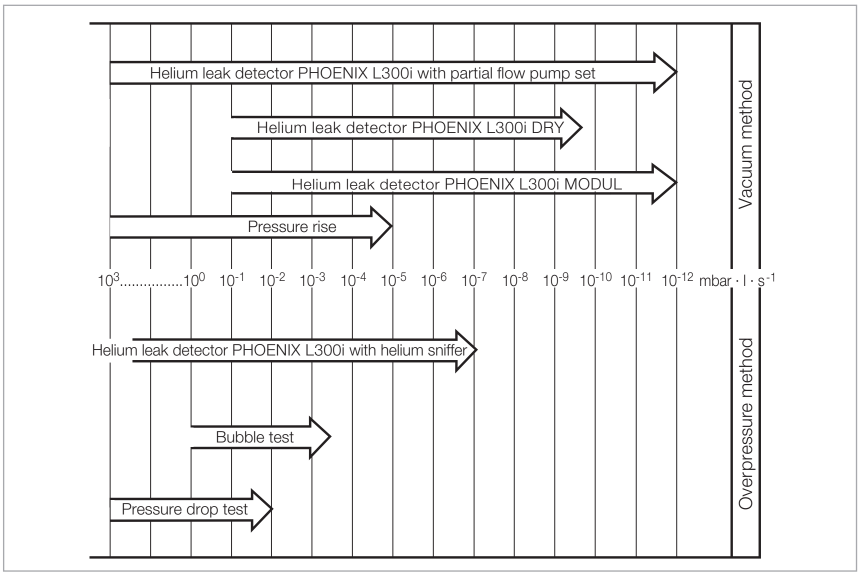
Leak Detection – Leak Testing

Whether a component or a system is leak-tight depends on the application it is to be used in and the leak rate that is acceptable. Absolutely leak-tight components and systems do not exist. A component is considered technically leak-tight if its leak rate remains below a value defined for this particular component. In order to provide a quantitative measure, the term "leak rate" with the symbol "q_L" was introduced. In vacuum technology mbar x l x s^{-1} is used as the unit for leak rates.

A leak rate of 1 mbar x l x s^{-1} exists in a closed vessel having a volume of 1 liter when the pressure increases by 1 mbar within one second, or in case of an overpressure it decreases by 1 mbar within one second.

$$q_L = \frac{V \times Vp}{\Delta t} \quad (\text{mbar x l x s}^{-1})$$

The wide range of leak rates from several 100 mbar x l x s^{-1} to below 10^{-11} mbar x l x s^{-1} as they occur in practice necessitates the use of different leak detection principles and hence leak detectors (see figure). Besides the determination of the total leak tightness, it is usually important to locate the leak, quickly and precisely, in order to seal it. Instruments for local leak detection are called leak detectors. The leak detectors presented in this product section can be used for the localization of leaks, and in addition some are suitable for determining the total leak rate of test objects.



Overview of the leak rate detection ranges

Leak Rate	**Pa x m³ x s⁻¹**	**atm x cm³ x s⁻¹ *)** **mbar x l x s⁻¹ *)**	**atm x cm³ x s⁻¹ *)** **cm³ x s⁻¹ *)**
Pa x m³ x s⁻¹	1	10	9.87
1 mbar x l x s⁻¹ (He)	0.1	1	0.99
1 atm x cm³ x s⁻¹ *) = cm³ (STP) x s⁻¹	0.101	1.01	1
1 Torr x l x s⁻¹ *)	0.133	1.33	1.33
1 kg x h⁻¹ air	23.4	234	234
1 g/a $C_2H_2F_4$ (R 134a)	6.41 x 10^{-7}	7.58 x 10^{-6}	6.3 x 10^{-6}

Leak Rate	**atm x cm³ x s⁻¹ *)** **Torr x l s⁻¹ 1)**	**kg x h⁻¹** **Air**	**g/a** **$C_2H_2F_4$ (R 134a)**
Pa x m³ x s⁻¹	7.5	4.28 x 10^{-2}	2.28 x 10^{6}
1 mbar x l x s⁻¹ (He)	0.75	4.3 x 10^{-3}	2.28 x 10^{5}
1 atm x cm³ x s⁻¹ *) = cm³ (STP) x s⁻¹	0.76	4.3 x 10^{-3}	2.3 x 10^{5}
1 Torr x l x s⁻¹ *)	1	5.7 x 10^{-3}	3.0 x 10^{5}
1 kg x h⁻¹ air	175	1	–
1 g/a $C_2H_2F_4$ (R 134a)	4.8 x 10^{-6}	–	1

*) According to international system of units only Pa x m³ x s⁻¹ is permissible

Leak Detection Methods

There are two main groups of leak detection methods; for both there are special instruments available:

Vacuum Methods

The equipment to be tested is eva-cuated. The pressure ratio between inside and outside is 0:1.

