INFICON

Leak Testing for Refrigeration, Air Conditioning and Heating (HVACR) Systems

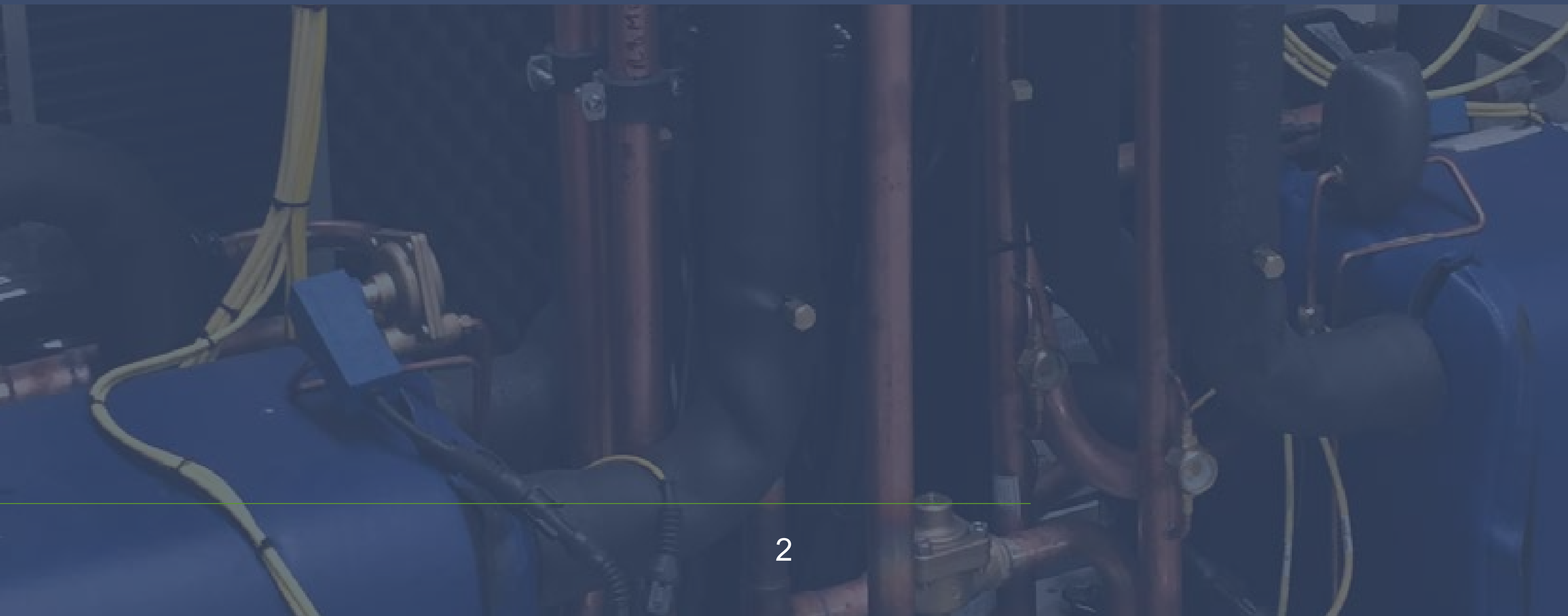
A guide

Foreword

Climate protection and energy efficiency are among the toughest challenges of our time - and they are particularly relevant to the manufacturers of refrigeration, air conditioning and heating systems. As energy consumption continues to rise on a global level, refrigeration, cooling and heating appliances must become more efficient, safer and more economical. Leak detection is a critical aspect in reaching this goal, since leak-proof equipment prevents climate-damaging substances from entering the environment. Only tightly sealed equipment is able to run at maximum efficiency by guaranteeing the proper charge of refrigerants. This also protects users from adverse health effects. And last but not least, it also protects manufacturers against warranty claims and complaints.

This e-book is designed to help you identify the right method for you to successfully test your devices or components. For this reason, we will first present you in the first part with all standard leak test and leak detection methods, including all of their advantages and disadvantages as well as their common areas of application. The second part of the e-book describes the specific challenges associated with the testing of refrigeration, air conditioning and heating systems, as well as the 10 most common errors in leak testing.

All this, of course, cannot replace advice from a competent expert. So, if you would like to upgrade your company's leak testing procedures, talk to us – we will be happy to assist you!



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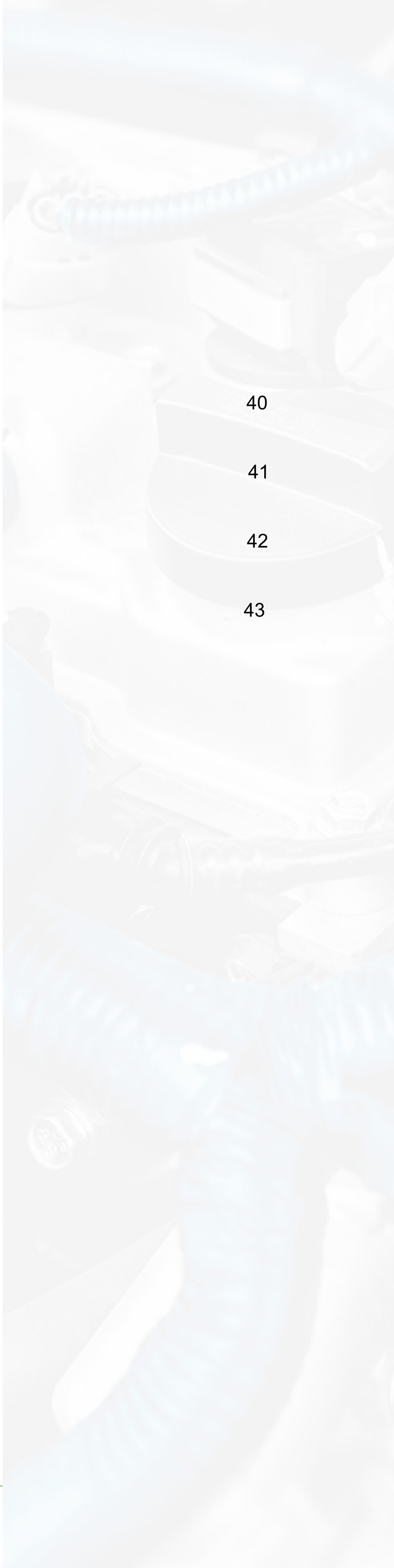
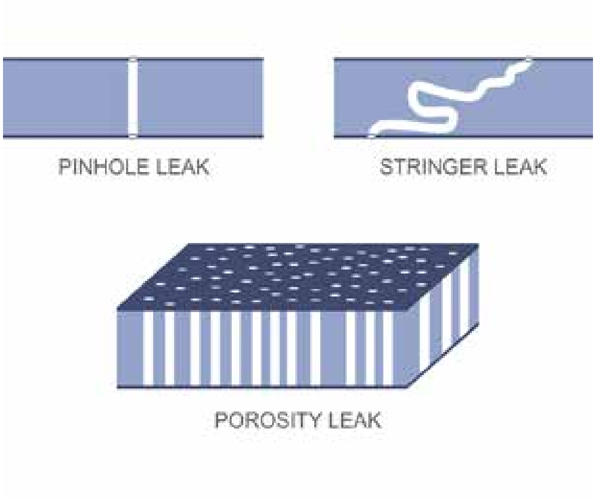


Part 1
Fundamentals of Leak Testing

1.1 Leak Types and Leak Rates

1.1.1 Types of leaks

A leak is a structure in the wall of an object, through which gases of 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. Permeation also shows a similar, delayed behavior.



