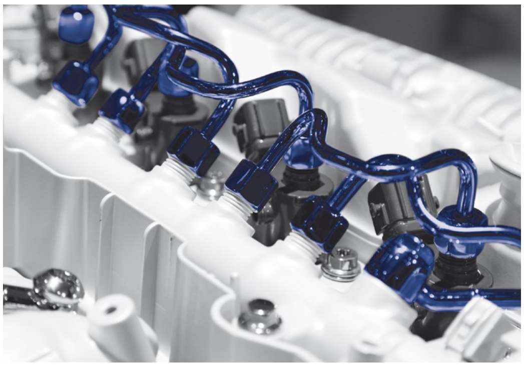
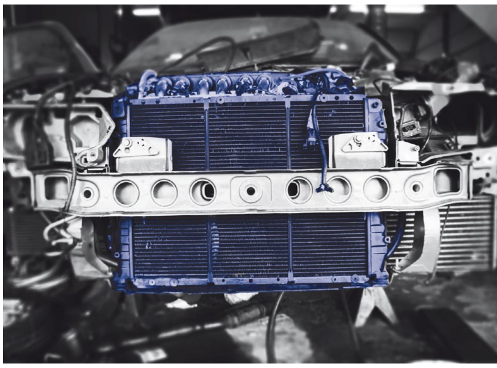
Leak Testing in the Automotive Industry





A Comprehensive Guide to Leak Detection

Foreword

Quality assurance is an issue of growing importance to the entire automotive sector. The demands are rising. Manufacturers already demand leak proof components from their suppliers. Vehicle components manufacturers define leak rates that must not be exceeded for volume production, whether it's an oil pan, brake boosters or injection valves.

It is critical that nothing escapes through leaks, such as the refrigerant in the air conditioning system, the transmission fluid in the torque converter of an automatic transmission, or the helium-argon mixture in the inflator of an airbag. As the demand for leak proof components increases, a stricter legislation may lead to new, stiffer tightness requirements. Just think of the stringent California and U.S. legislation regarding the emission of hydrocarbons and their implications for the leakage requirements for fuel tanks and lines.

Industrial leak testing and leak detection are not simple issues. Even the choice of the appropriate test method must be carefully considered. Which method is ideal for a specific application depends on many factors. Sensitivity plays a role, as well as the marginal leak rate of the method used, and the cycle times that can be achieved in integral testing on the production line. The repeatability and reliability of the testing process also should be considered along with the capital expenditure and operating costs, which are all based on the particular test method.

Part 1 explains the fundamentals of leak testing - Page 7

This e-book provides an overview of the broad field of leak testing and leak detection in the automotive industry and is divided into two parts. The first deals with the general principles of leak testing. The existing methods are described: bubble test, pressure decay testing, and helium testing in accumulation or vacuum chambers. The strengths and weaknesses of each process are explained, and attention is given to the typical challenges associated with each. The most commonly used tracer gases - helium, hydrogen and forming gas - are discussed, as well as final operating media such as R1234yf or CO_2. The various units of the leak rate, such as atm, cc/s, sccm, mbar, l/s and g/a are also explained.

Part 2 explains leak testing in the automotive industry - Page 25

In the second part of this e-book you will learn about the specific application of leak testing and leak detection processes in the automotive industry. It includes an explanation of which vehicle components are typically tested and the methods and leak rates employed. This section also provides some insight about where to expect increased tightness requirements in the near future. This includes components of the air conditioning system, the drivetrain emissions and any directly safety-related parts of the vehicle.

Part 2 illustrates in which applications older methods are not sufficient, such as bubble test, pressure decay and differential pressure methods. These methods sometime give a false sense of security. Last but not least, at the end of the second part, you will learn about the top 10 most common errors in leak testing. These includes contaminated test pieces, ignoring temperature and pressure changes in the testing process, and unidentified creep and gross leaks.

This e-book provides a reliable guide to leak detection that you can refer back to often as questions arise. However, the only way to avoid the many possible pitfalls of leak detection is to be properly informed. The proper selection, installation and operation of the optimal procedure, and the ideal test bench or system are all critical to your success. Contact INFICON , your leak detection solutions partner, with any questions you may have.

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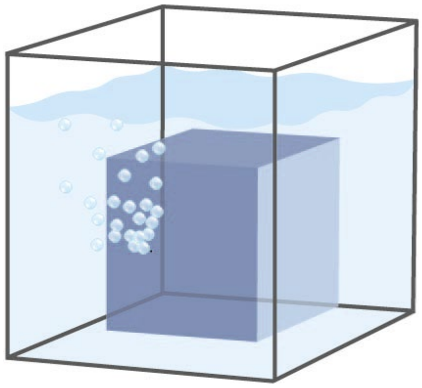
Part 1
Fundamentals of Leak Testing

1.1 Methods without tracer gas

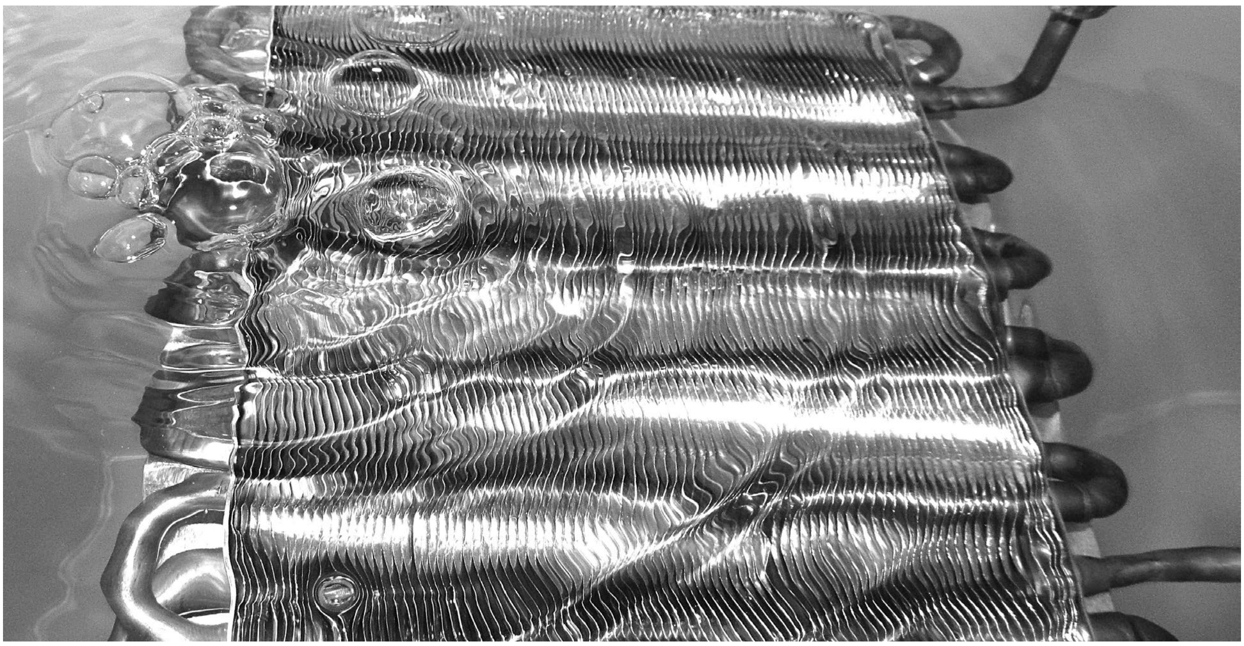
1.1.1 Bubble test

The water bath test, most commonly known as the bubble test is simply bubbles emerging from a test piece. Bubble testing is based on the assumption that what works with bike tires also will work well in production. In the bubble test method, the test piece is first filled with compressed air and then submerged in a water tank. The tester then observes whether bubbles rise. Ideally, the tester also can see where the bubbles are coming from. The bubble test is intended not only as an integral leak test, but also for leak detection. The test not only allows for a leak or no-leak statement, but also identifies the leak location.

For cost reasons, typically air is used for testing. In production conditions, leak rates of up to $5x10^{-2}$ mbar l/s (five hundredth of a millibar liters per second = 0.05 mbar l/s) can be identified reliably. With this leak rate there is a relatively clear and visible, albeit slow, stream of bubbles. With even smaller leaks, the test piece has to stay under water for a considerably longer time to produce just one bubble.



Water bath testing: as simple as testing bike tires



The detection limit of bubble testing deteriorates depending on the geometry of the test piece

In literature, a theoretical limit of detection (the smallest barely detectable leak rate) of up to $1x10^{-4}$ mbar l/s is usually quoted. Under ideal conditions, a leak rate of $1x10^{-3}$ mbar l/s (= 0.001 mbar l/s) will create one bubble per second. At a leak rate of $1x10^{-4}$ mbar l/s, it takes 30 seconds to form a single bubble. In real world applications, the detection limit of this method deteriorates significantly, depending on the geometry of the test piece and some other factors.

A bubble that would ascend unimpeded in free water will often be hindered from ascending from a test piece that has a complex shape. Also, if leaks are caused by porosity – for example in casted parts – in many cases no bubble will develop. Porosity leaks are often made up of millions of very small holes which together accumulate to a significant leak rate. However, each hole individually is too small to allow for enough air output to form a bubble due to the surface tension of water.

At first glance, a bubble test is very simple and inexpensive, but this method does have some disadvantages. One of the main problems is that after the bubble test, the test piece is wet and must be dried. This step is time consuming and costly, but must be done to avoid any consequential damage that may be caused by corrosion. This method is not suitable for test pieces that cannot tolerate moisture.

Another limiting aspect is the person testing the part, or the human factor. Whether bubbles are detected or not depends on the individual tester. Another problem that should not be underestimated is the clear view of the test piece and bubbles. If the test piece has a complex shape, or the location of the leak cannot be seen, a tester may not see the emerging bubble. There also is the inevitable process contamination. The water in the test tank becomes cloudy after four to eight weeks -- sometimes even within one day, depending on the condition of the part being tested -- and must be replaced. This often creates additional costs. To promote the formation of bubbles, typically chemicals are added to the water to reduce the surface tension of the water. The tank contents must therefore be disposed of as hazardous waste.