Overpressure Methods

The equipment to be tested is pres-surized with a search gas or a search gas mixture.

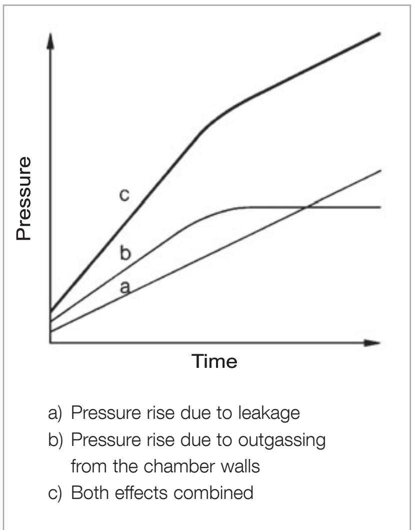
The pressure ratio between inside and outside is over 1:1.

Between the two methods there exist many variations depending on the par-ticular application.

General Notes

1. The lowest leak rates can only be measured by employing the vacuum method, whereby the following applies: The lower the leak rate, the higher the requirements are concerning cleanness and ultimate vacuum.

2. If possible the test objects should be tested under the same conditions that will be used in their final application, i.e. parts for vacuum operation should be tested according to the vacuum method and parts for overpressure operation should be tested using the overpressure method.



Pressure rise in a vacuum chamber after switching off the pump; double log. plot

Leak Testing Based on Vacuum Methods

(Vacuum inside the test object.)

Pressure Rise Method

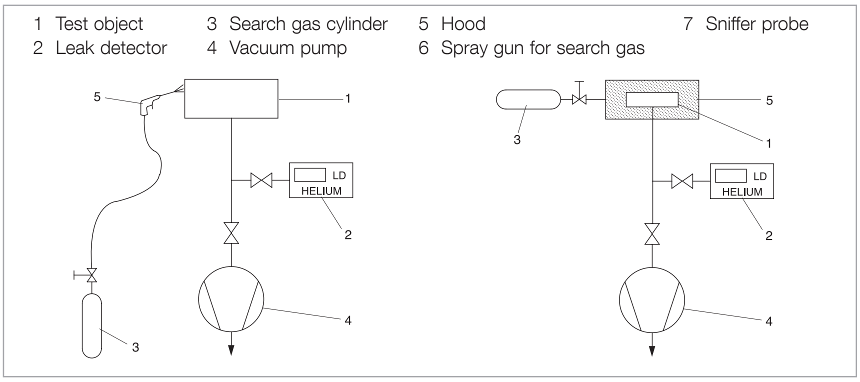
With this method it is only possible to determine the total leak rate. The test object is evacuated with a vacuum pump or a vacuum pump system. A valve is used to isolate the test object from the vacuum pump. The pressure will then rise as a function of time. Curve **(a)** shows the theoretical pres-sure rise if there is only a leak. Curve **(b)** shows the pressure rise due to outgassing from the surfaces of the test object. This pressure rise tends to tail off in the direction of a saturation level. If in such a case the time allowed for monitoring the pressure rise is too short, a leak will be indicated which in reality does not exist. If one waits long enough for the pressure to rise, i.e. after the bend of curve **(b)** the outgas-sing process can then be disregarded, so that the leak rate can be determined from the known volume of the test object and the measured pressure rise over a fixed rise time (see equation on page before). Curve **(c)** shows the pressure rise as it occurs in practice, where out-gassing and leak rate add. The detectable leak rate depends on the volume of the test object, the obtained ultimate pressure and the out-gassing from the test object. In con-nection with very large test objects this method is time consuming if extremely low leak rates are to be determined in the fine and rough vacuum range.