Schematic diagrams of three different types of leaks.

1.1.2 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 interval. For example: If 1 cm^3 gas under an overpressure of 1 bar emerges in exactly one second due to a leak, the leak rate is 1 millibar times liters divided by 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 $5 \cdot 10^{-3}$ mbar·l/s. In Europe, the unit mbar·l/s has been widely accepted for leak rates, but volumes and pressures can also 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.

Below is a list for the conversion of units:

1 atm·cc/s ≈ 1 mbar·l/s
1 Pa·m^3/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 = $7{,}6\cdot10^{-6}$ mbar·l/s (only for R134a)

1.1.3 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. Most bacteria have a diameter between 0.6 µm to 1 µm. One Ångström is about the diameter of a single atom. Even at very small leakage 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 considerthe maximum allowable leak rate.

Diameter of the hole	**Range 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

1.1.4 Factors influencing the leak rate

As described in the context of the pressure test, 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 may also 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. One other factor affecting the successful leak detection with tracer gases such as helium and hydrogen and for the localization of leaks with a manually guided probe, is the importance of keeping in mind the dependence on orientation. Modern equipment for helium sniffer leak detection, such as the Protec P3000XL from INFICON, draws in gas with a high gas flow of up to 3,000 sccm to overcome this problem.

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 tight	$< 10^{-4}$	< 0.006
Gasoline tight	$< 10^{-5}$	< 0.0006
Gas tight	$< 10^{-6}$	$< 6 \cdot 10^{-5}$
Virus tight	$< 10^{-7}$	$< 6 \cdot 10^{-6}$
Technically leak-tight	$< 10^{-10}$	$< 6 \cdot 10^{-9}$

1.2 Methods without tracer gas

1.2.1 Bubble test

Still quite common is the relatively simple water bath test, which is somewhat archaic. The water bath test, most commonly known, 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 test for 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 up to 5 x 10^{-2} mbar·l/s (five hundredth of a millibar times liters per second = 0.05 mbar·l/s) csn 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 be immersed under water for a considerably longer time to produce just one bubble. In literature, a theoretical limit of detection (the smallest barely detectable leak rate) of up to 1 x 10^{-4} mbar l/s is usually quoted. Under ideal conditions, a leak rate of 1 x 10^{-3} mbar·l/s (= 0.001 mbar·l/s) will create one bubble per second. At a leak rate of 1 x 10^{-4} mbar·l/s, it takes 30 seconds to form a single bubble.

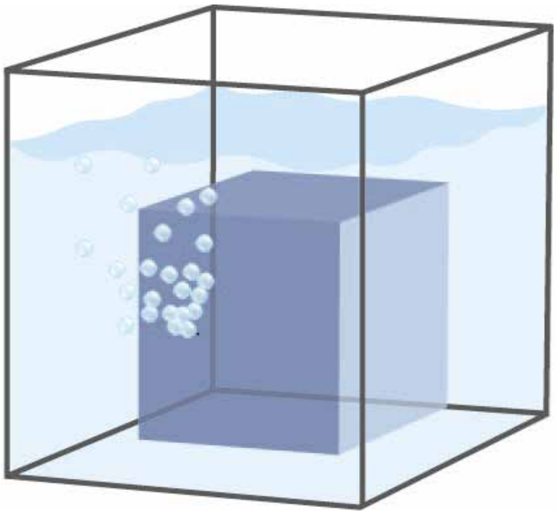
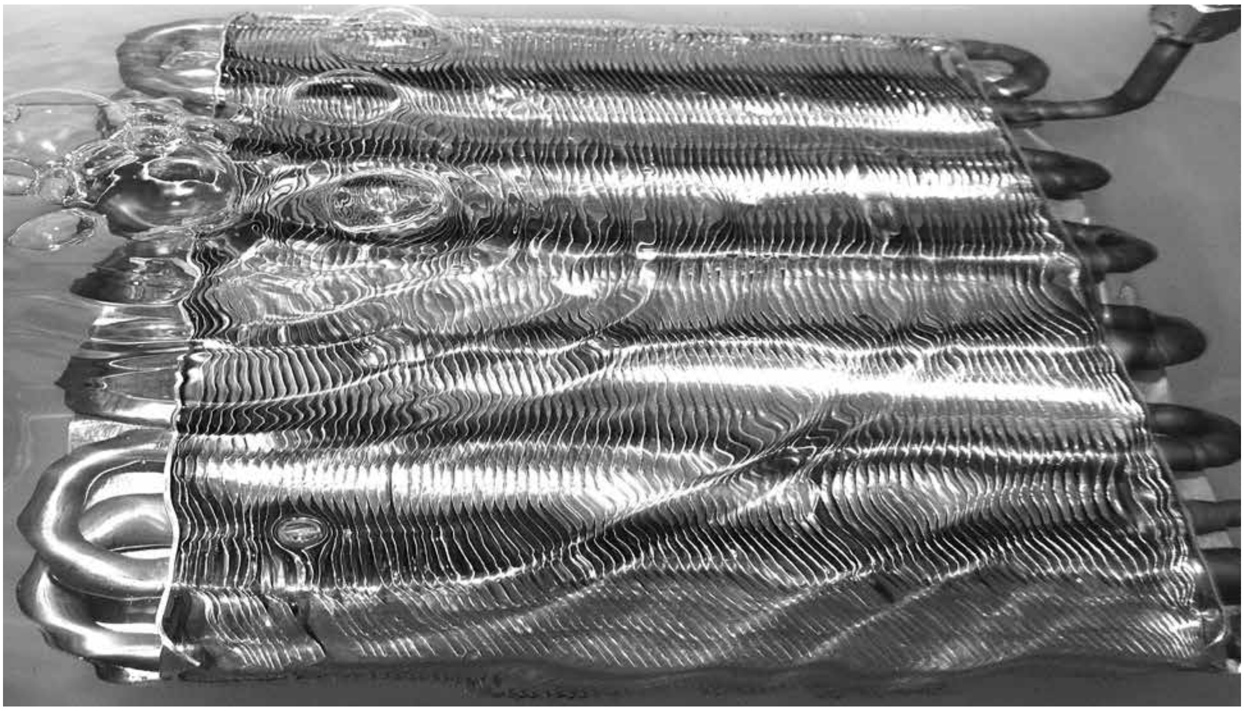


Diagram of the water bath method.

