Safety Bulletin
Hydrogen Fuel Safety Concerns

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Hydrogen Fuel Safety Concerns

Hydrogen has potential as a clean source of fuel for use in fuel cells along with use as a fuel in a more traditional sense, through the direct burning of hydrogen or blended hydrogen gas. As research continues into the possible applications of hydrogen as a clean fuel it is critical to understand the unique safety concerns related to its use.

Physical Prop**erties**

Molecular Size

Due to its low molecular size, pipelines and vessels involved in hydrogen transport and use require special attention to material selection, seal design, and facility siting concerns.
This is a major concern for transporting hydrogen via pipeline, as the leak rate is much greater than what is seen in traditional natural gas service. The chart below depicts estimates on how different blended ratios of hydrogen gas and methane would impact annual leak rates in US gas pipelines. [2]

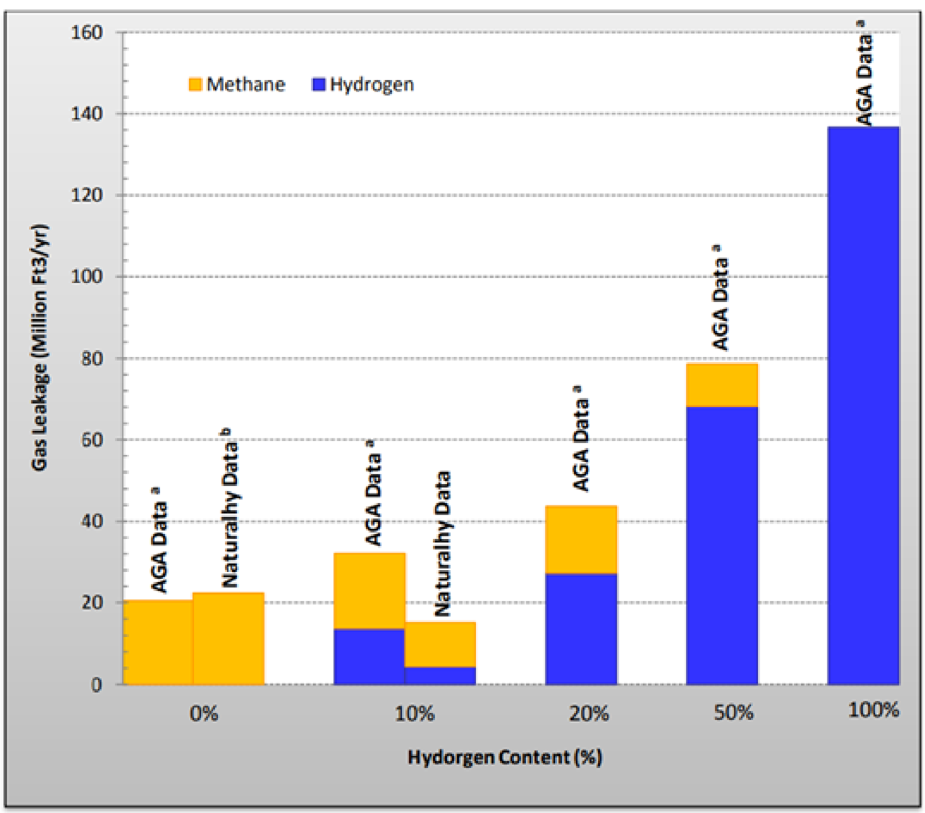

Figure 1: National Renewable Energy Laboratory (NERL) Estimate for Volume of Gas Leaked Annually Based on AGA Permeability Rates.[2]

In This Issue

This Safety Bulletin provides an overview of hydrogen fuel safety concerns, breaks down various hydrogen characteristics, and provides related hydrogen safety suggestions.

