Leak Testing with Helium for Blended Hydrogen Applications

Introduction

Energy systems are evolving to reduce environmental impact and face challenges related to resource depletion and a growing global population. Hydrogen, when produced through clean pathways, can be injected into natural gas pipelines to generate heat and power with lower emissions than using natural gas alone. A hydrogen blended natural gas is a mixture of hydrogen and natural gas that can be blended in any proportion, but typically a mixture of 10 to 20 percent hydrogen by volume represents the most promising near-term option.[5] The overall global hydrogen demand is expected to double within the next decade meaning there must be a practical way of delivering it to end users. A hydrogen blended natural gas allows for the initial deployment of hydrogen into the energy system without the need for expensive infrastructure investments.[5] It is intended to increase the output and decrease the carbonization of renewable energy systems. This paper will address the safety risks of a hydrogen blended natural gas, the necessary actions to reduce these safety risks and the process in which devices and equipment are considered acceptable for use in hydrogen environments.

Problem Statement

There can be complex engineering challenges associated with safely transporting a hydrogen blended natural gas. Currently, there is approximately 1,600 miles (about twice the distance from Florida to New York City) of existing hydrogen pipelines in the United States which are operating at pressures of 500-1200 psi. This can be compared to 3 million miles (about 4,828,032 km) of existing natural gas pipelines, of which in 2021 delivered around 27.6 trillion cubic feet of natural gas to about 77.7 million customers (about twice the population of California). Nearly 100% of U.S. transmission pipelines are steel with diameters of 4-48 in. These pipelines are typically operating at pressures of 600-1200 psig and in some cases up to 2000 psig.[4] Hydrogen blend limits are dependent upon the design and condition of current pipeline materials, pipeline infrastructure equipment and applications that utilize natural gas.

With the introduction of hydrogen in natural gas distribution systems comes many challenges. These challenges include pipeline compatibility, tolerance of end-use equipment, regulations, and standards, etc. One of the more concerning challenges that will be faced is the increased potential for leakage due to the smaller molecule size of hydrogen compared to a molecule of natural gas. The existing natural gas infrastructure must be assessed for compatibility with a hydrogen blended natural gas to ensure safe and accurate operation. Safety transcends all applications and is critical to the successful commercialization of hydrogen-based technologies.

Hydrogen has a very small molecular structure compared to the molecules that make up natural gas which in turn promotes higher rates of leakage. Volume leakage for hydrogen is about a factor of three higher and permeates 4 to 5 times that of methane. Hydrogen molecules are nearly 1/10th the size of methane molecules. This means that hydrogen has a greater risk of leaking from areas where natural gas cannot. Areas where natural gas has an opportunity to escape are now an even greater concern with the introduction of hydrogen.[6]

Areas of Concern

- Flanged connections
- Fixed connections (threaded, compression, welding, brazing, or gluing)
- Pipe fittings (pipe plugs, pressure measurement, temperature probes)
- Pores and cracks due to mechanical or thermal stress

Hydrogen leakage presents a key concern within natural gas distribution networks. Safety will transcend all applications and is vital to the successful commercialization of hydrogen-based applications.[5] There are several risks that come with adding hydrogen to natural gas being: hydrogen molecule separation and leakage, subsequent buildup in enclosures, all coupled with lower explosion limits. Accumulation of hydrogen increases the risk and severity of an explosion or fire. Hydrogen has explosive properties that make it extremely dangerous for use in a production or testing environment. Due to its smaller molecular structure, it is unable to react with odorant and in turn cannot be detected by smell. The odorant molecules are much larger, preventing it from escaping through leak paths that hydrogen can. Hydrogen burns clear and its molecules are much more energetic than methane. When compared to methane, hydrogen also has a much higher combustion. These differences in combustion properties can create complications for pipeline operations and end-user applications when blending hydrogen.[6]

Not only does hydrogen pose a risk of higher leakage, but it also causes economic and safety concerns because of the total gas loss. How do manufacturers in the natural gas industry ensure their products are sealed tight and leak resistant for use with a hydrogen blended natural gas? How do they qualify these products? How can municipalities, utilities and other stakeholders determine what blend of hydrogen their pipelines are able to safely handle? These are certainly the questions that must be asked.

Defining Leakage

Helium gas, when used for leak testing purposes enables the measurement of extremely small and finite leaks. Leakage can be characterized as a flow of gas from a higher pressure to a lower pressure through a fault in an assembled or manufactured part. These faults could stem from imperfections in the surface finish of parts, porosity in castings, poorly sealed connections, etc.

Leak Detection

A mass spectrometer, the mechanism that enables leak testing using helium, is simply an air sampling tool that takes highly accurate measurements using a series of pumps to quantitatively measure the amount of helium leaking from a closed vessel while contained within another test chamber.