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, like a heat exchanger, for example. Also, if leaks are caused by porosity, such as in the case of aluminum or copper 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.



Bubble test in the water bath.

At first glance, such 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 which 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 of contamination. The water in the test tank becomes cloudy after four to eight weeks – sometimes even within one day, depending on the condition on 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 water. The tank contents must therefore be disposed of as hazardous waste.

1.2.2 Soap spray test

The soap spray test or "snoop," is similar to the bubble test method. In both cases, the 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 on any given day and the tester’s individual skill. For objects that should not get wet, 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 1 x 10^{-3} mbar·l/s. However, the detection limit is worse than using the bubble test (5 x 10^{-2} mbar L7s). 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. Finally, tests in places that are difficult to access, such as the backsides of components or obstructed places (blind spots) cannot be tested.

Bubbles forming at a leak.

Foam test on a threaded connection.

1.3 Methods with tracer gas

1.3.1 Pressure tests with air

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

1.3.1.1 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 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: 1 x 10^{-3} mbar·l/s. In practice, however, often only values from 1 x 10^{-2} mbar·l/s or higher can be achieved. The primary reason why the sensitivity of the pressure decay test is ten times worse is temperature fluctuations. The measured pressure is naturally dependent on the temperature.

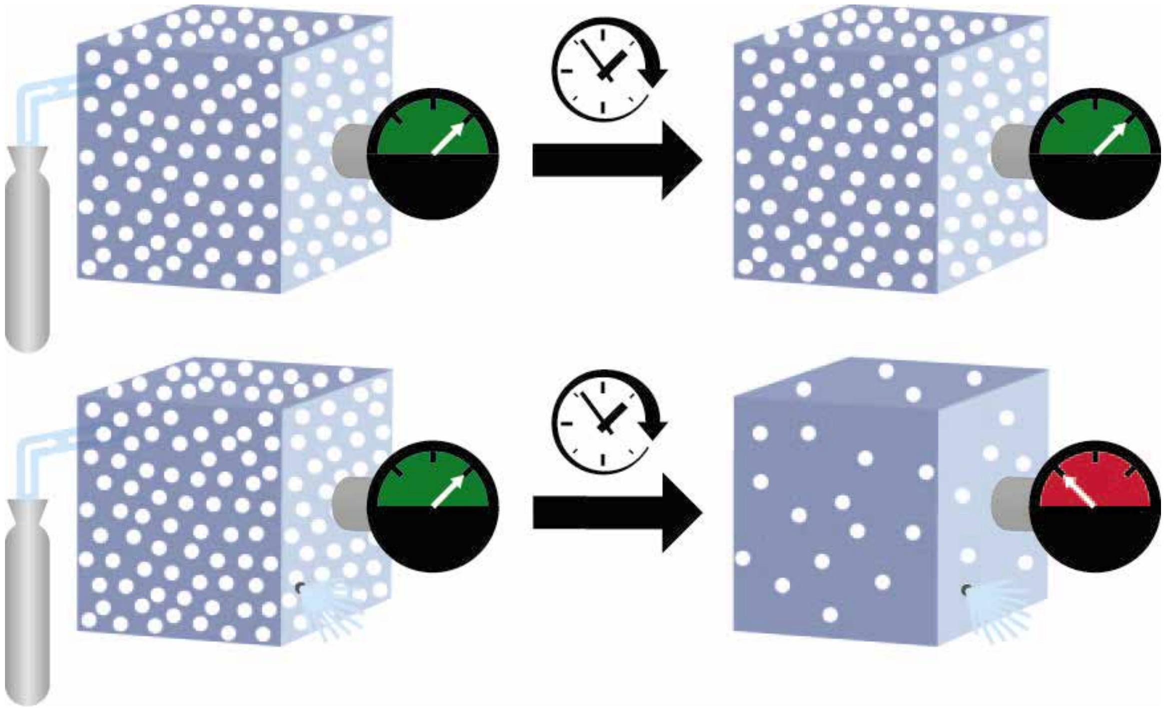


Diagram of pressure decay test, below with leak point.

A sample calculation:
If a test piece is filled to a volume of 3 liters with a pressure of 2.5 bar (25psi), 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 was 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 x 10^{-3} mbar·l/s (0.001 mbar·l/s) is, of course illusionary. The example shows that an increase in temperature 0.1° C, increases the detection limit by a factor of 100. This is why after filling, long settling times are often incorporated into the procedure so that pressure and temperature during the test are stable. Temperature fluctuations are the biggest drawback of pressure decay test. 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.

1.3.1.2 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 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 resolution higher than the pressure decay method. The theoretical detection limit of the differential pressure measurement is 10 times better than the pressure decay test, and is 1 x·10^{-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. However, the temperature effects as a result of filling only affect the test piece unless you also fill the reference piece anew every time.

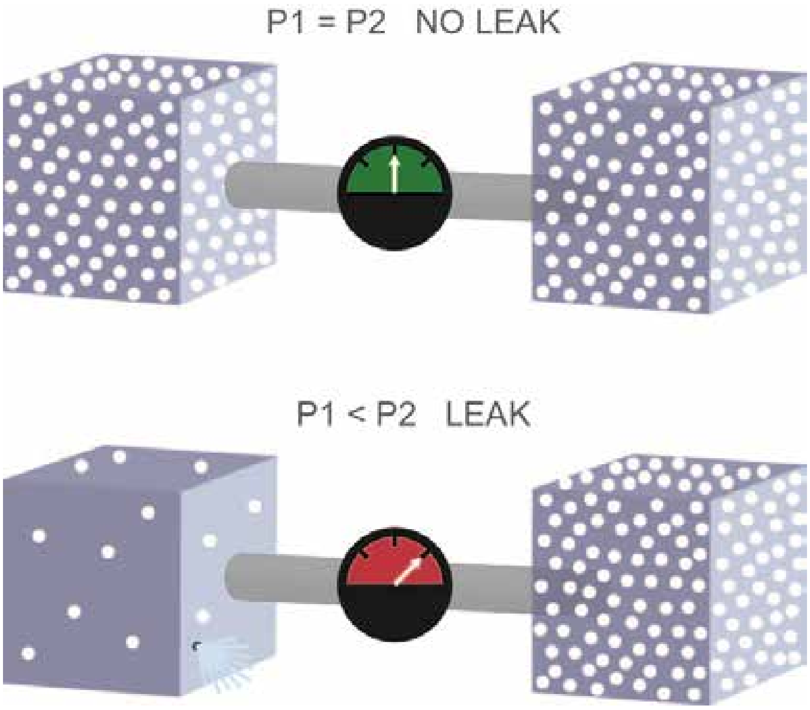


Diagram of differential pressure test, below with leak point.

