressures and temperatures involved. The pressure rating and internal volume of a container determines the quantity of hydrogen it can hold. Cylinders may be used individually or can be manifolded together to allow for a larger gas storage volume.

Tubes are mounted on truck-trailer chassis or in ISO frames for transportation and are referred to as tube trailers or tube modules, respectively. Stationary tube (also called hydril tube) modules store large quantities of hydrogen at customer locations.

Figure 1 depicts a typical tube trailer for transporting large volumes of gaseous hydrogen. Tube trailers are available in capacities up to 126,000 standard cubic feet (3,570 m³) at 2,640 psig (183 bar) pressure.

A bulk gaseous hydrogen customer storage system commonly consists of 3 to 18 tubes with total capacities up to 150,000 standard cubic feet (>4,250 m³) of hydrogen. Stationary storage tubes have individual valves and safety devices and are manifolded together so the customer can withdraw product from a single tube or multiple tubes. Customer storage systems are commonly filled to 2,400 psig (165 bar).

Portable and stationary gaseous hydrogen fueling systems with service pressures up to 7,500 psig (500 bar) are also in use.

Specifications

In the United States, cylinders and mobile tubes are manufactured according to Department of Transportation (DOT)-3A or DOT-3AA specifications. Cylinders and mobile tubes are hydrostatically tested upon manufacture and tested periodically thereafter at 5/3 times the service pressure as specified by DOT regulations. Hydrogen may be stored in ASME coded and stamped, National Board registered high-pressure gas storage tubes as part of a stationary installation. These tubes are hydrostatically tested by the manufacturer but, unlike cylinders and mobile tubes, they do not require periodic hydrostatic testing.

Valves

Brass pressure seal or o-ring seal valves are typically used on cylinders and tube trailers. The standard hydrogen cylinder valve outlet connection in North America is the CGA 350 for pressures up to 3,000 psig. Different connections are used for hydrogen in other locations based on national or regional standards. Further information on valves and valve outlet connections is provided in Air Products' Safetygram 23, *Cylinder Valves* and Safetygram 31, *Cylinder Valve Outlet Connections*.

Pressure Relief Devices

Pressure Relief Devices (PRDs) are employed to reduce the likelihood of container failure in fire situations. These devices take the form of frangible disks, fusible metal plugs or pressure relief valves.

In North America and Asia, pressure relief devices are commonly integral parts of the cylinder valves and are installed on both ends of portable and stationary tubes. In Europe, PRDs are not commonly used on gaseous hydrogen cylinders or on portable or stationary bulk containers.

Table 1	
Properties	
Chemical Formula	H ₂
Molecular Weight	2.02
Boiling Point at 1 atm	−423°F (−252.9°C)
Freezing Point at 1 atm	−435°F (−259.2°C)
Critical Temperature	−400°F (−240°C)
Critical Pressure	186 psia (12.8 bar)
Density, Gas at 70°F (21°C), 1 atm	0.006lb/ft ³ (0.1 g/l)
Specific Gravity, Gas (air=1) at 68°F (20°C), 1 atm	0.07
Specific Volume at 70°F (21°C), 1 atm	192.0 ft ³ /lb (11.99 m ³ /kg)
Latent Heat of Vaporization	192 Btu/lb (446 kJ/kg)
Flammable Limits at 1 atm in air	4%–75% (by volume)
Autoignition Temperature at 1 atm	1040°F (560°C)



For further information on PRDs, consult Safetygram15, *Cylinder Pressure-Relief Devices*.

Shipment: Hydrogen

Compliance with applicable Dangerous Goods regulations is required for all shipments by motor freight, rail, air and water. These regulations describe the marking, labeling, placarding, and shipping papers required. International shipments by air must comply with International Air Transport Association/International Civil Air Organization (IATA/ICAO) Dangerous Goods regulations. Final acceptance for air transport is at the discretion of the airline. International shipments by water must comply with International Maritime Organization (IMO) regulations.

Safety Considerations

The hazards associated with handling gaseous hydrogen are fire, explosion, and pressure. Although hydrogen tends to dissipate quickly, its

minimum ignition energy is extremely low, allowing relatively easy ignition of hydrogen mixtures in the flammable range. Hydrogen is easily ignited by open flames, electrical sparks and static electricity. Hydrogen may detonate and ignite when rapidly vented into the air. Hydrogen burns with an almost invisible flame, and severe burns may result from unknowingly walking into a hydrogen fire. The fire and explosion hazards can be controlled by appropriate design and operating procedures. Preventing the formation of combustible fuel-oxidant mixtures and removing potential sources of ignition (electric spark, static electricity, open flames, etc.) in areas where the hydrogen will be used are essential. Adequate ventilation will help reduce the possible formation of flammable mixtures in the event of a hydrogen leak.

Hydrogen's autoignition temperature (AIT) is 1040°F (560°C). The AIT is the minimum temperature required to initiate self-sustained combustion. The relatively high autoignition temperature makes ignition of a hydrogen/air mixture unlikely from heat alone without an additional ignition source.