1.1.2 Soap spray test

The soap spray test is similar to the bubble test method. In both cases, the person testing the part has to observe the formation of bubbles. With the soap spray test, the test piece is also filled with compressed air (or another gas). The tester, however, does not immerse the test piece under water, but sprays it with a foaming liquid -- specifically at the locations where any leak is suspected. If air leaks at a location, the liquid begins to foam.

Advantages and disadvantages of the soap spray test are basically the same as with the bubble test. The procedure is simple and relatively inexpensive, but its success or failure depends on how alert the tester is in on any given day and the tester's individual skills. For objects that should not get wet,

An easily identifiable bubble at a leaky connection

A simple procedure: soap testing of a threaded connection

soap spray testing cannot be used, and small leaks are not detectable using this method. The detection limit of the soap spray test is theoretically about $1x10^{-3}$ mbar l/s. However, the detection limit is worse than using the bubble test ($5x10^{-2}$ mbar·l/s).

A particular problem of soap spray testing is gross leaks. The compressed air exiting from gross leaks simply blows the foaming agent away before any bubbles can form. There are two reasons why a lack of foaming is difficult for the tester to distinguish. First, the test piece without a leak behaves like one with a gross leak. Second, the soap spray may not stick to the surface of the part and simply drop off, making leaks on the bottom of a part very hard to detect with soap spray.

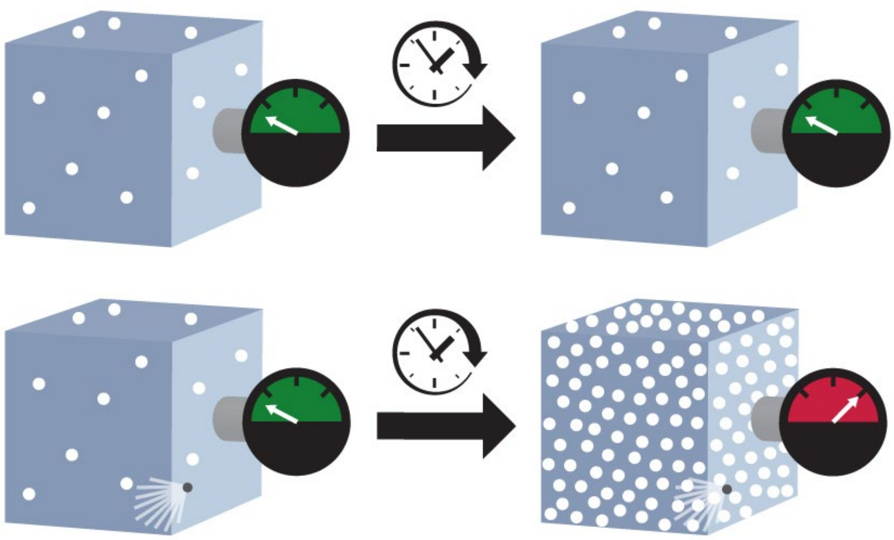
1.1.3 Pressure tests with air

There are three methods that identify leaks through measuring pressure changes: the pressure decay method, the differential pressure method and the pressure increase method. All three methods are used for integral leak testing, and their goal is a leak/no-leak statement for the entire part. Of these three methods used in the industrial sector, the pressure decay test is the most common.

1.1.3.1 Pressure decay test

With the pressure decay test method, the test piece is filled to a defined overpressure with air or another gas. After filling the test piece it is always necessary to wait before measuring until the parameters have stabilized and the pressure has settled. Usually this takes longer than the actual measurement. Exactly how long depends on the material and surface of the part being tested. The pressure in the test piece is then measured over a defined time interval. If the pressure reduces over time, there is a leak. The leak rate is calculated by multiplying the measured pressure variation with the internal volume of the test piece and divided by the length of the time interval. The theoretical detection limit of the pressure decay test is ultimately no better than that of the bubble test or soap spray test: 5×10^{-4} mbar·l/s, however, often only values of 1×10^{-2} mbar·l/s or higher can be achieved.

The primary reason why the sensitivity of the pressure decay test is 10 times worse is temperature fluctuations. The measured pressure is naturally dependent on the temperature.



The drawback of pressure decay testing (lower row with leak) is temperature fluctuations

A sample calculation:

If a test piece is filled to a volume of 3 liters with a pressure of 2.5 bar (25 psi), and the compressed air warms up to 40° C, the air then cools down again during the test interval of 20 seconds. If the air at the end of the measurement is only 1° C colder than at the beginning of the measurement, the pressure in the test piece is correspondingly less, and the leak rate appears larger than it really is by 1.2 mbar·l/s. As a result, it is a thousand times higher than the theoretical detection limit of $1x10^{-3}$ mbar·l/s.

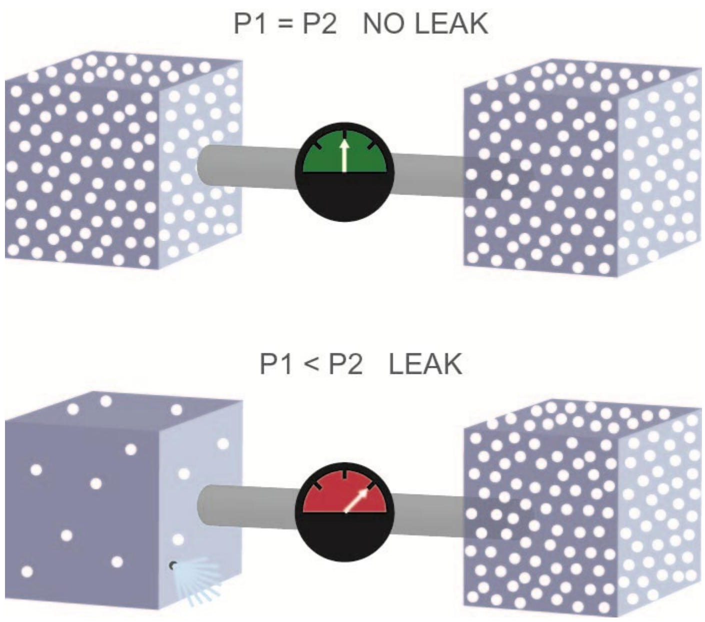
When using the pressure decay test, even a very small increase in temperature can cause a leak that cannot to be detected. If the temperature in a test piece increases during the measurement interval of 20 seconds by only 0.1°C, and with 3 liters of volume and 2.5 bar air pressure, there is an increase of the internal pressure to 2.50085 bar. Accordingly, any leak rate appears smaller than it actually is by a rate of 0.13 mbar·l/s. To reach the theoretical detection limit of 1×10^{-3} mbar·l/s (0.001 mbar·l/s) is, of course, impossible. The example shows that an increase in temperature of 0.1°C increases the detection limit by a factor of 100. This is why after filling, long settling times are built into the procedure so that pressure and temperature during the test are stable.

Temperature fluctuations are the biggest drawbacks of pressure decay testing. Temperature and pressure changes can be caused by sunlight, air movement, touch and by filling under pressure. Any test pieces that deform under the test pressure and change their volume, such as plastic parts, are difficult to reliably test using the pressure decay method. Also, any contact or deformation may quickly undermine the validity of each pressure decay test.

1.1.3.2 Differential pressure test

The differential pressure test also measures pressure differences. However, it compares the pressure in the test piece with the pressure in a reference object whose tightness is known. Both the test piece and the reference piece are simultaneously filled to the same overpressure. Any pressure differences are then measured with a differential pressure sensor for the duration of a defined time interval. The leak rate is the result of the pressure difference times the internal volume of the test piece divided by the time interval of the measurement. The difference between two pressures can be measured with a higher resolution than for the pressure decay method. The theoretical detection limit of the differential pressure measurement is 10 times better than that of the pressure decay test, $1x10^{-4}$ mbar·l/s.

Temperature fluctuations have less influence on differential pressure test, as long as the fluctuations act to the same extent and at the same time on both the test piece and the reference piece.



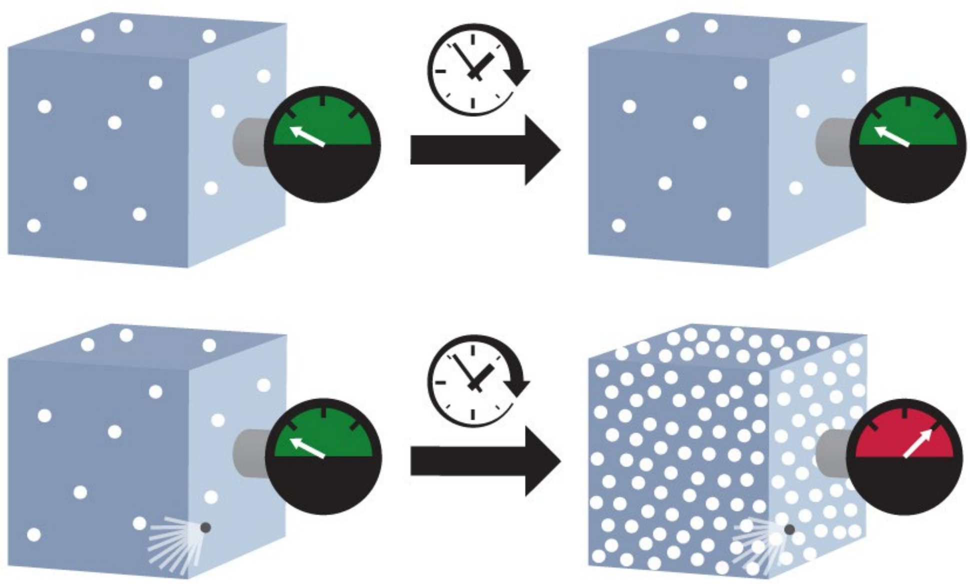
Differential pressure testing (lower row with leak) reduces temperature effects

However, the temperature effects as a result of filling only affect the test piece unless you also fill the reference piece anew every time. The problem is that after many fill cycles, the reference piece can become fatigued or accumulate heat from previous filling processes and then behave differently from the test piece. Ideally, you swap the reference piece for each test so it can settle down. Particular problems with the differential pressure test are more notable with easily deformable test pieces (such as plastic) or in those with a large volume. During regular use, the differential pressure test detection limits of $1x10^{-3}$ mbar·l/s are realistic.