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 1·x 10^{-3} mbar·l/s are realistic.

1.3.1.3 Pressure increase test

The third variant of the leakage 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 the pressure decay test: 1 x 10^{-4} mbar·l/s. But in actual use , the process usually has a detection limit of 1·x 10^{-3} mbar·l/s. Limiting factors for the pressure increase test - as for all pressure change methods - 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.

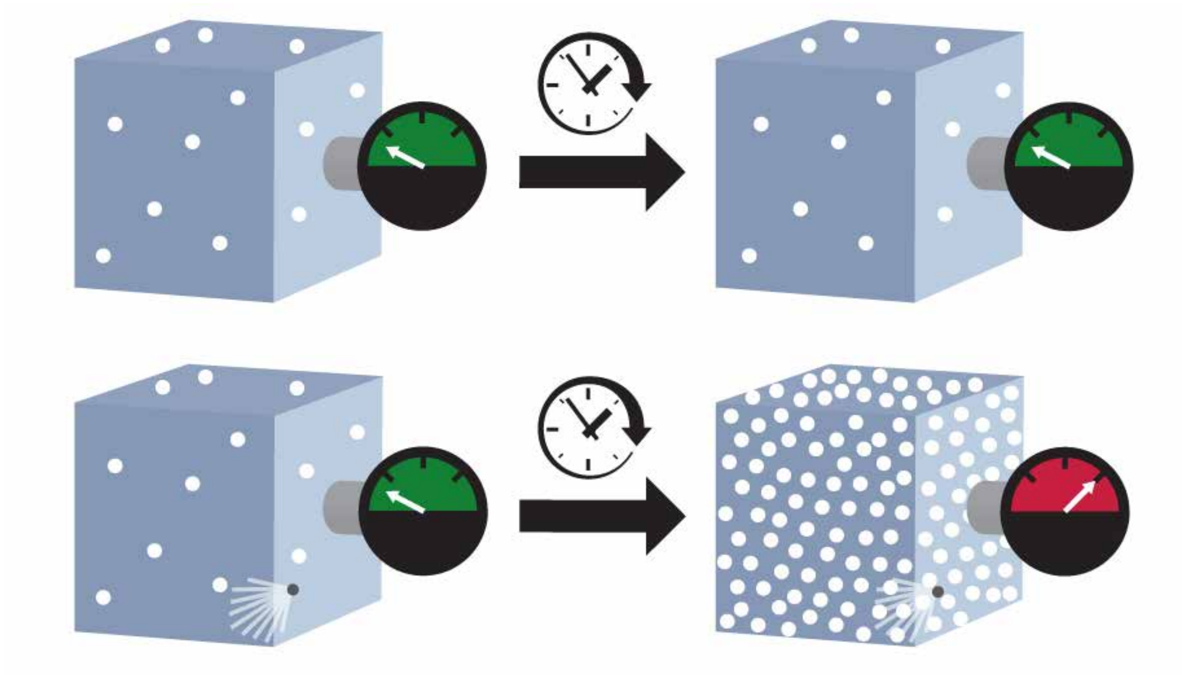


Diagram of the pressure increase test.

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 methods using tracer gases are among the most sensitive leak testing methods. The most common tracer gases are helium and diluted hydrogen, which is normally usedin 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.

1.3.1.4 Mass Flow Test

The mass flow test is suitable for large-size components and systems like tanks, for example, which are able to withstand a slight overpressure or vacuum. This method is used to determine the leak rate by routing air entering or exiting a test piece across a mass flow sensor. In a heated measuring channel, the temperature difference between the inlet and the outlet side can then be measured and displayed as a measured variable for the flow. Although the measurement of the mass flow rate is largely independent of the temperature and pressure of the test gas, changes in temperature at the time of the test or an elastic deformation of the test piece may falsify the measurement. This method also requires a certain stabilization/settling time. In order to avoid measuring errors, the tester must check the temperature, the pressure difference (compared to the atmospheric pressure) and the total gas volume at regular intervals. The theoretical detection limits are in the range of $1 \cdot 10^{-4}$ mbar·l/s, in practice, however, detection limits of $1 \cdot 10^{-3}$ mbar·l/s are more realistic.

1.3.2 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.

1.3.3 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 testing and leak detection, a so-called forming gas is used, which is a mixture of 95% nitrogen (N2) and 5% hydrogen (H2). 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.

1.3.4 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 refrigerants like R134a, R410A or R32. Also 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 grennhouse gas and its use as a pure tracer gas is prohibited. The same applies to many older refrigerants. All the procedures that use operating fluid as tracer gases are not used for integral leak testing during production, but to find subsequent leaks.

1.3.5 Inside-out and outside-in methods

Methods using tracer gas can be divided into two broad classesdependingon 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. 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

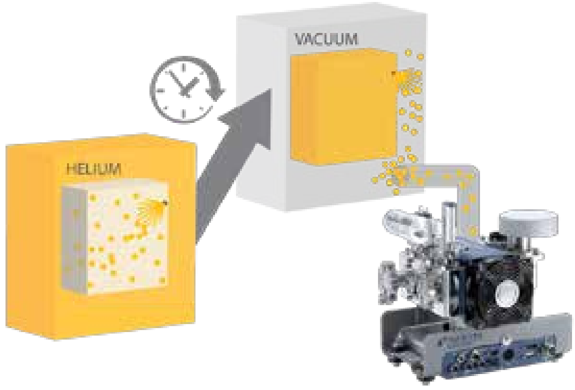


Diagram of the bombing leak detection method.

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 chamberso that the tracer gas from the interior of the test piece can escape by the same leak into the vacuum chamber again, there 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. One difficulty with this method can be that the test piece is not normally 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.

1.3.6 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 a tester or automatically, such as a robot arm. A pump generates a vacuum in the test chamber and the interior of the test part is filled via corresponding connections with the tracer gas helium. 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 tracer gas methods. The mass spectrometer used for the detection of the helium can, under best conditions, determine leak rates down to 1·x 10^{-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 an integral leak testing. Another advantage of the vacuum method is short cycles and fast cycle times, especially in fully automated test sequences.

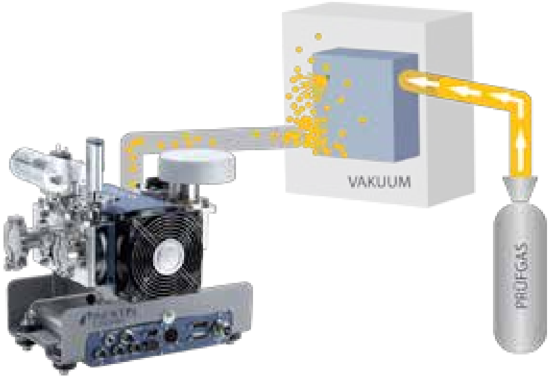


Diagram of the vacuum method – with a vacuum in the test chamber.