Purging

To prevent the formation of flammable mixtures, gaseous hydrogen systems must be purged of hydrogen before opening the system to the atmosphere, and purged of air, oxygen, or other oxidizers prior to admitting hydrogen to the systems. If the piping systems are extensive or complicated, multiple purging and evacuation cycles may be required for optimum results. Purging can be done using system evacuation, inert gas pressurizing-depressurizing cycles (cycle purging), flowing inert gas through the equipment or combinations of these methods. System configuration considerations including total volume, inclusion of piping “dead ends,” and availability of evacuation capability should all be taken into account when selecting the purging methods to be used.

Before opening a hydrogen-filled system to the air, the hydrogen concentration should be reduced to well below the lower flammable concentration (4%). The hydrogen concentration should be reduced to well less than 25% of the lower flammable concentration (below 1% actual).

Before introducing hydrogen into systems that were open to air, the oxygen concentration in the system should be reduced to less than 1% (well below the minimum oxygen concentration needed for hydrogen ignition). Additional purging will often be needed to meet higher purity application requirements.

Cylinder Handling and Use

Compressed gas cylinders must be stored properly, handled correctly, and used with the appropriate equipment to reduce the risk of incidents and injuries. Safetygram 10, *Storage, Handling and Use of Compressed Gas Cylinders*, describes good practices. CGA's publication P-1, *Safe Handling of Compressed Gases in Cylinders*, also provides safe handling guidance.

Be aware that refilling and shipping a compressed gas cylinder without consent of the owner is not allowed.

Gaseous Hydrogen Siting Recommendations

General

- Air Products can provide site-specific location recommendations for bulk gaseous hydrogen installations.
- The system should be located so it is readily accessible to delivery equipment and to authorized personnel.
- It is preferable to locate all bulk gaseous hydrogen systems outdoors. Total storage capacity of an indoor hydrogen system should be limited as much as possible and should not exceed 3,000 ft³ (85 m³) of hydrogen without additional engineering safety analysis.
- Systems must be located above ground.
- Systems should not be located beneath electric power lines.
- Systems should not be located close to flammable liquid or other flammable gas piping.
- NFPA 55 *Compressed Gases and Cryogenic Fluids Code* or equivalent local codes specify minimum recommended safety distances for various outdoor exposures from bulk gaseous hydrogen systems. Based on NFPA 55, Table 2 shows the minimum distance for various outdoor exposures for gaseous hydrogen system pressures of >250 to ≤ 3,000 psi and a maximum internal diameter of interconnected piping of 0.747 inches. For other pressure or diameter ranges, consult the latest edition of NFPA 55 or equivalent local codes.
- It is advisable to locate the system on ground higher than flammable liquid storage or liquid oxygen storage. Where it is necessary to locate the system on ground that is lower than adjacent flammable liquid storage or liquid oxygen storage, suitable protective means (such as diking, diversion curbs, or grading) should be employed. For hydrogen storage requirements, see the latest edition of NFPA 55 *Compressed Gases and Cryogenic Fluids Code* or equivalent local codes.
- Electrical equipment within 15 feet (4 meters) shall be in accordance with Article 501 or the National Electrical Code for Class 1, Division 2, Group B locations or in compliance with alternate codes where used.
- Gaseous hydrogen storage vessels and associated piping must be electrically bonded and grounded.
- If protective walls or roofs are provided, they should be constructed of noncombustible materials. If the enclosing sides adjoin each other, the area should be properly vented.
- The area within 15 feet (4 meters) of any hydrogen container should be kept free of dry vegetation and combustible material.
- Adequate lighting shall be provided for nighttime transfer operations where appropriate.
- The hydrogen storage location should be permanently placarded: “Hydrogen – Flammable Gas – No Smoking – No Open Flames,” or equivalent.

Indoor Storage Systems

- Provide adequate ventilation, particularly near roof areas where hydrogen might collect. Forced ventilation may be necessary in some applications.
- All vents should be piped to the exterior of the building and must be installed in accordance with local regulations.
- The atmosphere in areas where hydrogen gas may collect should be monitored with portable or continuous flammable gas air monitors calibrated for hydrogen.
- Where large quantities of hydrogen can be released indoors, provide an explosion-venting surface or vents, taking care to vent a pressure wave to areas where people or other equipment will not become involved. Explosion vents may not be required where small quantities of hydrogen are involved.
- Electrical equipment must conform to electrical codes in any area classified as hazardous (where elevated hydrogen gas concentrations can exist).
- Building materials should be noncombustible.
- Hydrogen storage inside a building should not be near oxidants or other combustible materials storage.

Personal Protective Equipment

Flame retardant protective clothing should be worn where possibility of fire exists. Safety glasses, safety shoes, and sturdy work gloves should be worn when handling cylinders.

Emergency Response

Only trained and qualified emergency personnel should respond to emergencies. For emergencies, a fire-resistant suit and gloves should be worn. Supplied air respirators or self-contained breathing apparatus (SCBA) is also recommended to reduce possible fire or heat injury to the face and airway. Responders must NOT enter or work in areas with hydrogen concentrations in the flammable range or where flammable/explosive atmospheres may be formed.