1.1.3.3 Pressure increase test

The third variant of leak tests using pressure changes is the pressure increase test. In this case, a vacuum is created in the test piece. Then a measurement is taken to see how much the pressure rises inside the test piece over a given period of time. The leak rate is calculated by multiplying the internal volume of the test piece with the change in pressure and dividing by the measurement period. Theoretically, the method is 5 times more sensitive than that of the pressure-decay test: $1x10^{-4}$ mbar·l/s, but in actual use, the process usually has a detection limit of $1x10^{-3}$ mbar·l/s.

Limiting factors for the pressure-increase test – as for all pressure change processed – include the rigidity of the test pieces and the size of the volumes. In addition, most of the components are over-pressurized when in use. Therefore, the test situation with a vacuum in the test piece does not match the application. Some leaks occur only in one direction and can therefore not be detected using the pressure increase test. A principal advantage of the pressure increase test is that it avoids temperature effects by generating a vacuum in the test piece. At the same time, it also limits the usable pressure difference for the test. This amounts to a maximum of 1 bar – the difference between the atmospheric pressure outside the test piece and the vacuum inside the test piece.



The rigidity of the test pieces influences pressure rise testing (also called vacuum decay testing)

1.2 Methods with tracer gas

The methods using tracer gas are among the most sensitive leak testing methods. The most common tracer gases are helium and diluted hydrogen, which is normally used in a forming gas mixture. Leak testing and sniffer leak detection with tracer gases use the pressure difference that is created between the inside and the outside of a test piece so that the tracer gas can flow through a possible leak and be selectively detected.

1.2.1 Helium tracer gas

Helium is the most widely used of all testing or tracer gases. The noble gas only occurs atomically and is chemically inert. Helium is non-toxic and non-flammable. Also, its low molecular weight of only 4 makes it ideal to be used as a tracer gas. An important advantage is also its low background concentration: The natural concentration of helium in air is 5 ppm.

1.2.2 Hydrogen tracer gas (forming gas)

Probably the biggest advantage of hydrogen gas for leak testing and leak detection is the very low natural background concentration of hydrogen in air, which is 0.5 ppm. A disadvantage of pure, molecular hydrogen gas (H_2) is, of course, its flammability. Such risks, however, are not a problem, as pure hydrogen is never used as a tracer gas. For leak testing and leak detection, a so-called forming gas is used, which is a mixture of 95% nitrogen (N_2) and 5% hydrogen (H_2). The more affordable forming gas, which is also used as a shielding gas during welding, is non-flammable at hydrogen concentrations of 5% or less.

1.2.3 Operating fluid as tracer gases

Sometimes gaseous operating fluid is used for leak testing and leak detection. The test piece is filled according to its purpose and is then used for leak detection. For example, the propellant and refrigerant R-134a (chemically: 1,1,1,2-tetrafluoroethane) functions as the tracer gas at the same time, or sulfur hexafluoride (SF_6) which can be directly detected. This gas serves as an insulating gas for medium and high voltage applications and, for example, in gas-insulated high voltage switches and switchgear. SF_6 is the most effective quenching gas, but it is a greenhouse gas and its use as a pure tracer gas is prohibited. The same applies to many older refrigerants. All of the procedures that use the operating fluid as tracer gases are not used for integral leak testing during production, but to find subsequent leaks.

1.2.4 Inside-out and outside-in methods

Methods using tracer gas can be divided into two broad classes depending on the outlet or inlet direction of the tracer gas. Methods in which the tracer gas is introduced into a test piece so that it can be released into the environment from possible leaks are referred to as the inside-out method.

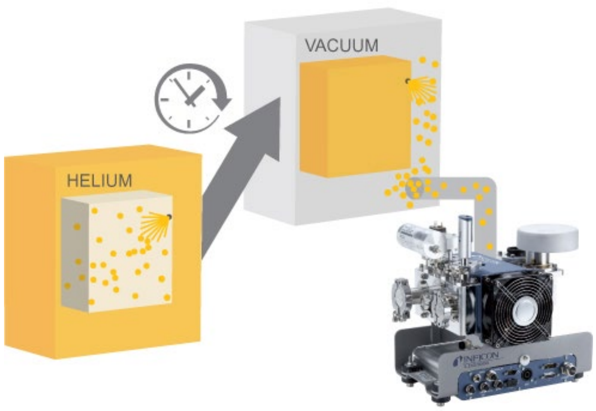
Inside-Out	Outside-In
Sniffer leak testing	Vacuum leak testing
Vacuum leak testing	Spraying
Accumulation leak testing	
Bombing	Bombing

A sniffer leak detection method is used to locate these leaks. When using the sniffer method, a measuring probe is guided manually over the test piece filled with the tracer gas. There are two very widespread methods for integral leak testing that work on the inside-out principle. One method is testing in the accumulation chamber. The second is testing in the vacuum chamber. Both measure how much tracer gas escapes from a test piece in the respective test chamber.

Both outside-in methods are based on the use of vacuum. In the vacuum leak detection test, a vacuum is created in the test piece and the tracer gas is sprayed from the outside. Location and size of the leak is determined by how much tracer gas inside the test object can be detected in a certain time interval.

The other outside-in method is the leak testing in a chamber. The test piece is placed in a chamber and a vacuum is created inside the test piece. The chamber is filled with the tracer gas, which then penetrates through any leaks into the vacuum in the test piece, where it can be measured.

The bombing method combines both the inside-out and outside-in methods. Bombing first uses the outside-in, and then the inside-out principle. The test piece is brought into the first chamber in which a tracer gas overpressure is produced so that the tracer gas enters through any leaks into the interior of the test piece. Then the test piece is placed in a vacuum chamber so that the tracer gas from the interior of the test piece can escape by the same leak into the vacuum chamber, where it can be measured. The bombing leak detection method makes sense for hermetically sealed test pieces without their own internal pressure, where evacuation or filling is not an option -- for example with sensor housings. Often the bombing test method serves to exclude a possible penetration of moisture.

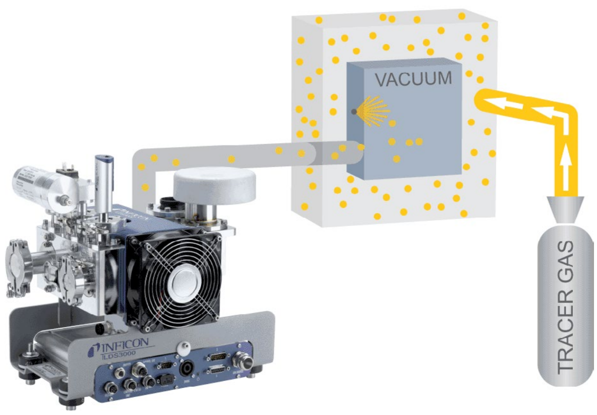


Leak testing via bombing lends itself to hermetically sealed test pieces

One difficulty with this method can be that the test piece is usually not filled to 100% with helium, which degrades the detection limit. Another problem is posed by gross leaks. If during the evacuation of the vacuum chamber the helium contained in the test object is also fully evacuated, then later no helium can escape and be measured - the test piece will appear incorrectly as leak proof.

1.2.5 Vacuum method

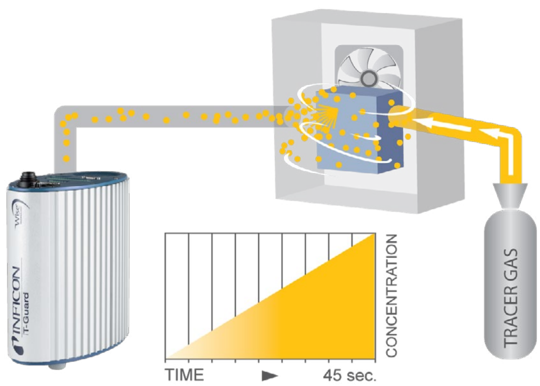
Integral leak testing in a vacuum chamber is often an inside-out test. The test piece is first placed in a chamber, either manually by an operator or automatically, by a robot arm. A pump generates a vacuum in the test chamber, and the interior of the test part is filled with helium via corresponding connections. Although this method is relatively expensive because of the more stringent leak rate requirements for the chamber and the costly vacuum pump, it does have some major advantages. First, the helium testing in the vacuum chamber is the most sensitive of all of the tracer gas methods. The mass spectrometer used for the detection of the helium can, under best conditions, determine leak rates down to $1x10^{-12}$ mbar·l/s. The vacuum method is particularly well-suited for production line testing and in many automated production processes, where each part is subjected to integral leak testing. Another advantage of the vacuum method is short cycles and fast cycle times, especially in



Vacuum leak testing (with vacuum in the test piece) is often well suited for production line testing fully automated test sequences. In addition, the sensitivity of the vacuum method often allows for the reduction of the helium concentration significantly, to approximately only 1%, which also reduces the cost of the tracer gas accordingly.

1.2.6 Accumulation method

Tracer gas in the accumulation chamber also falls into the category of inside-out test procedures, but is much less expensive than a test in the vacuum chamber. The test piece is placed in a simple accumulation chamber, which is required to meet significantly less stringent sealing requirements than a vacuum chamber. Odor tightness is already sufficient for an accumulation chamber. The interior of the test piece is filled with a tracer gas -- often with helium.



Accumulation leak testing in a simple accumulation chamber does not need a vacuuum

The tracer gas then escapes from any leaks in the test piece. To insure that the tracer gas escaping is evenly distributed in the accumulation chamber, usually a fan is used. The leak rate is calculated by determining how much tracer gas escapes from the leak during a defined period of time and collects in a given volume in the test chamber.

Such leak testing with helium in an inexpensive accumulation chamber instead of installing, operating, and having to maintain an elaborate vacuum chamber, first became popular when INFICON brought its patented Wise Technology™ sensor to market. The inexpensive Wise Technology sensor measures exclusively the helium concentration, does not need any vacuum, and under best conditions can detect leak rates in the accumulation chamber as low as $5x10^{-6}$ mbar·l/s.