In addition, the sensitivity of the vacuum method often allows for the significant reduction of the helium concentration, to approximately only 1%, which also reduces the cost of the tracer gas accordingly.

1.3.7 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 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. The tracer gas then escapes from any leaks in the test piece. To ensure 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 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 5·x 10^{-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 cycle times 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.

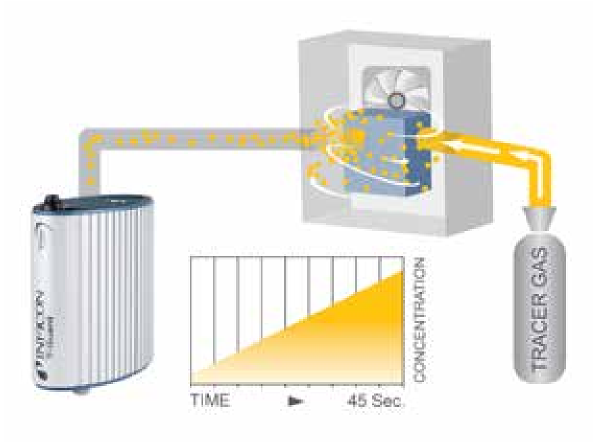


Diagram of the accumulation method - without vacuum in a simple accumulation chamber.

1.3.8 Sniffer Leak Detection

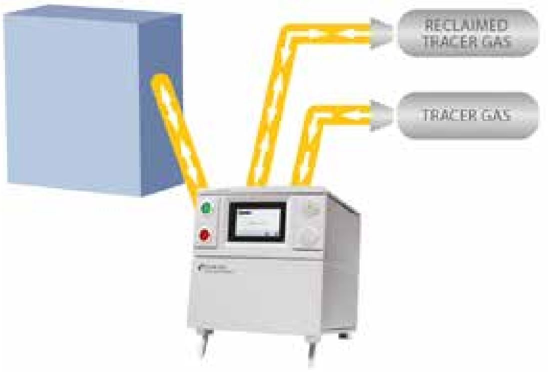
The so called sniffer leak detection with tracer gases is typically used to find the exact location of a leak. Often sniffer leak detection is used after a failure. For already pre-tested and installed components, the sniffer leak test can also be used to check the leakproofness of joints and connecting point during final assembly. The sniffer leak detection also is an inside-out method. The part to be tested is pressurized with the tracer gas so that tracer gas escapes through the leak.

Diagram of the sniffer leak detection – with a manual sniffer tip.

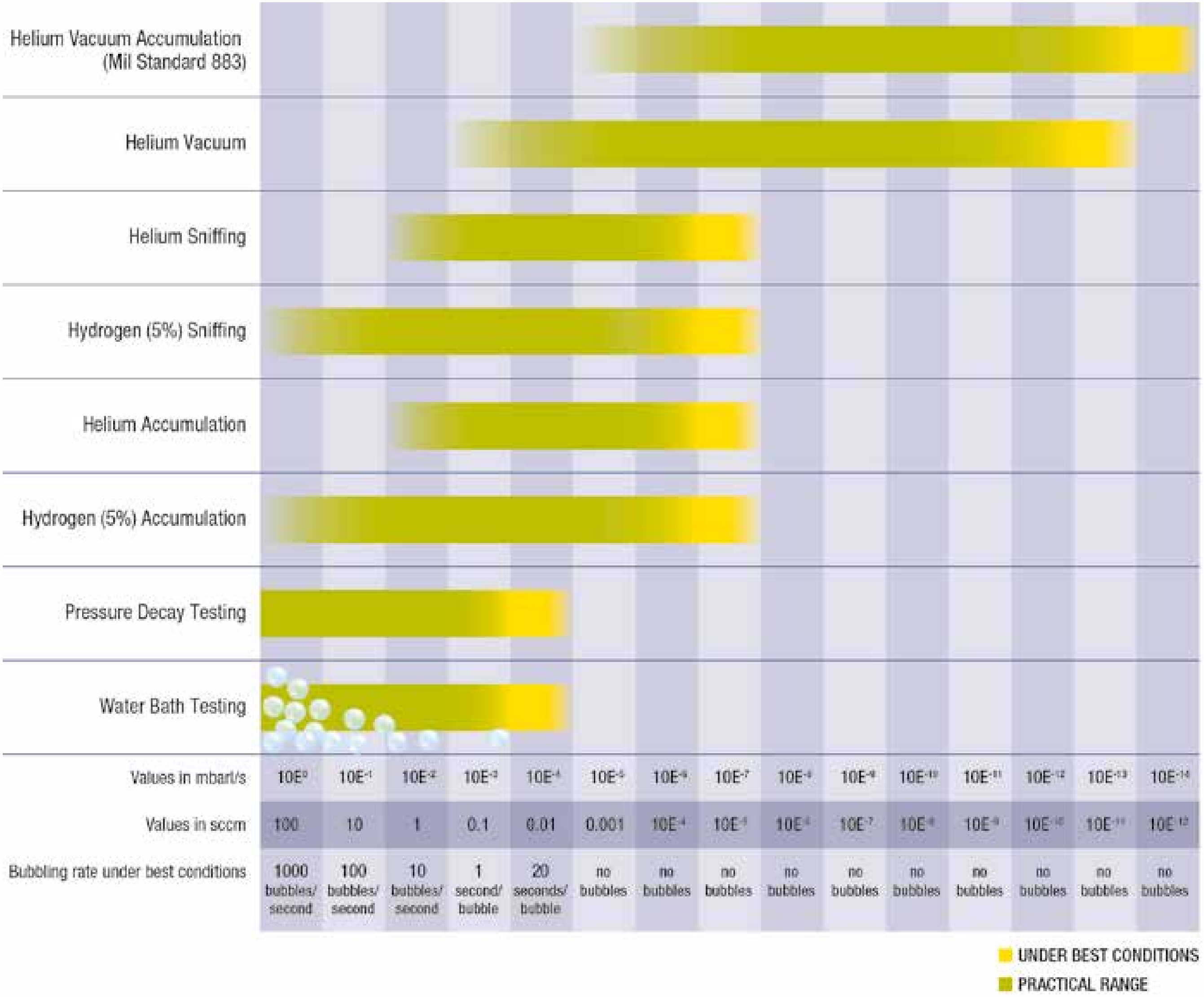
The sniffer tip of the leak detector is then guided either manually or automatically across the surface of the test part – until the leak detector identifies the location with the highest leak. Because the sniffer line of the leak detector sucks in a mixture of air and escaping tracer gas,a low background concentration of tracer gas is desirable. For sniffer leak detection, helium or forming gas, but also the gaseous operating media of a test part, such as R134a, CO_2 or R290 can be used. For a sniffer leak detector, like the INFICON Protec P3000(XL), the smallest detectable leak rate is in the range of $1 \cdot 10^{-7}$ mbar·l/s.

