Hydrogen as Tracer Gas for Leak Testing

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Abstract: Helium is the most commonly used tracer gas for leak detection. However, it has a number of limitations in many industrial applications. The molecular weight of hydrogen is only half that of helium, and hydrogen has a much higher molecular velocity. As a result, hydrogen diffuses rapidly inside test objects, and dissipates far more quickly than helium. These properties, and the low price of hydrogen, make it a very attractive alternative.
There are two main reasons why hydrogen is not already more commonly used than helium as a tracer gas: a) the perception that hydrogen is too dangerous and b) the availability of suitable hydrogen detectors.
The flammability problem is easily solved by using a readily available standard mix of 5% hydrogen and 95% nitrogen, which is classified as non-flammable.
The other obstacle was overcome by the introduction of a new type of hydrogen detector, based on microelectronic hydrogen sensors. These have high sensitivity and selectivity to hydrogen. Moreover, they are cost-effective and sufficiently robust for industrial applications, allowing leaks of $5x10^{-7}$ mbarl/s to be detected using the 5% hydrogen mix. The use of hydrogen as a tracer gas is now increasing rapidly in the automotive, chemical, power generation, aerospace and telecommunications industries, among others.

Introduction:

There are many different technologies and methods currently in use for leak testing. Water baths and foaming agents, for example, are widely employed in industrial leak location, and are capable of detecting leaks with leak rates down to 10^{-3} mbarl/s. However, test objects need to be cleaned or dried after testing, and both methods are unsuitable for test objects where it is important to avoid exposure to moisture.
Leak testing often involves the measurement of pressure changes. In industrial conditions, this method, too, is capable of detecting leak rates of approximately 10^{-3} mbarl/s for small-volume test objects. With larger volumes, however, sensitivity decreases significantly. The accuracy of measurements is also affected by temperature fluctuations and elastic deformation of test objects. These variables must therefore be taken into account when determining leak rates. If leak testing by means of pressure measurement reveals leakage in excess of permissible levels, the next step is to locate the leak.
The tracer-gas method can be used for both leak location and leak testing. It is also ideal for locating smaller leaks. Test objects remain dry, and measurements are unaffected by temperature changes and elasticity. Various tracer gases are currently used for this purpose. Helium and hydrogen are most common for a wide range of industrial applications. Other gases, such as sulphur hexafluoride (SF_6) or carbon dioxide (CO_2), are employed for highly specialized applications.

Results

Hydrogen has a number of properties that make it particularly well suited to use as a tracer gas. It has a very low viscosity and the background concentration of hydrogen in ambient air is relatively low.

Comparison of the physical properties of hydrogen and helium with those of air:

	Hydrogen	Helium	Air
Dynamic viscosity	8.7 µPas	19.4 µPas	18.3 µPas
Background concentration in air	0.5 ppm	5 ppm	100 %
Mol. mass	2 g/mol	4 g/mol	29 g/mol

Assuming laminar flow (generally the case for leakage rates up to 10^{-5} mbarl/s), the amount of tracer gas that escapes through a leak during a defined unit of time depends on its dynamic viscosity. The background concentration of a tracer gas in ambient air affects the detection limit.
A standard mixture of 5% hydrogen (H_2) and 95% nitrogen (N_2) is generally employed in leak testing. Certified as non-flammable to ISO 10156, this gas presents no safety risks. It is primarily deployed as a shielding gas for welding, soldering, and brazing, and is usually provided by industrial gas suppliers in 200 bar (2.900 psi) and 300 bar (4.350 psi) pressurized gas cylinders. The mixture costs a fraction of helium, the price of which has recently risen sharply due to increased demand. Moreover, as global resources are finite, helium is expected to become even more expensive. By contrast, the cost of hydrogen, which is increasingly seen as a source of energy, is steadily falling.
Unlike helium, hydrogen is a renewable resource, which is an important consideration for environmental audits under ISO 14001. Furthermore, hydrogen is non-toxic and non-corrosive.
The physical properties of hydrogen also offer a number of practical benefits. Hydrogen diffuses much more rapidly than helium, quickly achieving uniform concentration within the test object. Evacuation of the test object is not generally required before testing. Moreover, there is far less risk of contamination. In addition, hydrogen does not adhere to surfaces, and can be flushed out much more rapidly.
The above factors make hydrogen the ideal tracer gas.

Discussion

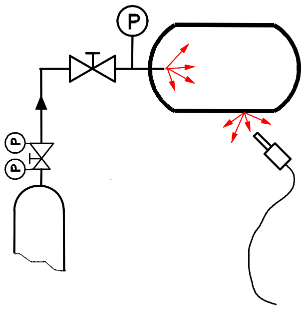
We have seen that hydrogen is highly suitable as a tracer gas. However, the hydrogen method requires a testing device with corresponding range and selectivity (i.e. exclusive to one gas).
The testing device presented here is based on a semiconductor sensor similar in design to a field-effect transistor. Hydrogen molecules adhere to the surface of the sensor, where they dissociate into hydrogen ions (protons). These protons can then penetrate the lattice structure of the sensor, where they cause a change in an electrical field, triggering a signal that passes along a signal-processing chain to be displayed by the testing device. The sensor responds selectively to hydrogen. The detection limit is based on the natural background concentration of hydrogen in air (0.5 ppm).
To detect a leak, the sensor, which is integrated into the probe, is placed directly over the leak. This means that no pumps are required to suck gas into the device. The sensor is linked to the testing device by a single cable. As a result, no filters or other maintenance-intensive components are needed. A further benefit is that this direct measurement method has very rapid response times, irrespective of the cable length, and very short recovery times. The sensitivity of the device can be adjusted at the touch of a button across a range from 1 to 4,000, depending on the task involved.
The easy-to-operate, rugged devices are ideal for industrial applications, and can be quickly and easily calibrated using a reference leak or calibration gas. During calibration, the current status of the sensor is displayed. A battery-operated version allows several hours of uninterrupted mobile use.