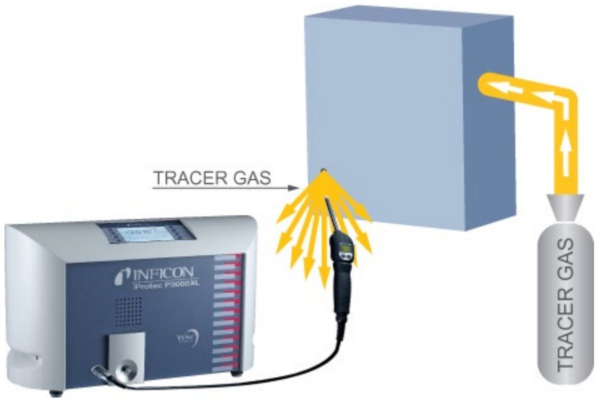
Leak testing using a mass spectrometer, on the other hand, normally requires a vacuum. The actual testing in the vacuum chamber takes two to three seconds, as opposed to a test in the accumulation chamber that takes about five times longer. However, when calculating the cycle time of a vacuum test, one must also add in the time for evacuation, which is not needed with the accumulation method. The accumulation method has a cost benefit two to four times lower than the faster vacuum test.

1.2.7 Accumulation method in a high vacuum

Particularly small leak rates can be measured by combining the principles of accumulation and the vacuum chamber. Currently the leak detector capable of detecting the smallest leak rates is a vacuum leak tester from INFICON. The Cumulative Helium Leak Detector (CHLD) Pernicka 700H works on the principle of accumulation in an ultrahigh vacuum. With its precise mass spectrometer, it detects the lowest leak rates down to as little as 4x10^{-14} mbar·l/s.

1.2.8 Sniffer leak detection

The so called sniffer leak detection with tracer gas is typically used to find the exact location of a leak. Often sniffer leak detection is used after a failure during an integral test. The sniffer leak detection also is an inside-out method: The part to be tested is pressurized with tracer gas so that tracer gas escapes through the leak. The sniffer tip of the leak detector is then guided across the surface of the test part (manually or by a robot) until the leak detector identifies the location with the highest leak rate. Because the sniffer line of the leak detector sucks in a mixture of air and escaping tracer gas, a low background concentration of tracer gas is desirable.

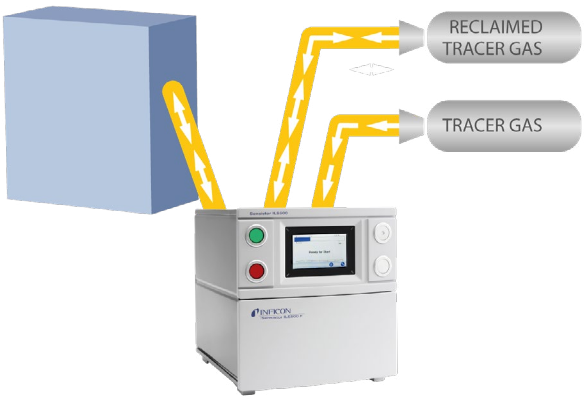


Sniffer leak testing (with manual sniffer probe) finds the exact location of a leak

For sniffer leak detection, helium or forming gas can be used as tracer gas, but gaseous operating media like refrigerants (R134a, CO_2, etc.) or SF_6 can be used. For a sniffer leak detector like the INFICON Protec P3000(XL), the smallest detectable leak rate is in the range of 1x10^{-7} mbar·l/s.

1.2.9 Evacuation, filling, gas recovery

When using the tracer gas method for integral leak testing, it usually is sensible to use an automatic filling device along with the actual sensor for the tracer gas. An automatic filling station allows the test pieces to be quickly and completely filled with the tracer gas. It also ensures the correct filling pressure – fluctuations in the filling pressure would skew the leak rate.



Tracer gas filling station INFICON ILS500F - for easy control of correct filling pressure and reclaiming of tracer gas. To achieve the highest productivity, however, INFICON can recommend a solutions provider.

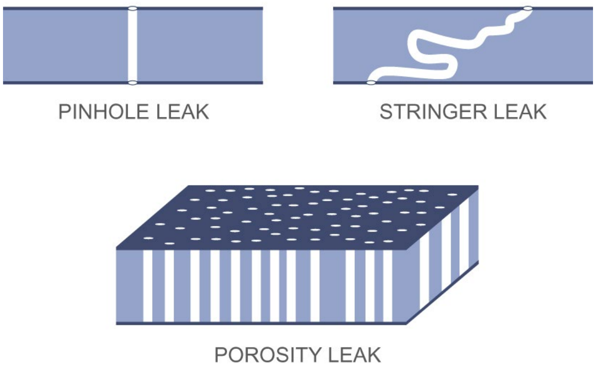
The re-evacuation following the leak testing prevents tracer gas from being released and accumulating in the work area, which eventually could distort the measurement results. Gas recovery systems also make it possible to regain 90% of the tracer gas used, which can then be used for further testing. If the detection limit of the leak testing is high enough, it also can be a useful and cost-saving measure either to reduce the tracer gas pressure or dilute the tracer gas. In both cases, however, the theoretically possible detection limit of the system is reduced accordingly.

1.3 Leak rates and types of leaks

1.3.1 Types of leaks

A leak is a structure in the wall of an object through which gases or liquids can escape. It may be a simple hole, a permeable, porous region or a stringer leak, which is often difficult to identify.

Stringer leaks pose a special challenge for leak testing. With a stringer leak the gases and liquids do not emerge immediately. They move slowly through a system of narrow channels or capillaries before they leave the interior of a test piece. It is also possible that larger volumes in the test piece wall have to fill before the gas escapes. This makes the detection of such leaks within short periods of time quite difficult.



Three basic types of leak geometries - permeation also shows a similar, delayed behavior

1.3.2 Units for the leak rate

A leak rate is a dynamic variable which describes a volume flow. The leak rate indicates how much gas or liquid passes a leak at a given differential pressure during a defined time. For example: If precisely 1 cm^3 gas under an overpressure of 1 bar emerges in exactly one second due to a leak, the leak rate is 1 millibars times a liter per second: 1 mbar·l/s. One could also say that the gas is escaping at a volume of 1 cm^3 at 1 bar pressure per second. Another alternative explanation of the unit: If the pressure in a container with a volume of 1 liter changes by 1 millibar per second, the leak rate is 1 mbar·l/s. When stating the leak rate in mbar·l/s, generally the exponential, scientific notation is used: so instead of 0.005 mbar·l/s it is written 5×10^{-3} mbar·l/s.

In Europe, the unit mbar·l/s has been widely accepted for leak rates, but volumes and pressures also can be specified in alternative units, resulting in a different unit of measurement for the leak rate. Internationally, measurements have been standardized to SI units, using the leak rate unit Pa·m^3/s. The United States often uses atm·cc/s. In pressure decay testing, the „standard cubic centimeters per minute“ (sccm) is a common unit to record the leak rate.

1 atm·cc/s	≈ 1 mbar·l/s
1 Pa·m³/s	= 10 mbar·l/s (SI unit)
1 sccm	≈ 1/60 mbar·l/s

For refrigerants such as R134a, leak rates are typically stated as a mass flow (escaping mass per year) rather than a volume flow (escaping volume at a given pressure in a specific period of time). Therefore, the unit g/a (grams per year) has been commonly accepted for refrigerants -- or in the U.S. oz/yr (ounces per year). The escaping mass always depends on the molecular weight of the gas. In the case of R134a the conversion is:

1 g/a = $7.6 \cdot 10^{-6}$ mbar·l/s	(only for R134a)

1.3.3 Size of leaks

It is useful to consider the relationship between a helium leak rate and the size of a leak. In other words: What diameter must a circular hole have to cause a certain leak rate? Provided the diameter of the hole is considerably larger than its wall thickness, a hole of 0.1 mm diameter at a pressure difference of 1 bar causes a leak rate of 1 mbar·l/s.

Diameter of the hole	**Size of the helium leak rate**
10^{-2} m = 1 cm	10^{+4} mbar·l/s
1 mm	10^{+2} mbar·l/s
0.1 mm	10^{0} mbar·l/s
0.01 mm	10^{-2} mbar·l/s
10^{-6} m = 1 µm (Bacterium)	10^{-4} mbar·l/s
0.1 µm	10^{-6} mbar·l/s
0.01 µm (Virus)	10^{-8} mbar·l/s
1 nm = 0.001 µm	10^{-10} mbar·l/s
10^{-10} m = 0.1 nm = 1 Ångström	~ 10^{-12} mbar·l/s

Most bacteria have a diameter between 0.6 to 1 µm. One Ångström is about the diameter of a single atom. Even at very small leak rates in the order of 10^{-8} mbar·l/s, you still have a hole through which many thousands of helium atoms can flow at the same time. Which exact leak rate is still tolerable in a specific case and which test piece can be said to fail leak testing is always dependent on the specific quality requirements in the production process. Accordingly, the selection of the test procedure should always consider the maximum allowable leak rate.