1.3.9 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. The re-evacuation following the leak testing prevents tracer gas being released and collecting in the work area, which eventually could distort the measurement results. Gas recovery systems make it possible also 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 can also 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.



Leak detection filling unit Sensistor ILS 500 F from INFICON.



Detection ranges of the different leak test methods.

Part 2
Leak testing for Refrigeration, Air Conditioning and Heating (HVACR) Systems

2.1 Increasing Demands for Environmental Sustainability and Efficient Use of Energy

For several years now, the trend in the HVRAC field has been towards energy efficiency and environmental friendliness. Since December 2011, all refrigeration and cooling appliances for the European market must be marked with the EU energy label. Back then, the new efficiency ratings of A+, A++ and A+++ were added to the existing ones. Since then, cooling appliances operating less energy-efficiently have almost completely been taken off the market. The energy-saving systems, however, often are composed of smaller, more complex parts, which are more challenging to test. For example, the typical tube spacings of a heat exchanger have become smaller and smaller in the last few years, and the localization of leaks has accordingly become more difficult.

In Europe,in addition, the revision of F-Gas Regulation No. 517/2014 of January 1, 2015 has led to new requirements for manufacturers, which on one hand apply to the refrigerant fill levels and on the other hand to the reduction of partially fluorinated hydrocarbons. But not only Europe is looking into reducing the greenhouse gases. The USA uses EPA SNAP regulations, similar to Europe, which will be implemented with other deadlines. Asian countries like China or Japan will follow this trend or have their own regulations. But the main driver for future refrigerant business right now is the European F-Gas regulation. In the future, manufacturers in the refrigeration and air conditioning industry will be forced to use climate-friendly refrigerants with a low Global Warming Potential. This might affect the necessary tightness of the product as well as the leak testing. Refrigerants with a higher Global Warming Potential are becoming less and less important.

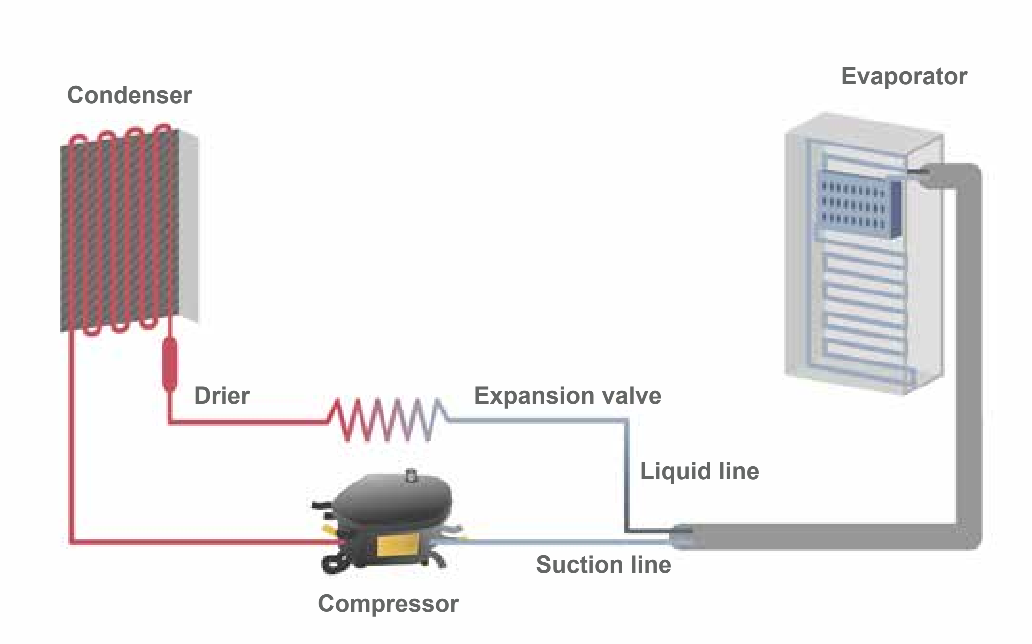
These changes will get things moving, especially in the refrigeration and air conditioning industry. Previously, traditional CFC refrigerants like R404A and R507 have such high Global Warming Potential (GWP) that, starting in 2018 in Europe, manufacturers will no longer be allowed to use them. New refrigerants with a lower GWP will therefore gain ground in the coming years.

Manufacturers as well as suppliers should always consider the cost-benefit ratio when it comes to the identification and implementation of the most sensible, quality-assuring and cost-effective leak test method for a specific application. In doing so, the choice is never solely dependent on the leak rate specification against which a component must be tested to. When choosing the optimal method, factors such as automation, speed and reliability of the check always play a role. At first look, a water bath test may be simple, but do human testers really 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 second to none, but is this considerable effort always really justified? A much simpler leak testing using sniffer leak detection with a test part under pressure could be more effective and gives a better balance between quality assurance and costs.

The choice for the optimal leak detection method is often influenced by the human factor. We also realize this to ourselves. We prefer to leave everything to our own senses. This is one reason why the water bath and soap spray are still used in many application scenarios where they can be replaced by a significantly more efficient test method. The tester wants observable evidence, he wants to see the leak. The gas exiting from a leak when using tracer gas method or pressure difference method is not visible. These methods are more accurate, faster, more reliable and reproducible than any visual check – but is less perceptible than a rising air bubble. This also sometimes leads to the fact that testers adhere to old methods, of which they should know exactly how inaccurate and misleading they are for their particular application. Sometimes even air conditioning components are submerged under water, even though the leak rate limit of this method of 10^{-3} mbar·l/s is much too high for such an application.

2.2 Cooling Systems



Schematic Diagram of a refrigeration cycle.

2.2.1 Air Conditioning Systems

The air conditioning industry will have to change over the coming years. Due to the revision of F-Gas Regulation 517/2014 in Europe, or SNAP in the US, some of the refrigerants, such as R404A and R507 which have been used until now, will no longer be usable in the near future. Nevertheless, even refrigerant with a GWP within the legal limits still hold a high greenhouse-effect potential. The trend towards environmentally friendly "New Generation Gases" will continue, not only due to legal regulations, but also due to the increasing environmental awareness of manufacturers and consumers. Gas mixtures such as R442A, R452A, R407F and R1234ze are just starting to establish themselves on the market as more climate-friendly alternatives. They may involve new requirements for leakproofness and leak detection. Today, many parts are still being tested in the production process using the water bath method – evaporators and condensers, for example. These large-surface components have many small-part connecting points, which must be located precisely. This can hardly be accomplished with the water bath method since the bubbles do not exit reliably at the site of the actual leak. Furthermore, such components should typically be tested for a leak rate of $1 \cdot 10^{-5}$ mbar·l/s. In practice, however, the water bath method can only reliably detect leak rates of up to $1 \cdot 10^{-2}$ mbar·l/s. For parts like evaporators, expansion elements, filter dryers, solenoid valves and control valves, it is therefore practical to check them in the vacuum chamber.