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Density, Buoyancy and Dispersion

- Gaseous Hydrogen

  Due to its low density, leaking hydrogen gas can quickly accumulate within an enclosure. Adequate ventilation, accounting for the buoyancy of hydrogen gas, is required to prevent the formation of hazardous atmospheres. For this reason, it is also important to install proper leak detection as well as H gas detection in all storage and handling areas.

  Cryogenic hydrogen gas (20 K – 23 K) has a density greater than air. As a result, a loss of containment of cryogenic hydrogen gas will not disperse as rapidly as a high pressure gaseous release. Additionally, as the gas warms, a cold fog will form as water vapor condenses from the air.

- Liquid Hydrogen

  Liquid hydrogen must be stored under pressure at cryogenic temperatures. This means that upon release, liquid hydrogen will begin to spill, but rapidly vaporize, expanding rapidly in volume.

  H has a gas/liquid expansion ratio of 865. This means that if liquid H loses its cooling, it will rapidly expand, displacing air if leaked, or building pressure if blocked in, likely rupturing piping or storage. Proper pressure relief and purging of liquid hydrogen systems are important for preventing. Pressure relief device sizing guidance can be found in CGA Pamphlet S-1.3 - Pressure Relief Device Standards Part 3 which deals with pressure relief devices in cryogenic liquids.

Embrittlement

Embrittlement is another factor of concern when using hydrogen. Embrittlement occurs as hydrogen atoms diffuse into a material, either forming small voids as molecules reform, or forming metal hydrides in the material. This leads to reduced ductility of the material which can increase likelihood of leaks or failure. The concern for these effects increases with increased pressure and hydrogen concentration.

The following are several of the mechanisms by which embrittlement takes place, along with a graphic depicting these mechanisms.

HELP – Hydrogen Enhanced Local Plasticity
HEDE – Hydrogen Enhanced Decohesion
HESIV – Hydrogen Enhanced Strain-Induced Vacancies

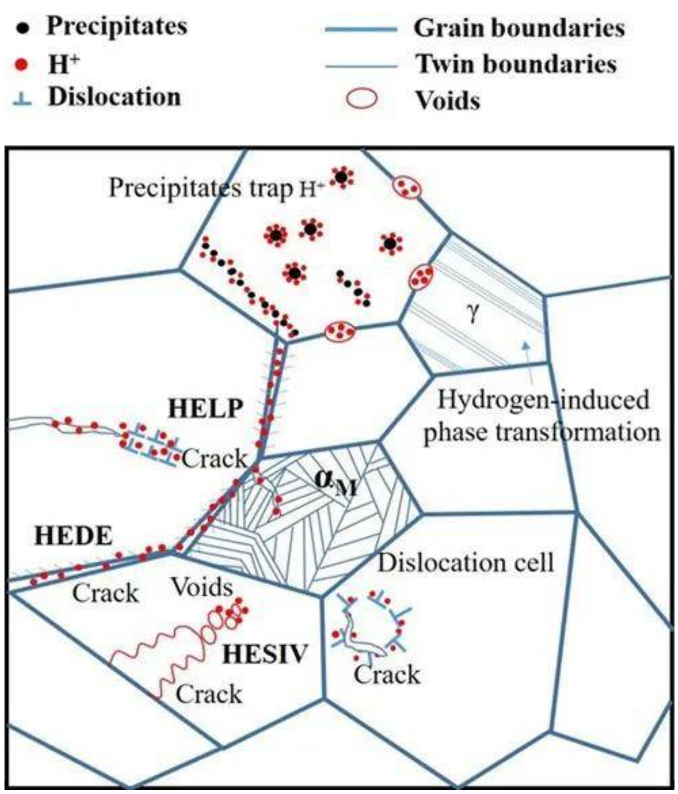

Figure 2: Hydrogen Embrittlement Mechanisms.

Flammability and Energy Capacity

While the Lower Flammability Limit (LFL) of hydrogen gas in air is higher than some common fuels, it has a Minimum Ignition Energy (MIE) that is an order of magnitude lower than that of other common fuels. As a result, hydrogen leaks are very susceptible to ignition.