LEAK RATES

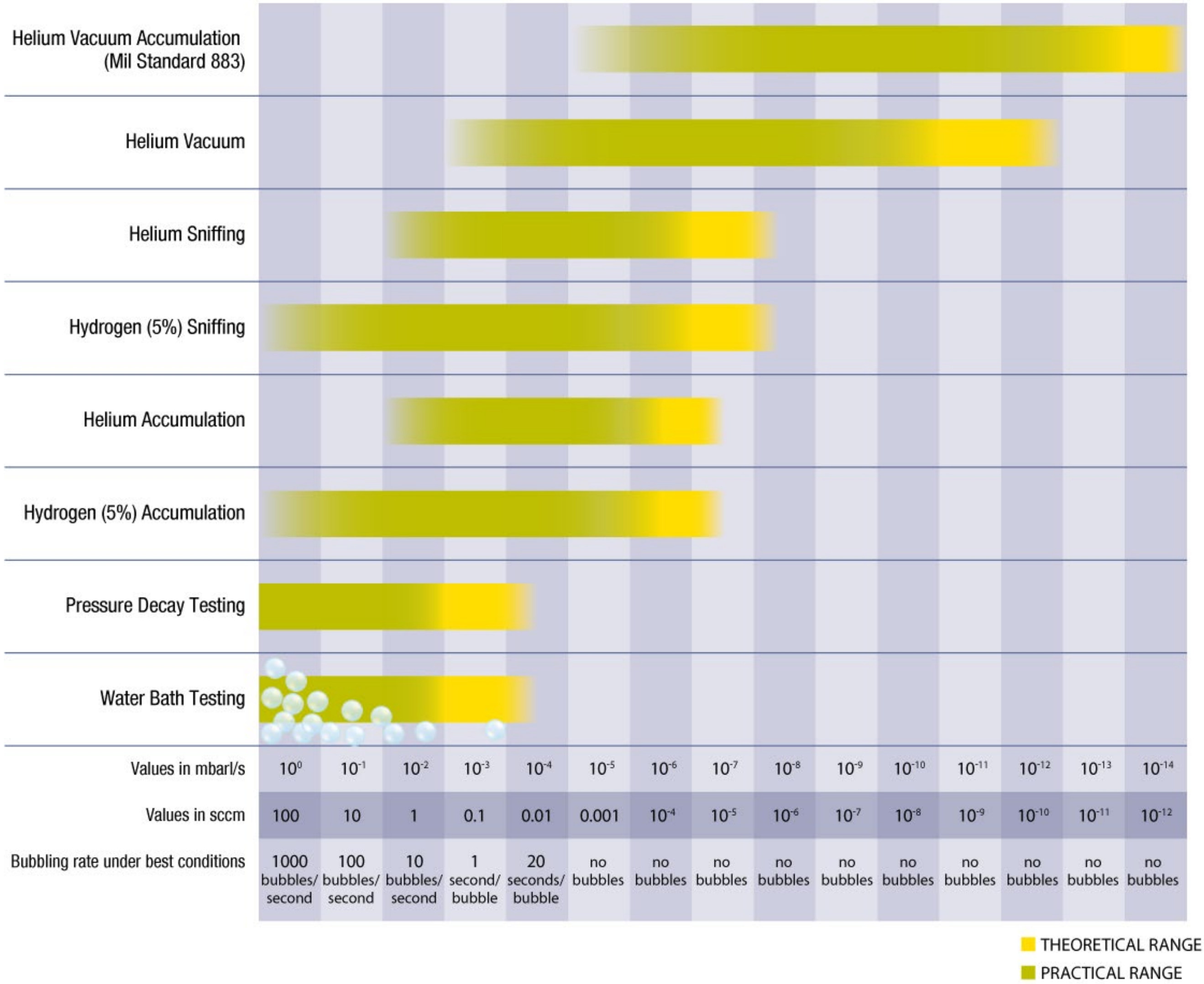
Requirement	Leak rate [mbar·l/s]	Leak rate [sccm]
Water-tight	$< 10^{-2}$	< 0.6
Oil-tight	$< 10^{-3}$	< 0.06
Vapor-tight	$< 10^{-3}$	< 0.06
Bacteria-proof	$< 10^{-4}$	< 0.006
Gasoline-proof	$< 10^{-5}$	< 0.0006
Gas-tight	$< 10^{-6}$	$< 6 \cdot 10^{-5}$
Technically leak-tight	$< 10^{-10}$	$< 6 \cdot 10^{-9}$

1.3.4 Factors influencing the leak rate

As described in the context of the pressure tests with air, temperature and pressure changes have a significant impact on the leak rate. Some test pieces, such as those made of plastic, deform quite readily under pressure and temperature changes. The geometry of a leak also may change under such conditions -- with corresponding effects on the leak rate, which is determined during the test.

Also, the exact difference between the pressure in the test piece and outside, of course, affects the leak rate. The greater the pressure difference, the greater the leak rate. When working with tracer gases, the detectable leak rate can also be dependent on the exact orientation of the leak.

The exiting tracer gas may not disperse evenly and because of a breeze of air it may not create the same concentration of tracer gas in all directions. For successful leak detection with tracer gases, such as helium and hydrogen and for localizing leaks with a manually guided probe, it is important to take this uneven distribution of tracer gas into account. Modern equipment for the helium sniffer leak detection, such as the Protec P3000(XL) draws in gas with a high gas flow of up to 3,000 sccm to overcome this problem.



Detection limits are important when choosing a suitable method for a given application

Part 2
Leak Testing in the Automotive Industry

2.1 Leak limits are becoming more stringent

Automotive manufacturers and suppliers are facing more stringent leak testing requirements than in years past. Quality assurance plays an increasingly important role, and car manufacturers expect their suppliers to implement appropriate quality control. If such leak tests are not reliable, this can lead to costly recalls and damage to their reputation. The most recent dramatic example was the recall of millions of products due to potentially defective air-bags. There was the risk of moisture ingress -- with serious consequences in the event of spontaneous airbag deployment.

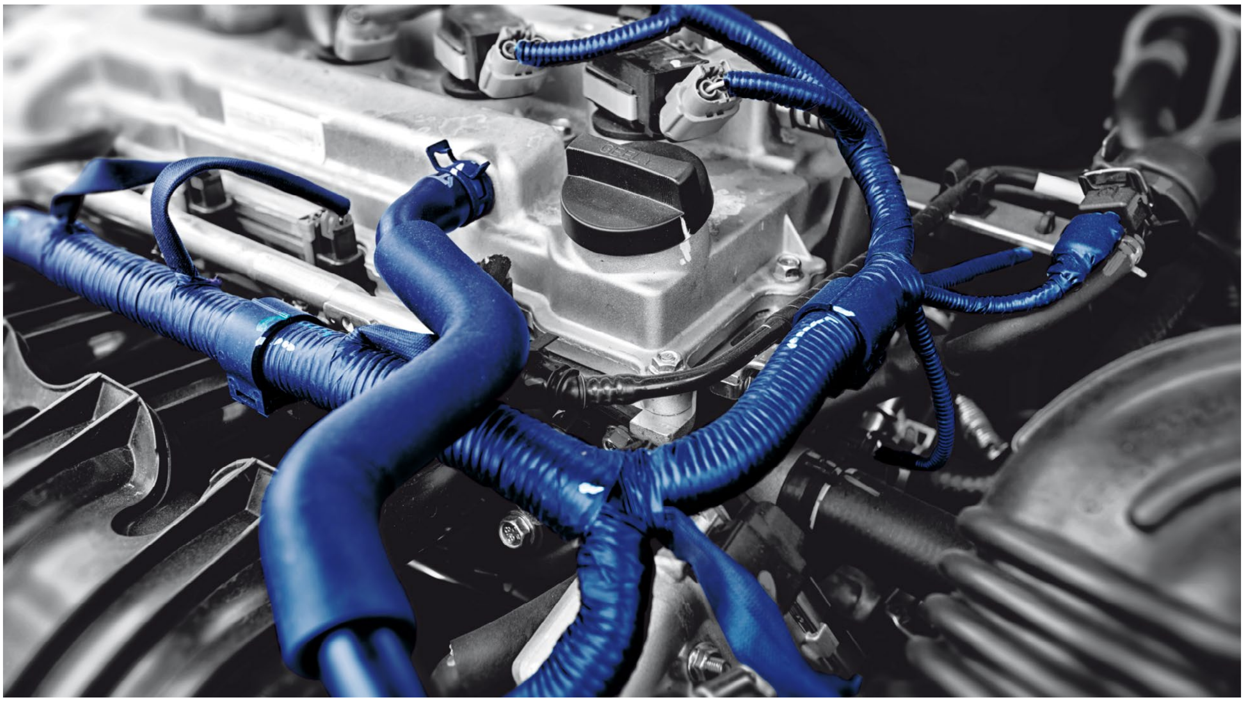
Such pyrotechnic inflators for airbags today are often checked to a maximum leak rate in the order of 10^{-6} mbar·l/s. Stringent leak rate requirements of this magnitude can only be met through the use of tracer gases. But the leak rate requirements for injection pumps and fuel systems are also becoming more demanding. One important reason for this is the use of fuel injection for increased fuel economy. Injectors in modern engines work under much higher pressure -- modern common rail systems operate with pressures up to 3,000 bar. In spite of the high internal pressure, the leak rate still must remain low, leading to more stringent inspections.

In the field of air conditioning systems used in cars, the industry is also progressing. The use of fluorinated greenhouse gases, like R134a are

being phased out. The EU Directive 2006/40 / EC prohibits the use of R134a refrigerants beginning in January 2017. In the USA, the Environmental Protection Agency announced deadlines to end the use of R134a because safer, climate-friendlier alternatives are now available. R134a will be banned in new motor vehicles starting in 2020 (model year 2021) and replaced by a coolant with a significantly lower Global Warming Potential (GWP). Alternatives, such as using CO_2 as a refrigerant are safe and can be gained from the atmosphere.

The use of CO_2, however, requires a tenfold increase in pressure and therefore involves correspondingly higher demands on the leak rate requirements of the components, as well as the entire system. Other new refrigerants such as R1234yf are flammable even at low temperatures and therefore cause a higher safety risk in the event of a leak.

Although the sealing requirements in the automotive industry are steadily increasing, the tightening of these requirements is never viewed as an end in itself. Car makers and suppliers must keep the cost-benefit ratio in mind when it comes to finding the most useful, cost-effective quality assurance method for a specific purpose and for its implementation. That choice never depends solely on which leak rate limit a component must be checked for. When choosing the optimal method, factors such as automation, speed and reliability of the test always play a role. A bubble test may be simple, but do human testers always see the leaks that they should see? At the other extreme: The detection limit (sensitivity) and



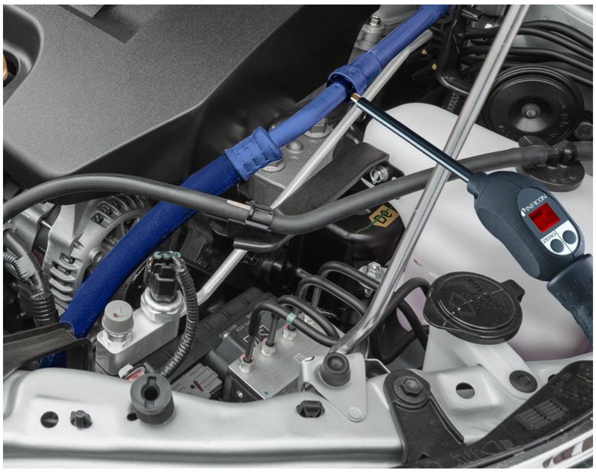
the speed of automated helium testing in a vacuum chamber are unmatched, but is this extensive and costly effort always justified? A simpler leak test in the accumulation chamber with special helium sensors is often more effective and gives a better balance between quality assurance and cost.

The choice for the optimal leak detection method is often influenced by the human factor. Human nature tends to lean heavily on the senses. That is another reason why bubble tests and leak detector spray are still used in many application scenarios where they should have been better replaced by a tracer gas solution. The tester wants observable evidence and wants to see the leak. When the helium exiting from a leak is measured using the tracer gas method, it is more accurate, faster, more reliable and reproducible than any visual check -- but the procedure is more difficult to learn than looking for rising air bubbles. Testers sometimes are bound by traditional methods, even though those methods can be quite inaccurate and misleading. Even today, some air conditioning components are submerged under water for testing, despite the fact that the leak rate limit of this method is 10^{-3} mbar·l/s, which is much too high for such an application.