The test gas used for this purpose is typically helium. This allows detection of the necessary leak rates of $1 \cdot 10^{-5}$ mbar·l/s or much lower.

Architecture of an air conditioning system.

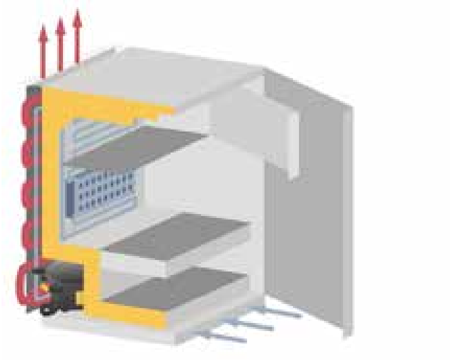
Besides these tests, complex components, e.g. large compressors with an especially large number of connections, are good candidates for sniffer leak detection due to the size of a needed vacuum chamber. This allows the connection points to be checked and the leakage to be safely located. This method is also suitable for the pre-assembled unit consisting of evaporator, compressor and valves. If this unit is found to be leak tight, the completely assembled installation is finally charged with the appropriate refrigerant for the final test, with the typical leak rate for refrigerants in air conditioning systems of a maximum of 2.0 g/a to 5.0 g/a (0,07 – 0,18 oz/yr). If during the final test a leak occurs, there is no other remedy but to reclaim the contaminated refrigerant, which is why a reliable and sufficient test of the components is recommended in advance.

2.2.2 Refrigeration Systems

Refrigeration systems are classified according to their application into commercial, residential, or industrial systems. The cooling capacities of commercially used refrigeration systems generally range between 10 kW and 500 kW. They include, for example, the cooling systems in supermarkets with central refrigeration and a large number of cooling racks connected to it. The cooling capacities of industrial refrigeration systems, on the other hand, range above 500 kW and sometimes even exceed 1,000 kW. Their applications include plants for the cooling of chemical processes and cooling systems used in the production of food, for example in breweries. The assembly process is followed by sniffer leak detection using helium or forming gas. The admissible leak rate is often bigger than $1 \cdot 10^{-5}$ mbar·l/s. After installation at the actual location of use, the installation team will check the connections with a service leak detector, often based on forming gas. Only then is the system charged with refrigerant. Some installations are filled with refrigerant already and then leak tested for refrigerant. If needed the refrigerant will be reclaimed.

Components of refrigeration systems for private or residential use, such as refrigerators and freezers, are normally tested using helium in a vacuum chamber. The industry-specific leak rate for the evaporator, condenser and compressor is $1 \cdot 10^{-5}$

mbar·l/s. If the system is subsequently installed and charged with typical refrigerants such as R600a, R290 or R134a, a final check of all connections, valves, seals and clamps should be performed with a sniffer leak detector for refrigerants to ensure the safety of the system. The standard leak rates applicable in this case are significantly lower than those of the industrial sector and range from 0.5g/a to 2g/a (0.018 – 0.07 oz/yr).



Operating principle of a refrigerator.

2.3 Heating Systems

Although the market for heating systems generally faces less drastic changes than the manufacturers of cooling and refrigeration systems, the growing focus on energy efficiency and climate protection is becoming increasingly important here as well. Furthermore, there is always the possibility that legislators will tighten or adapt existing regulations, like F-Gas Regulation 517/2014, in such manner that refrigerants like R410a, R134a, and R407c, which are frequently used in heat pumps, will be affected as well. Another factor is the steady rise in global energy consumption with its inherent new challenges. Heating systems are some of the installations with the highest energy consumption, which is why since 2015, hot water boilers are also labeled with energy efficiency ratings. The quality and safety requirements of heating systems are also increasing. Water escaping from a heating circuit, or cooling fluid draining from a heat pump, ensure that heaters no longer function smoothly and effectively. This, in turn, can lead to defamatory and costly recall actions. To avoid warranty problems, manufacturers must therefore always be able to count on a reliable leak test.

Many traditional manufacturers still have a water tank and therefore use the water bath method for leak detection. Others resort to leak detection sprays. At first glance, a changeover to vacuum or accumulation chambers operating with helium, for example, seems often too costly. This is, however, a fallacy, because the water bath method is often much more cumbersome and requires a long drying time to boot. Vacuum chambers and the more economical accumulation chambers, on the other hand, can be connected directly to the control units of the line, just like a sniffer device, and can automate the leak detection. In the long term, this not only saves working time, but also ensures higher production capacities with better quality.

For the initial inspection of individual parts, leak detection via vacuum or accumulation chamber is particularly appropriate. Sniffer leak detection lends itself every now and then to the testing of individual components. To secure all connection points, the pre-assembled cooling, gas or water circuits - consisting of the evaporator, compressor, valves, piping, etc. - should be subjected to a leak detection test in an intermediate step. Depending on the system, the typical leak rates for these types of tests are range from $1 \cdot 10^{-2}$ up to $1 \cdot 10^{-5}$ mbar·l/s. A thorough final test, in which connection points are examined, for example, often makes sense as well.

2.3.1 Heat Pumps

Heat pumps work in an effective and environmentally friendly manner with renewable energies and use the ambient heat to produce heat.In moderate climates heat pumps are used for air conditioning as well, by running the process cycle reverse to produce cool air. The refrigerants used in heat pumps require a specific leaktighness of all parts installed in the circuit and accordingly, a reliable leak test. As with many other systems, the long-term trend towards a more compact design does also apply to heat pumps. This poses a challenge for leak testing with traditional methods, such as the water bath. Hidden or difficult parts to reach are difficult to test. If, for example, a bubble rises from a leaky compact test piece in the water bath, it may get caught on another component and the tester won't be able to observe it. In a situation like this a test spray may be useless since the test location is not observable. For the main components of the circuit, for example, compressors, heat exchangers and expansion valves, manufacturers should ideally test the relevant leak rate of 1·10^{-5} mbar·l/s directly during production in the vacuum chamber. Tests in the water bath, on the other hand, can only detect leak rates in the range of 1·10^{-2} mbar·l/s. A test of the pre-assembled cooling circuit group with the sniffer method also presents itself. This makes it possible to ensure at an early stage that the connecting points, such as welds and screw connections, are not leaking.

Picture of a storage heater.

2.3.2 Water Storage

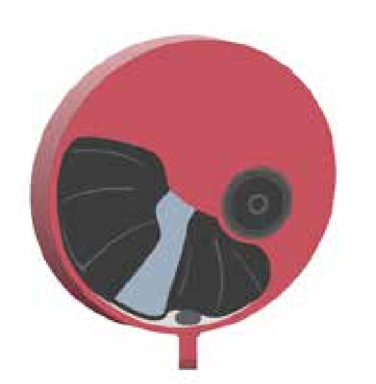
For virtually no other construction is a leak test as important as for hot water storage. This is not about the detection of especially small leak rates, but watertightness of 1·10^{-2} mbar·l/s must in any case be provided. A leaking storage tank causes not only a lack of water for domestic use, but may also lead to serious water damage. Above all, the welding seams are prone to large leaks. A special case is the storage-in-storage system. The service water tank is located in the storage tank for the heating water, which is heating the hot water. In order for the heating water not to contaminate the service water, the service water tank must be watertight, i.e. leak-proof up to 1·10^{-2} mbar·l/s – otherwise, health implications may arise. The same applies to the hot water storage of a solar system.