Table 2

**Minimum Distance (ft) from Outdoor Gaseous Hydrogen Systems to Exposures
System Pressure >250 to ≤3000 psi, Maximum Piping ID: 0.747 inches***

Type of Outdoor Exposure NFPA 55, Chapter 10, 2010 Edition	Minimum Distance from Hydrogen System (ft)
1. Lot lines; includes lot lines to other customer owned properties	45 ¹
2. Exposed persons other than those involved in servicing of the system	25 ¹
3. Buildings and structures	
Combustible construction	20 ³
Noncombustible non-fire-rated construction	20 ³
Fire-rated construction with a fire resistance rating of not less than 2 hours	5 ³
4. Openings in buildings of fire-rated or non-fire-rated construction (doors, windows, and penetrations)	
Openable; fire-rated or non-fire-rated	45 ¹
Unopenable; fire-rated or non-fire-rated	20 ¹
5. Air Intakes (HVAC, compressors, other)	45 ²
6. Fire barrier walls or structures used to shield the bulk system from exposures	5 ³
7. Unclassified electrical equipment	15 ³
8. Utilities (overhead), including electric power, building services, hazardous materials piping	20 ²
9. Ignition sources such as open flames and welding	45 ³
10. Parked cars	25 ¹
11. Flammable gas storage systems, including other hydrogen systems above ground	
Nonbulk (<400 scf for hydrogen)	20 ³
Bulk	15 ³
12. Aboveground vents or exposed piping and components of flammable gas storage systems, including other hydrogen systems below ground	
Gaseous or cryogenic	20 ³
13. Hazardous materials (other than flammable gases) storage below ground	
Physical hazard materials or health hazard materials	20 ³
14. Hazardous materials storage (other than flammable gases) above ground;	
Physical hazard materials or health hazard materials.	20 ³
15. Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, and combustible waste and vegetation other than that found in maintained landscaped areas	20 ³
16. Heavy timber, coal, or other slow-burning combustible solids	20 ³

* Based on NFPA 55 Compressed Gases and Cryogenic Fluids Code 2010 Table 10.3.2.2.1(a) Minimum Distance from Outdoor Gaseous Hydrogen Systems to Exposures (U.S. Units). Table 10.3.2.2.1(a) contains other pressure or diameter ranges.

¹ Distances can be reduced by 1/2 of the distance shown if a fire barrier is installed between the system and the exposure. The fire barrier must have a minimum fire resistance rating of 2 hours. The resultant distance should be measured from the downstream side of the fire barrier wall to the exposure.

² A fire barrier cannot be applied to air intakes and overhead utilities.

³ All distances except for air intakes and overhead utilities, unless otherwise noted in note 1, shall not apply if a fire barrier is installed between the system and the exposure. The fire barrier must have a minimum fire resistance rating of 2 hours.

Firefighting

Hydrogen is easily ignited by open flames, electrical sparks, and static electricity. Hydrogen may detonate and ignite when rapidly vented into the air. It will burn with an almost invisible flame. Most hydrogen fires have the flame characteristic of a torch or jet and originate at the point where the hydrogen is discharging. If a leak is suspected in any part of a system, a hydrogen flame can be detected by cautiously approaching with an outstretched broom, lifting it up and down.

The most effective way to fight a hydrogen fire is to shut off the flow of gas. If the fire is extinguished without stopping the flow of gas, an explosive mixture may form, creating a more serious hazard than the fire itself should reignition occur.

The usual fire fighting practice is to prevent the fire from spreading and let it burn until the hydrogen is consumed or can be closed off. An adequate water supply should be available to keep surrounding equipment cool in the event of a hydrogen fire. The local fire department should be advised of the nature of the products handled and made aware of the appropriate methods for combating hydrogen fires.

Additional Information

If more information is needed on hydrogen, please contact the Air Products Technical Information Center at 800-752-1597 or +1 610-481-8565. Material safety data sheets are available at www.airproducts.com/MSDS.

Emergency Response System

For assistance involving Air Products and Chemicals, Inc. products call:

- Tel 1-800-523-9374 (Continental U.S. and Canada)
- Tel +1 610 481 7711 (other locations)

24 hours a day, 7 days a week

Product Safety Information

- For MSDS, Safetygrams, and Product Safety Information
www.airproducts.com/productsafety

Technical Information Center

Monday–Friday, 8:00 a.m.–5:00 p.m. ET

- Tel 1 -800-752-1597 (U.S.)
- Tel +1 610 481 8565 (other locations)
- Fax: 1-610-481-8690
- E-mail: gastech@airproducts.com

Information Sources

- American Chemistry Council (ACC)
www.americanchemistry.com
- Asia Industrial Gases Association (AIGA)
www.asiaiga.org
- Compressed Gas Association (CGA)
www.cgnet.com
- European Industrial Gases Association (EIGA)
www.eiga.org

For More Information**Corporate Headquarters**

Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195-1501

tell me more
www.airproducts.com/productsafety