2.2 Components, methods, and typical leak rates

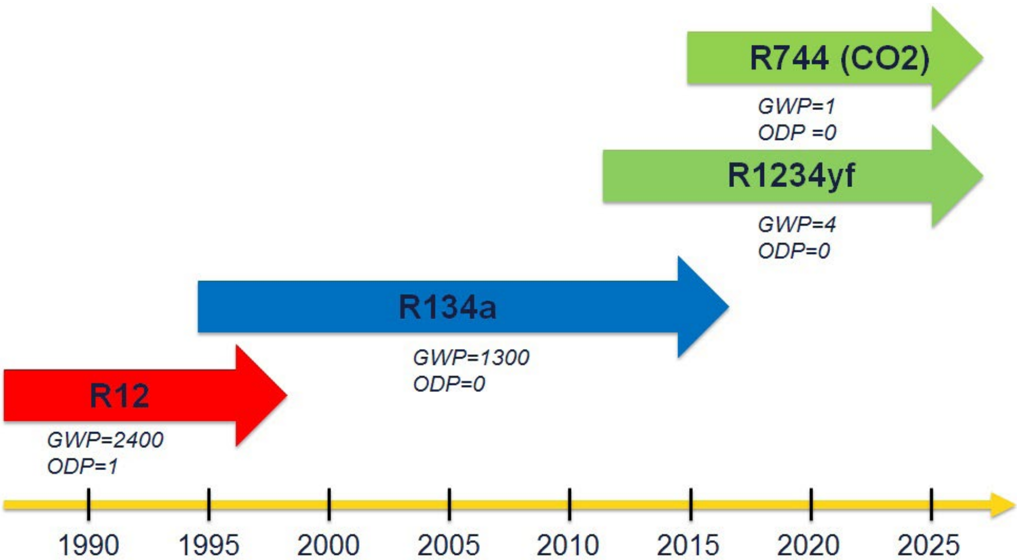
2.2.1 Air conditioning

Beginning in 2017 in Europe and with model year 2021 in the USA, the well-known refrigerant R134a will be banned as a highly climate-damaging fluorinated greenhouse gas. Replacements include R1234yf (chemically: 2,3,3,3-tetrafluoropropene), which, unfortunately is classified as extremely flammable and also reacts when heated to form highly corrosive hydrofluoric acid. R1234yf also is by far more expensive than R134a. Both of those factors are prompting manufacturers to calculate a lower reserve of refrigerant for their systems, which in turn, increases the leak rate requirements. R1234yf is favored currently by car manufacturers in Asia and the U.S. German automakers are looking at another popular alternative: carbon dioxide (CO_2).



Sniffer leak detection with a manual probe detects leak rates up to $1x10^{-7}$ mbar·l/s

Using CO_2, however, creates quite different technical requirements for air conditioning systems because it is used with a significantly higher operating pressure -- up to 120 bar. Whether the choice is R1234yf or CO_2, the leak rate requirements for air conditioning systems and their components are rising.



Refrigerants are being phased out regularly and replaced by newer, more environmentally friendly substances (GWP: Global Warming Potential, ODP: Ozone Depletion Potential)

The old rule of thumb – a maximum leak rate of 5 grams of R134a per year will most likely be obsolete when introducing new and future refrigerants.

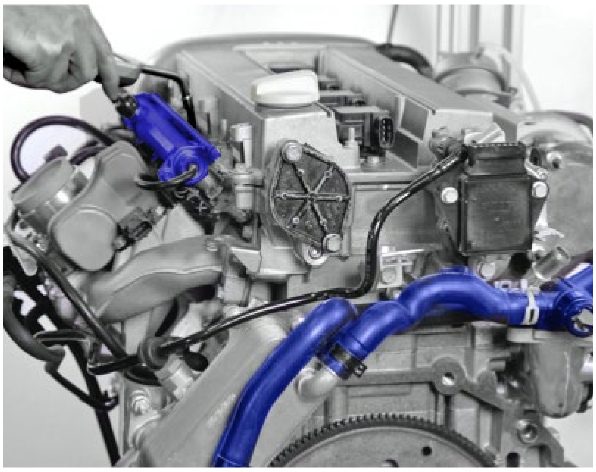
A refrigerant loss of 5 grams per year corresponds to a helium leak rate of $4x10^{-5}$ mbar·l/s. Most air conditioning components are currently tested for leak rates in the order of 10^{-4} to 10^{-5} mbar·l/s. For air conditioning hoses, a helium test in a vacuum chamber is used in order to achieve short cycle times. Components such as evaporators, condensers or filling valves can be tested in accumulation or vacuum chambers. To perform a gross leak test on air conditioning systems before filling with refrigerant, the pressure increase and pressure decay methods are still widespread. However, they can only determine large leak rates in the order of 10^{-2} to 10^{-3} mbar·l/s.

Automakers already expect suppliers to implement quality assurance and checks for leaks on the component level. After the installation of the air conditioning system on the assembly line, an additional leak test on as many as three to six joints of the air conditioning system, which have been created during final assembly by the car manufacturer, is needed. Automakers strive to have as few such connections as possible, especially in more expensive vehicles with extensive interior cladding, which limits access to potential leak sites.

Leak testing of the junctions normally takes place in final assembly with a sniffer leak detector. In the past, forming gas or helium was used as a tracer gas, but now sniffer leak detectors can detect the respective refrigerant and measure traces of escaping R134a, R1234yf or CO_2.

2.2.2 Powertrain

For many powertrain components integral leak testing methods are used, such as pressure decay or differential pressure. Typical leak rates for checking oil circuits of engine blocks or cylinder heads, for example, are approximately 10^{-1} to 10^{-2} mbar·l/s (~ 12 to 1 sccm). For water circuits of engine blocks and cylinder heads, on the other hand, it is sufficient to have 10^{-1} mbar·l/s (~ 10 sccm). Water tightness would only be guaranteed with a limit leak rate of about 10^{-3} mbar·l/s (~ 0.05 sccm). Such leak rates, however, often cannot be tested using the pressure decay method.



For engines, sniffer leak detection using tracer gas is cleaner, more efficient and more accurate than leak testing spray

With torque converters, the standard for the allowable leak rate was previously 10^{-2} mbar·l/s. But given the increasingly popular and technically demanding 9- and 10-speed automatic transmission, future leak rates in the order of 10^{-3} or even 10^{-4} mbar·l/s will need to be detected. Testing of a modern, fully automatic transmission is best done with tracer gas in the accumulation or vacuum chamber. This also applies in charge-air coolers, where there is a typical leak rate of 10^{-3} mbar·l/s. Here integral leak testing with helium is well-suited.

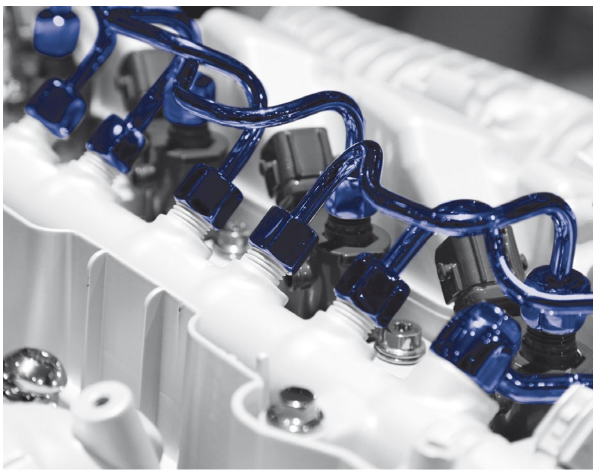
If a test piece fails the leak test, it is often still submerged in water to locate the leak. With cast-iron housings, this may still be a viable and relatively quick method. But to submerge a modern, fully automatic transmission worth several thousand dollars in water and then dry and clean it again is costly and is not the best method to locate a leak. In addition, the bubble test method to find a leak has a proven detection limit of only 10^{-2} mbar·l/s, which is a hundred to a thousand times worse than the leak rate that was detected in the previous leak test. Using a sniffer leak detector and tracer gases, such as helium or forming gases, are preferable in this situation, particularly because a water bath always bears the risk of rust and damage to electrical components.

In many cases, a test tank is still used simply because no one has reviewed the choice of the leak testing method. But as a general rule of thumb: the larger the test piece, the more often the soap spray test is used instead of the bubble test. For engine blocks, leaks are often localized using leak detector spray, but the subsequent drying and cleaning effort is still unavoidable. Sniffer leak detection using tracer gas is cleaner, more efficient and more accurate.

2.2.3 Fuel systems

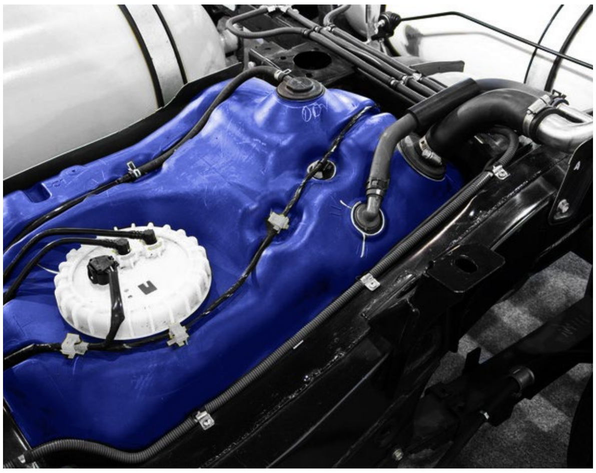
For a number of fuel system components the integral leak test with helium in the accumulation chamber is a good choice. The leak rates limits for modern injectors today are in the range of 10^{-4} to 10^{-5} mbar·l/s. The leak rate test for gas pumps today is in the order of 10^{-4} mbar·l/s. Because of the particularly high operating pressures, common rail injectors often have higher leak rate requirements -- between 10^{-4} to 10^{-6} mbar·l/s. Less demanding are diesel filters, which often only need to be tested to a leak rate of about 10^{-2} mbar·l/s.