Picture of a storage-in-storage system.

The heat carrier fluid, located inside a coil in the service water, must not enter the water circuit either. Therefore, the respective tanks should be carefully tested for leaks, for example either in a vacuum chamber or, in order to test the tightness of the welding seams with a sniffer device.

2.3.3 Expansion vessel

Expansion vessels are found in most heating systems. They consist of a tank in which heating water and a gas component with excess pressure, usually nitrogen or air, are separated by a membrane. This mechanism regulates the pressure in the closed water circuit. Heated water expands and forces the gas back. When the water loses volume due to cooling, the membrane compensates for the drop in pressure. If an expansion vessel is no longer fully functional, the pressure in the water circuit drops and the heaters are no longer getting sufficiently warm. A leak in the outer wall often results in a pressure drop. Either water drips from the expansion chamber, which the user should refill, or gas escapes from a leak. Welding seams as well as the fill nozzle often show these types of defects, causing many devices to be replaced within the warranty period. Due to thorough leak detection during production, this is becoming obsolete, however. The container/chamber must be tested for a water tightness of $1 \cdot 10^{-2}$ mbar·l/s in the section of the heating water, whereas the gas section must tighter; therefore, a test of up to $1 \cdot 10^{-4}$ mbar·l/s in the vacuum chamber is recommended. Sniffer leak detection can be used to reliably detect defects in the welding seams, making the costly replacement of faulty parts at a later time unnecessary.



Schematic illustration of an expansion vessel.

10 most common errors in leak testing

1 Wrong Test Method

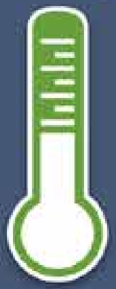
The leak testing method is selected based only on the marginal leak rate and other influencing factors are neglected.

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.

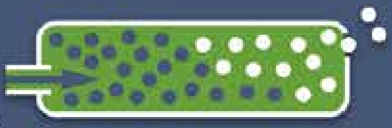


4 Disregarded Temperature Influence

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 No calibration of the test equipment takes place

To make sure that your system is measuring correctly, a test by a reference leak is necessary.

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.

2.4 10 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 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 compressor even before additional components are attached to it because if the pre-assembled components subsequently fail the series test and must be ejected, the effort is much higher and the assembly work hours are then 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 gases can then possibly no longer escape from the test piece (or enter it).

On metal parts, 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 a heat exchanger, in some cases leaks only occur when it has reached its typical operating temperature.

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 then even more important.

Error 6: No calibration of the test equipment takes place

One problem which may occur frequently are so-called stringer leaks consisting of capillary-like corridors. 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 the 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 and gross leaks before filling the test piece with helium.

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 (g/a) of an air conditioning system 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 do an automatic conversion, such as the Protec P3000(XL) from INFICON. 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.

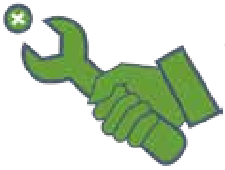
It also would be a serious mistake to equate a leak rate with a concentration of gas that is indicated on some instruments as parts per million (ppm). The concentration is a snapshot, it only indicates how many particles are in a given space at a given moment. The leak rate indicates, however, the size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

Error 8: Stringer leaks and gross leaks are underestimated

Sometimes, errors in the 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. Test leaks with a glass capillary are also significantly less sensitive to moisture and contamination. 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 to their system instead of a helium bottle.

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 regularly checked. 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.



Error 10: We can do it ourselves

Maybe, but think about it very 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 ist o do the right measurement and in the right way, every day and at every level.

Part 3
Appendix

3.1 Source of Illustrations

Cover:	INFICON
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3.3 About INFICON

INFICON GmbH in Cologne (www.inficon.com) is one of the world's leading developers, producers and suppliers of instruments and devices for leak detection. The leak detectors are used in the production and quality control of demanding industrial processes and cover a wide range of applications. The main customers of INFICON are manufacturers and service companies for air conditioning and refrigeration equipment, the automotive and automotive supply industry, the semiconductor industry and manufacturers of leak detection systems.

Nearly all manufacturers of refrigeration and air conditioning systems and their suppliers are our customers. INFICON technology is used to test refrigerators, air conditioning systems and their components, heat pumps, drinking water dispensers, hot water storage tanks or gas heaters for hot water or heating purposes.

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

INFICON experience in leak detection technology spans more than 50 years. INFICON processes worldwide sales through production facilities in Cologne (Germany), Balzers (Liechtenstein), Linköping (Sweden), Syracuse (USA) and Shanghai (China), as well as sales offices in all major industrialized countries and an extended network of sales partners. In the fiscal year 2017, INFICON AG with its approx. 1,000 employees, achieved worldwide sales of US$373.6 million. The registered shares of INFICON (IFCN) are traded at the SIX Swiss Exchange.

3.4 References

Manufacturers of refrigeration appliances:

ALI Group, Beko, Bosch Siemens Haustechnik, Daewoo, Dometic, Electrolux, Fagor, Frigidaire, GE appliances, Gorenje, Gree, Haier, Hitachi, Hisense, Hoshizaki, Hotpoint, Indesit, Kirsch medical, LG, Liebherr, Maytag, Midea, Miele, Mitsubishi Electric, Panasonic, Samsung, Sharp, Smeg, Toshiba, True Manufacturing, Webasto, Whirpool, Zanussi.

Manufacturers of air conditioning systems:

Airedale, Amana, Baxi, Blue Star, Carrier, Climaveneta, Daikin, DeLonghi, Fujitsu, Galanz, GlenDimplex, Goodman, Gree, Haier, Hisense, Hitachi, Johnson Controls, LG, Midea, Mitsubishi, Panasonic, Rheem, Robert Bosch, Samsung, Sanden, Sanhua, Sanyo, Thermo King, Toshiba, Trane, Vaillant, Videocon, Viega, Viessmann, Walton Group, Whirlpool, York International.

HVRAC Suppliers:

Agramkow, Alcoil, Alfa Laval, Bitzer, CIAT, Copeland, Dalian Sanyo, Danfoss, Dorin, Dunham-Bush, Eaton, Embraco, Fujikoki, Huayi, Johnson Controls, Kelvion, Kobelco, LU-VE, Luvata, Mayekawa, Modine, Onda, Parker Hannifin, Sanden, Sanhua, Sanwa, Secop, Sest, Tecumseh, Trane.

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