Substance	Lower Flammability Limit (LFL) (%)	Upper Flammability Limit (UFL) (%)	Minimum Ignition Energy (mJ)
Hydrogen	4	75	0.016
Methane	5	17	0.21
Propane	2	10	0.25
n-Pentane	1.4	8	0.28

Table 1: Flammability Data of Hydrogen and Other Common Fuels.

Safety Suggestions

In order to avoid leaking and the impacts of embrittlement, hydrogen pipelines and storage should be designed with proper material of construction and process design in mind.

ASME B31.12 Hydrogen Piping and Pipelines provides design standards for hydrogen piping systems, including design equations, such as the equation presented below, which provides guidance on the relationship between the design pressure and nominal pipe wall thickness.

$$P = \frac{2St}{D} FETH_f$$

P= design pressure, psig
S = specified minimum yield strength, psi, stipulated in the specifications under which the pipe was purchased from the manufacturer.
t = nominal wall thickness, in.
D = nominal outside diameter of pipe, in.
T= temperature derating factor
E = longitudinal joint factor
H_f = material performance factor

Location Class[7]*	F, Design Factor[7]
Class 1, Division 2	0.5
Class 2	0.5
Class 3	0.5
Class 4	0.4

*Location Class is determined by the ASME B31.8 System Class Criteria. The location class is determined based on the number of buildings and the traffic density along a 1 mile section of pipeline.

Hydrogen Operations Material Selection

All pipes, valves, fittings, and other piping components should be properly rated for hydrogen service as specified by the manufacturer. The following is a list of material of construction suggestions from ASME, ICC, and other hydrogen industry best practices.

- Avoid gray, ductile and malleable cast iron
- Avoid nickel and most nickel alloys
- Commonly used materials of construction include austenitic stainless steels, aluminum alloys, copper and copper alloys (aluminum alloys should be avoided for liquid hydrogen services)
- Ferritic steels should be tested with scrutiny as they are susceptible to embrittlement

Material Selection Testing

- ANSI/CSA CHMC 1, *Test Methods for Evaluating Material Compatibility In Compressed Hydrogen Applications – Metals.*

  This test analyzes various mechanical properties of the metal being tested including ductility, fatigue, and fracture characteristics, along with stress factors. While advice on material selection exists, it is advised that materials for hydrogen operation should be tested to verify the physical properties.

Ventilation and Detection

- Mechanical exhaust or fixed natural ventilation shall be provided at a rate of not less than 1 scf/min/ft2 (0.0051 m3/sec/m2) of floor area over the area of storage or use.

  Hydrogen detection should be present in all hydrogen storage and handling areas, located in areas most likely for the gas to accumulate. Monitors should be set to alarm at 25% of LFL, or 1% H2 by volume.[1] Designs for monitoring systems should be based on ISO 26142:2010 *Hydrogen detection apparatus – Stationary applications.*

References:

1. https://cdn.standards.iteh.ai/samples/52319/a5cab00c94b942dd831df4fc3b2d0956/ISO-26142-2010.pdf
2. https://h2tools.org/bestpractices/hydrogen-leaks#:~:text=Because%20gaseous%20hydrogen%20consists%20of%20such%20a%20small,enough%20to%20cause%20a%20flammable%20mixture%20in%20air
3. https://h2tools.org/lessons/gaseous-hydrogen-leak-and-explosion
4. https://h2tools.org/sites/default/files/dispersion.pdf
5. https://www.engineeringtoolbox.com/explosive-concentration-limits-d_423.html
6. https://www.lanl.gov/orgs/eng/engstandards/esm/welding/vol2/WFP%202-01-Att-3-R1.pdf
7. https://www.researchgate.net/publication/267611438_ASME_B3112
8. https://www.sohu.com/picture/434050769
9. NFPA 2 Hydrogen Technologies Code. National Fire Safety Association; 2020.