Generally for fuel systems, fuel tanks and fuel lines there are higher leak rate requirements. This is motivated by the need to meet stricter U.S., and especially California, regulations for preventing hydrocarbon emissions. This also makes the use of permeable plastics particularly problematic.



Due to high operating pressures, common rail injectors often have leak rate requirements between 10^{-4} to 10^{-6} mbar·l/s

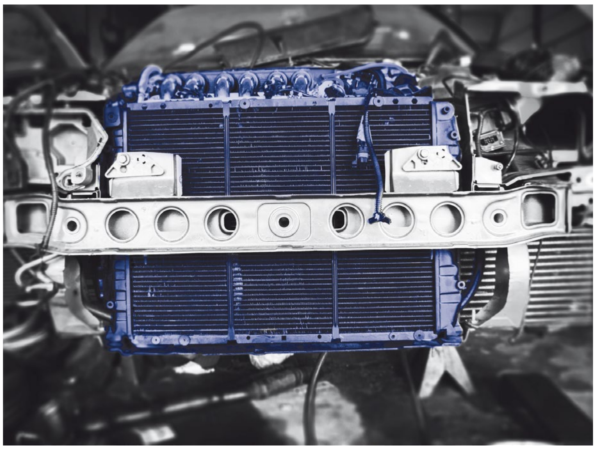
Fuel tanks and fuel lines today are tested by many manufacturers against leak rates up to 10^{-4} to 10^{-6} mbar·l/s. This excludes the use of bubble tests or pressure decay and differential pressure tests. Such a leak limit rates can only be detected by integral leak testing with tracer gases. For smaller parts such as injectors or motorcycle tanks, the test in the accumulation chamber is ideal. Because the detection limit of the accumulation method is dependent on the free volume of the test chamber, very large parts are tested by the vacuum method.



For testing a truck‘s fuel tank against leak rates up to 10^{-4} to 10^{-6} mbar·l/s neither bubble tests nor pressure decay tests are sensitive enough

2.2.4 Oil and water circuits

The most stringent leak rate requirements for oil and water circuits of the vehicle are for the oil cooler that removes heat from the oil for better lubrication. These tighter requirements are in place so that the oil and water do not mix, preventing costly engine damage. Typical leak rates are 10^{-2} to 10^{-4} mbar·l/s, and the cost-effective accumulation chamber is recommended. Similarly, demands are high on a vehicle's plastic oil tank, which is usually tested against leak rates of 10^{-3} mbar·l/s in the vacuum chamber for efficiency reasons. Testing via pressure decay or differential pressure methods do not work well here because of the natural deformability of the plastic material, which can skew the results considerably. Other components such as oil pans and oil pumps are often tested against leak rates of 10^{-2} mbar·l/s. On the one hand, leak testing is needed to guarantee that no oil escapes from the circuit, but making sure that no water from the cooling circuit enters the oil circuit is also critically important.



In a water bath test, bubbles may not be able to detach from a water cooler's fine ribbed structure

In water pumps and radiators the leak rate may often not exceed a leak rate of 10^{-2} mbar·l/s. With radiators, bubble testing is still quite common. The bubble test is insufficient with a radiator casting that has a fine ribbed structure. Bubbles may form, but because they cannot detach themselves from the test piece, the human tester cannot perceive them. Here tracer gas methods are more reliable. The pressure decay method also is not suitable for radiators. Because of its very composition, a radiator is susceptible to temperature variations, and the pressure decay measurement would be seriously inaccurate.

2.2.5 Safety features

For all directly safety-related components in a vehicle, the demand for tightness is naturally quite high. For brake hoses, brake fluid reservoirs and brake boosters, the typical allowable leak rate is in the order of 10^{-3} to 10^{-4} mbar·l/s. In this case a helium test in the accumulation chamber is recommended.

Airbag gas generators have come into the news recently because of significant vehicle recalls. To prevent moisture entering the pyrotechnic gas generator, tests today are mostly to a leak rate of 10^{-6} mbar·l/s. Often the bombing method is used. In these tests the igniter is first exposed in a pressure chamber with helium overpressure so that the tracer gas enters the test piece through leaks. Then, the igniter is put into a vacuum chamber. After the evacuation of the vacuum chamber, the helium in the test piece can leak into the chamber, where it is measured by mass spectrometry.

The leak rate requirements for cold gas generators for airbags are slightly higher. Cold gas generators are usually filled with a helium-argon mixture. In order for this gas mixture to inflate the airbag when discharged, it is under high pressure. This pressure must be maintained for at least 10 years – with some manufacturers looking for 15 to 17 years. Hence, the tightness of cold gas generators is tested in the vacuum chamber, often against a leak rate of 10^{-7} mbar·l/s.

Using the bombing method, airbag ignitors are tested against a leak rate of 10^{-6} mbar·l/s

2.2.6 Wheel rims, shock absorbers and other components

Even with aluminum rims, tightness plays an important role for wheels. This is true for more expensive alloy wheels, which are usually two parts welded together, as well as for the simpler, cast lightweight wheel rims. In cast wheel rims, it is important to make sure there are no porosity leaks so that tubeless tires will not lose air through the porosity in the wheel rim. Modern wheel rims are often tested in the vacuum chamber to a leak rate of about 10^{-4} mbar·l/s.

The same method with the same typical leak rate is used for the integral leak testing of shock absorbers. For servo oil tanks and the power steering housing, the helium test in the accumulation chamber is a good solution. The leak rates here are usually in the order of 10^{-2} to 10^{-4} mbar·l/s.

Modern wheel rims are often tested in the vacuum chamber to a leak rate of 10^{-4} mbar·l/s

For integral leak testing of batteries, the accumulation chamber also is a good choice. The leak rate that a car battery may not exceed when tested is usually in the region of 10^{-3} mbar·l/s. Batteries are currently often tested using the pressure decay method, but face the problem of deformability of the plastic housing.

10 most common errors in leak testing

1 Wrong Test Method

The leak testing method is selected based only on the marginal leak rate and other influencing factors are neglected.

2 Wrong Point in Time for Testing

It often makes sense to leak test single components or subassemblies early in the process. Replacing a defective part after final assembly is more costly.

3 Contaminated Test Piece

Leak testing should always be performed on clean, dry test pieces. Otherwise, small leaks may already be clogged by the cleaning solution.

4 Disregarded Temperature Influence

Even the smallest change in temperature can affect the size of the leak and the detectable leak rate, respectively, and lead to the exclusion of certain test methods.

5 Fluctuating Test Pressure

To detect leaks reliably and consistently requires that the test piece is always filled with the exact same test pressure.

6 Filling without Previous Evacuation

To make sure all areas of the test piece are filled with tracer gas and potential leaks can emit tracer gas, it is mandatory to evacuate the test piece before filling.

7 Not Knowing

A reproducible test method is preferred over the personal perception of a tester.
It is important, however, that testers know what they are detecting and the properties and capabilities of each test fluid.

8 Underestimated Stringer and Gross Leaks

How long does it take for the tracer gas to make its way through the test piece and to escape from a stringer leak? Does the tracer gas empty from the test piece even before the actual leak testing starts?

9 Neglected Maintenance

To assure accuracy and reduce costs all connections, hoses and adaptors need to be checked regularly. It is important to also regularly verify the proper functioning and accuracy of a test system by using a consistent reference leak built into a master test part.

10 Doing Things Yourself

Selecting the best test method, configuring the test system properly and designing the test process as reliably as possible is a job for experts.

2.3 Ten most common errors in leak testing

Error 1: Using the wrong method for the test leak rate

Often the bubble test method produces the wrong results. If the tester does not see any bubbles, then, it is assumed there is no leak. The tester believes what he does not see and is satisfied.

A basic condition for determining whether a leak test or leak detection method for a particular application is suitable is its leak rate. It is interesting how often this simple rule is violated. Plastic parts are tested using the pressure decay method without considering their deformability and the change in volume due to the compressed air. Also, the leak rate of an integral leak test and subsequent leak detection have to work together. Sometimes the integral leak test is carried out in the helium chamber, but the subsequent localization of leaks is carried out using the bubble test method instead of using the more precise sniffer leak detection method with tracer gas.

Error 2: The wrong point in time in the production process is chosen for testing

It is important to think twice about selecting the best point in the production process to perform a leak test. It often makes sense to test individual subcomponents for leaks prior to assembly. For example, it is a very good idea to check the tightness of a transmission case before the transmission is assembled because if the housing fails in the final test and must be ejected, all of the work of assembling the transmission is lost.

Error 3: The test piece is already contaminated

Generally, for all test methods the following should apply: The leak test or the leak detection always should take place on new, unused test pieces. If a component has already been in operation or has been filled with oil or water, the danger is great that small leaks have already clogged. It is possible that compressed air or tracer gas can then possibly no longer escape from the test piece (or enter it).

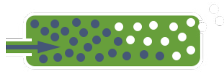
On castings, sometimes cutting-oil residues are found after the machining process. Before a leak test takes place, the test piece must first be cleaned. After cleaning, the part must then be dried again, which also insures that the cleaning fluid does not clog potential leaks in the short term.

Error 4: Temperature changes are ignored

Temperature fluctuations represent a serious problem especially for integral leak tests using pressure decay or differential pressure measurement. Even small temperature fluctuations can change the measurable leak rate by several orders of magnitude. The size of a leak also is influenced by a temperature increase and the expansion behavior of the material to be tested. In an exhaust gas cooler, in some cases leaks only occur when it has reached its typical operating temperature. Some manufacturers therefore carry out type testing in climatic chambers.

Error 5: The test pressure fluctuates

To be able to determine leak rates reliably and reproducibly, it is critical, even when using tracer gas methods, to always fill the test piece at the same constant pressure. Automated tracer gas filling systems guarantee this. But be careful. With some test pieces the correct filling is only possible after a prior evacuation. Heat exchangers usually consist of long, snakelike tube systems. If you fill a tracer gas here, you can increase the pressure in the test piece, but only after a previous evacuation can you ensure that the tracer gas reaches every possible leak. In addition, especially with the helium tracer gas test, the concentration of the tracer gas may be reduced to save on testing costs. Some tests are performed with a helium content of only 1% -- which means that the proper distribution of the tracer gas is even more important.