Conclusions

The hydrogen method is suited to applications where a flow of tracer gas is emitted from the test object. Differential pressure can range from zero to several thousand bar. Even with absolute differential pressure of zero bar, partial pressure differential is sufficient to cause hydrogen gas exchange via the leak.
The device is primarily employed to perform leak location or integral leak testing by means of the hood method.

Leak location

This type of detection is also commonly known as “sniffing” – which is not strictly accurate here, since tracer gas does not have to be sucked into the device. With forming gas (95/5), the detection limit is $5x10^{-7}$ mbarl/s. In the hydrogen industry, testing is sometimes performed with higher hydrogen concentrations – and corresponding safety measures – or even using pure hydrogen. Here, the detection limit drops in proportion to the concentration, enabling lower leakage rates to be detected.



Example applications:

- Leak location on objects of complex shapes.
  If a test object (e.g. engine, transmission or axle) has been found to be leaking, the leaks need to be located as quickly and accurately as possible to enable repairs. The properties of the tracer gas outlined above and the variable sensitivity of the testing device enable rapid, straightforward, and precise location of all sizes of leaks. Results are unaffected by background concentrations of hydrogen. Since tracer gas does not adhere to surfaces, the effectiveness of repairs can be conclusively verified by subsequent testing.
- High background levels of helium.
  Components previously tested using helium are often installed in cooling and air-conditioning systems. As a result, the background concentration of helium at the assembly site is too high for accurate subsequent measurement.
- Rapid leak location for vacuum systems.
  In vacuum systems where there are gross leaks or considerable moisture, leak location can be extremely time-consuming or impossible. Creating a sufficient vacuum is a difficult and prolonged process, which the hydrogen method accelerates significantly. Leak location can begin after the test object has been flushed with forming gas. Experience shows that the majority of leaks lie within the range of 10^{-2} to 10^{-5} mbarl/s, i.e. within the device measuring range. Due to the properties of the tracer gas described above, results are unaffected by the background concentration of hydrogen.
- Mobile applications
  In large, complex systems of the kind encountered in plant engineering, and the chemical and aerospace industries, leak detection is often extremely time-consuming. Where testing equipment is insufficiently mobile, and there are background effects due to the tracer gas, the process can take even longer. The hydrogen leak detection device described above is available in a battery-powered version for applications of this type.

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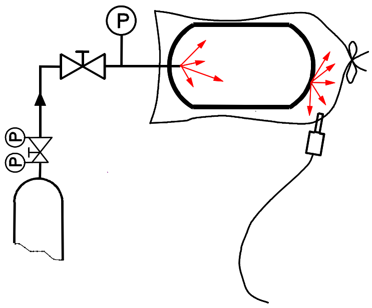
- Hydrogen systems
  Systems that run on or contain hydrogen, such as electrolysers, reformers or even fuel cells, can be tested during operation. This solution is particularly attractive for regular testing during ongoing operations, where there is a need to avoid system downtime.

Hood method (integral testing)

As in leak location, the test object is filled with tracer gas. The increase in the hydrogen concentration is measured in a known volume created around the test object. The duration of the test depends on the permissible leakage rate and on the specific volume involved. Depending on the application, the known volume is created using either a flexible hood or a solid enclosure.



Example applications
- Systems engineering
  With heat exchangers and valves, for example, it is important to check for leaks at the interfaces between individual areas, as well as for external leaks of the test object. In many cases, overpressure testing involves significantly less time and effort than vacuum methods. Independent studies verify that results of equal quality are achieved using both methods.
- Volume production
  In the automotive industry and refrigeration systems manufacture, components with low permissible leakage rates are often tested in a vacuum chamber. As a result, tests performed using this method often involve high capital expenditure and running costs. In many cases, leak testing can be performed in a simple test chamber at atmospheric pressure, considerably reducing investment and running costs.
- Research and development
  In R&D, it is often necessary to determine the leakage rate of a variety of test objects with a minimum of effort. Measurement using a flexible hood is particularly suitable. As described above, the tracer gas rapidly diffuses uniformly within the hood and does not adhere to surfaces, allowing repeated measurements to be quickly and easily performed.
- Car manufacturing
  The tightness requirements for fuel systems in cars are becoming ever more stringent. With conventional fuels, it is increasingly common to measure the total emissions of the stationary vehicle (PZEV standard). For hydrogen-powered vehicles, a simple test of the overall leakage rate of the entire vehicle is required. Measurements are performed using a hood.
- Permeability
  Testing of permeability is a specialized application. Forming gas is applied to one side of a material sample, and the increase in the hydrogen concentration over time is measured on the opposite side. This procedure is used for packaging materials and membranes.