Flow and pressure possess a linear relationship. As pressure builds, the greater the flow is across a leak path. The ideal approach to leak testing is to test with air or gas. It is non-destructive, measurable, and much faster when compared to dunk-tank or hydro testing in a production environment. In fact, using helium for leak testing can be between one thousand and one million times more sensitive than pressure decay techniques.[2]

Leak Rate

Leak rate is a function of the type of gas, pressure differential, the path, and temperature. It is necessary to determine the leak rate that can be tolerated, as no objects are 100% tight. Everything will leak under the correct conditions. Objects can leak in terms of ingress, penetration by dust or moisture, or egress, the loss of some internal state of equilibrium. The formula for leak rate is derived from the Ideal Gas Law[1]:

$$LR_{[scc/min]} = \frac{(V_{[CC]} \times \Delta P_{[psi]})}{(t_{[sec]} \times 14.69_{[psi]})} \text{ X } 60_{[sec/min]}$$

LR – calculated leak rate [standard cubic centimeters per minute]

V – test circuit volume (free air space within part, test line and pneumatics) [cubic centimeters]

ΔP – pressure loss (measured during test time) [pounds per square inch]

t – test time [seconds]

14.69 – atmospheric pressure [pounds per square inch]

60 – conversion constant [seconds per minute]

Pressure, volume, and temperature are all related in a closed system such as a leak test chamber. If the temperature of a part is changed during a test, the pressure within the part will also change. The higher the pressure the greater the odds are that there will be a flow across a leak path.

It is one thing to find a leak, but the leak rate determines the amount of gas leaking within a specified time period. In any leak test, there must be an accurate means of measuring the leak rate using a reliable and repeatable test. There must be an established acceptable leak rate and test cycle time. Any test object will eventually leak to some degree. No matter how exact specifications are, every part will have an allowable gas air loss measurement. The question that must be considered is what an acceptable leak rate is. The key is to establish a leak rate specification that will define the largest amount of tolerable leakage for a properly functioning test object that will still meet the customer's specifications.

Leak Testing with Helium

Leak testing with different gases and gas mixtures can be utilized for products that must be qualified as "acceptably" leak resistant to hydrogen. Helium is commonly used as a tracer gas for leak testing. Using helium in vacuum is one of the most sensitive and repeatable leak test methods.[3] Helium has one of the smallest molecular structures and unlike hydrogen, it is an inert gas which means it is non-combustible and non-flammable. Helium has three traits that make it an ideal tracer gas. It is non-explosive, non-toxic and non-destructive. These three characteristics ensure that helium will not interfere with or affect any materials used in the products being tested. The inert and odorless nature of helium makes it chemically inactive when it comes in contact with different material types. When leak testing with helium, smaller leaks can be detected than with other processes such as a dunk-tank or hydro testing. It is a largely temperature independent, dry technique.

Helium (He) has a smaller atomic radius of 28 picometers compared to hydrogen (H_2), which is 31 picometers as seen in

Figure 1. This allows helium to detect any leak paths hydrogen would also escape from. All leak testing must be thorough, accurate and most importantly done in a safe manner.

When leak testing with helium, it is paramount that the tooling and pipework necessary to create the test volume and gas supply must be to a leak tightness of a higher degree than the leak test threshold. Therefore, careful engineering of the seals is needed, most importantly where complicated seals are required.[2] Special consideration may be given to the sizing of the vacuum pipework. Most testing uses readily available balloon gas, but on certain occasions certifiably pure gas is used.[2]

In most helium leak testing applications, a mass spectrometer tuned to detect trace amounts of helium is utilized. A mass spectrometer is a sensitive piece of laboratory equipment that can be used in a production environment. Leak detection using a mass spectrometer is by far the most sensitive method and one that is most widely used in industry. A mass spectrometer will only work when under a vacuum. During helium testing, the test chamber and test object are evacuated of all air. The chamber is then subject to a vacuum and the test object is pressurized with helium. The test duration depends on the permissible leakage rate and the specific volume involved. The mass spectrometer then detects any helium leaking from the test object and measures the rate at which it is leaking. Once a device passes helium testing and is sealed against a leak rate that is considered acceptable, it is then qualified for use in a hydrogen environment.

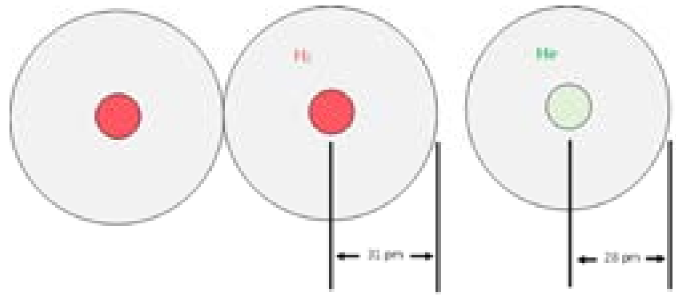

Fig 1: Atomic radio of helium (He) as compared to diatomic hydrogen (H_2)

Conclusion

As it has been stated, there are inherent safety risks when dealing with a hydrogen blended natural gas mixture. Increased risk for leakage is a more concerning issue because of hydrogen's small molecular structure and explosive properties. One way to certify products for use in hydrogen applications is to leak test using a tracer gas such as helium. Helium molecules are similar in size and can identify leak paths that would also be subject to hydrogen leakage. Understanding leak rates and calculating what is considered as acceptable is vital in conducting this testing. Hydrogen is too dangerous to use in most production settings, so helium becomes a more realistic solution for leak detection. All manufacturers of natural gas containment, transport, measurement and regulation equipment will need to qualify their products for hydrogen applications, and using helium is a promising method.

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