Error 6: Filling with tracer gas without previous evacuation

For proper leak testing it is absolutely mandatory to evacuate the test piece before filling with tracer gas. This is particularly important for long and narrow geometries. If you do not evacuate before filling, the air in the test piece will simply be pushed to the end of the geometry and no tracer gas will get to this area, hence potential leaks will only release air and cannot be detected by your tracer gas leak detector. Evacuation is also especially important if you fill the part to be tested with low pressures of tracer gas only as the left-in air will dilute the tracer gas filled in. Example: If the piece is filled with air at atmospheric pressure and you add one atmosphere of tracer gas, the tracer gas concentration in the piece is only 50%. If you add two atmospheres of tracer gas, the concentration of tracer gas will be 66%.

Error 7: The testers do not know what they are actually measuring

Using a reproducible measurement method as an integral leak test, rather than to continue to rely on the mere perception of a human tester is a big step in the right direction. It is important to know what you are actually measuring and which test medium is being used. Occasionally leak rates are specified for air, but helium has a slightly higher dynamic viscosity than air. If the leak rate is specified for air but helium is being used, proper conversion data must be used to provide a more precise leak rate. If you want to measure the leak rate in grams per year of an air conditioning unit with an integral leak test (escaping mass per year) keep in mind that the helium measuring instrument used for the test may under certain circumstances, indicate a volume flow of helium in mbar·l/s

There are devices that perform an automatic conversion, such as the Protec P3000(XL). The exact conversion factors of these units result from the different molecular weights of the refrigerant. If, for cost reasons, testing is done with diluted helium mixtures, the helium concentrations that can be measured are different. This must be taken into account when interpreting the leak rate results. Moreover, tightness requirements always apply to a specific operating pressure. The pressure that is used for the test often deviates. It may be higher or lower than the later operating pressure of the test piece, which also makes a proper conversion of the leak rate necessary.

It also would be a serious mistake to equate a leak rate with a concentration of gas that is indicated on some instruments as parts per million (ppm). The concentration is a snapshot; it only indicates how many particles are in a given space at a given moment. The leak rate indicates, however, the size of the volume flow through a leak.

Error 8: Stringer leaks and gross leaks are underestimated

Stringer leaks consisting of capillary-like corridors can seriously affect airbag manufacturers. It is important to consider how long it takes for the helium tracer gas to distribute so that it also emerges from these stringer leaks. If you work with very short times between filling and testing, it is difficult or even impossible to identify stringer leaks. Another example: Even on cable feedthroughs there might be leak channels several centimeters in length. It may take several minutes for the tracer gas to leak out of them.

The opposite of a stringer leak is a gross leak. In a gross leak the helium escapes from the test piece before the actual test interval. In effect, you evacuate the vacuum test chamber and the helium from the test piece at the same time. Sometimes a simple pressure decay test is integrated into the tracer gas system to identify any gross leaks before filling the test piece with helium.

Error 9: Maintenance of the test system is neglected

If no leak rates are measured on a test station for days or weeks, it could mean one of two things; either the quality of the production is superb, or the test system is functioning inadequately. Sometimes there are leaking tracer gas lines that prevent correct measurement in the test chamber. All interconnect points, hoses, test piece brackets, etc., must be checked regularly. Sometimes the tracer gas systems are extensively and inexpertly repaired. If an interconnect point is wrapped in Teflon™ tape, in the hope that the connection is sealed, this is most definitely a mistake. Helium gas will always escape through the porous Teflon tape, causing accuracy and cost problems.

Sometimes, errors in a test setup can be identified by regularly checking the functioning and accuracy of the system by using a reference leak that, due to its defined size, is always the same leak rate. If this leak rate is not determined during the test, the system has inaccuracies. It is best to opt for a test leak in the form of a glass capillary. For less demanding test leaks, metal is squeezed to a narrow point. These test leaks will vary in leak rate greatly depending on temperature and pressure -- glass capillaries are therefore better for this purpose. A regular check of the system with a calibration leak prevents sometimes other, very fundamental problems. For example testers have mistakenly connected an oxygen bottle instead of a helium bottle to their system.

Error 10: We can do it ourselves

Maybe, but think about it carefully. When it comes to industrial leak testing and leak detection, it is important to consult with experts and get advice.

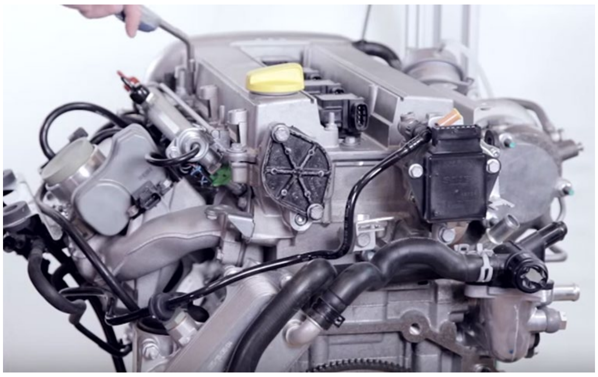
It is critically important to choose the appropriate test method for a specific application, to configure the system correctly, and to make the review process as foolproof and reliable as possible -- certainly not a trivial task. Again, seek professional support. If you want to ensure the quality of your production and avoid costly product recalls, it is not enough to simply say, „yes, we do check something." A negative test is no guarantee that a test piece actually meets the requirements set. You can only have this guarantee if your test methods and processes work reliably. The challenge is to do the right measurement and in the right way, every day and at every level.

Appendix

3.1 Web links

3.1.1 Videos

Robotic leak testing on GDI engines



Leak location on engine in rework

Leak testing of evaporators for car A/C with T-Guard

Leak testing of car A/C hoses

3.1.2 Description of leak testing applications

- **Leak testing of transmissions**
- **Leak testing of plastic containers**
- **Leak testing of fuel injectors**
- **Leak testing of heat exchangers**
- **Leak testing of airbag gas generators**
- **Leak testing of fuel and DEF tanks**
- **Leak testing of fuel rails**
- **Leak testing of wheel rims**

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3.3 About INFICON

INFICON is one of the leading companies when it comes to development, production and sales of instruments and devices for leak testing. INFICON leak testing equipment is used in demanding industrial processes in production and quality control. INFICON leak detectors cover a wide variety of leak testing applications. Main customers of INFICON are manufacturers as well as service companies for the RAC industry, the automotive industry, the semiconductor industry and manufacturers of leak testing systems. Almost all automotive manufacturers and their suppliers are INFICON customers. INFICON technology helps testing airbags, car air conditioners and their components, fuel systems and all types of fluid containers. (www.inficonautomotive.com).

INFICON production facility in Syracuse, NY – development, design and manufacturing of leak detection service tools

INFICON production facility in Köln, Germany – development, design and manufacturing of leak testing production tools

For more information about INFICON, visit us at www.inficon.com.

3.4 References

3.4.1 Manufacturers of passenger cars

Adam Opel AG
Alfa Romeo
Audi
Bentley Motor Cars
BMW
Brilliance Jinbei
Bugatti
BYD
Changan Automobile
Chrysler
Daewoo Tata
Daimler
Dongfeng Motor
Ferrari
Fiat Chrysler
Ford
Foton Motor
Geely
General Motors
Great Wall Motor
Honda
Hyundai
Isuzu
Jaguar
Kawasaki
Kia
Land Rover
Maserati
Mazda
Mercedes-Benz
Mitsubishi Motors
Nissan
OAO ZMA (Sollers ZMA)
Peugeot Citroën Automobiles
Porsche AG
Qoros Motors
Renault
Rolls-Royce Motor Cars
Rover
Saab
Seat
Skoda Auto
Toyota Motor
Volkswagen
Volvo
Wuling Motors

3.4.2 Manufacturers of heavy duty vehicles

Bobcat
Caterpillar
Claas
Evobus
IVECO
John Deere
Liebherr Baumaschinen
MACK Trucks
MAN
Motor Coach Industries
Scania

3.4.3 Automotive component suppliers

ABC Group Fuel Systems, Inc.
Aeroquip
Alcoa Wheels
Allgaier Automotive
Allison Transmission
ARC Automotive (Atlantic Research Corporation)
Autoclima
Autoliv
Behr
Benteler Automobiltechnik
Bergstrom Climate Systems
Bertrandt
Borbet
Borg Warner
Brunel Car Synergies
Calsonic Kansei
Central Motor Wheel of America
Chaoli Hi-Tech
Cinetic Automation
Clean Energy
Coclisa
Cognis
Continental Automotive
ContiTech
Cummins Inc.
Dare Wheel Manufacturing
Dayco
Delphi Automotive
Denso
Deutsche ACCUmotive
Deutz AG
Dicastal Weel
Dominion Technology
Dürr Somac
Durr Systems
Eaton
Eberspächer
EDAG
ElringKlinger
Federal Mogul
Flextronics Automotive
FTS
Frankling Precision Industry
Freudenberg
Fuel Cell Energy
FuelCon
Fuel-Tec
Getrag
GLS Automotive
Grammer
Griffin Thermal Products
Halla Climate Control
Halla Visteon
Hayes Lemmerz Alukola
Hella KG
Hengst
Hirschvogel
Honeywell
H S Automotive
Hutchinson (SNC)
INERGY Automotive Systems
Ingersoll Rand
IPETRONIK
ixetic

Johnson Controls
Kautex
Kayser Automotive System
KB Autotech
Keihin
KEPICO
Key Safety Systems
Köhler Automobiltechnik
Kostal
KTM Kühler
Landi Renzo
Leonardo
Lovato Gas
LuK Fahrzeug-Hydraulik
Magna
Magnetti Marelli
Mahle
Mammoth Air Conditioning
Mangels
Mann + Hummel
Manuli Auto
Martinrea Industries
MCS Cylinder Systems
Mecachrome
Michigan Automotive Compressor
Microflex Automotive
Mobile Climate Control
Modine
Motion Industrie
MTU
Navistar
NHK
Nichirin
NOK
NuCellSys
Parker Hannifin
Perkins Motors
Philips Automobile Lightning
Robert Bosch
Sanden Behr Automotive
Sanden Manufacturing
Sanhua Automobile
Schrader
Senstar Automotive
SMA Metalltechnik
Takata
TI Automotive
Tokyo Industries
Tokyo Radiator
Topvalue Global
Topy America, Inc.
TRW Vehicle Safety Systems
Valeo
Valeo Fawer Compressor
VDO Siemens
Vibracoustic
Visteon
Zexel Valeo Compressor

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