Local Leak Detection

The test object is evacuated by a vacu-um pump (auxiliary pump) until the pressure is low enough for the leak detector to operate. When using a helium leak detector, its own pump system will take care of further eva-cuation. Suspicious spots on the test object will then be sprayed with a fine jet of search gas. Search gas ente-ring through leaks into the test object is pumped out by the vacuum pump and it is converted by the leak detector into an electrical signal which is then dis-played. This permits rapid detection and determination of the size of even the smallest leaks.

Integral Method

Determination of the total leak rate of a test object. The testing arrangement is the same as for local leak detection, but in this case the test object is not sprayed with search gas on selected areas, but it is surrounded by a hood or a chamber which is filled with the search gas. Thus the entire outer sur-face of the test object comes into con-tact with the search gas. If the search gas enters the test object, the total leak rate is indicated independently of the number of existing leaks. With helium leak detectors it is possible to determi-ne the helium content of the air. This is utilized in the detection of gross leaks.



Local leak detection – Evacuated test object (left) and Integral method – Evacuated test object (right)

Leak Detecting Instruments

Leak Testing Based on Overpressure Methods

(Overpressure within the test object.)

Pressure Drop Method

The test object is filled with a gas (for example air or nitrogen) until the testing pressure is reached. Precision vacuum gauges are used to detect a possible pressure drop during the testing period. This method is simple to implement, it is suitable for the determination of gross leaks and can be improved upon by using differential pressure gauges. By applying soap solutions or similar, leaks can be located.

Local Leak Detection with Leak Detectors – Sniffing

The test object is filled with the search gas or the search gas/air mixture to which the leak detector is sensitive. The leak detector is equipped with a sniffer probe, whereby there is a low pressure at the probe tip. If the sniffer tip passes suspicious points on the test object the search gas coming out of the leak is sucked in and transferred to the detection system of the leak detector. After conversion into electrical signals these are displayed optically and acoustically by the leak detector.

Integral Method – Hood Test

To determine the total leak rate of a test object subjected to a search gas overpressure, the test object is surrounded by a hood of a known volume. The search gas which escapes through the leaks collects in the hood.

After a fixed accumulation period a sniffer probe is used to measure the concentration of the search gas which has collected in the hood.

Before this the leak detector should be calibrated by a reference measurement using a known search gas concentration.

The leak rate can then be determined by the equation for q_L where V is the volume of the hood, Δp is the partial pressure difference of the search gas (concentration change) and t is the accumulation period.

Uncertainties in the determination of the volume, leaks in the hood and a wrong accumulation period make precise leak rate measurements based on this method very questionable.

Integral Method – Vacuum Hood Test

This test is a variation of the hood test described above, which has considerable advantages. A vacuum chamber which is evacuated by an auxiliary pump and which is connected to a leak detector is used as the hood. The search gas escaping through the leaks is converted by the detection system of the leak detector into electrical signals which are immediately displayed. After calibration of the leak detector with a calibrated leak it is possible to quantitatively determine the total leak rate.

This method permits the detection of very small leaks and is especially suited for automatic industrial leak detection.

Integral Method – Bombing-Test

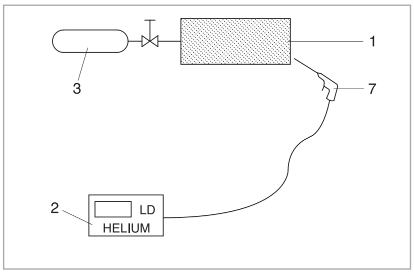
This method is used for testing hermetically sealed components such as transistors, IC-packages or dry reed relays. It is basically a variation of the vacuum hood test. Here the test objects are placed in a vessel which is pressurized with the search gas – preferably helium. At a fairly high search gas pressure and after a period of up to several hours it is tried to enrich the search gas inside leaky test objects. This is the actual so called “bombing” process.

After this, the test objects are transferred to a vacuum chamber and their total leak rate is determined in the same way as in the vacuum hood test. During evacuation of the vacuum chamber down to the required testing pressure, those test objects which have a gross leak already lost their accumulated search gas. These parts are not detected as leaking during the actual leak test. Therefore the test with the vacuum chamber is often preceded by a “bubble test”.

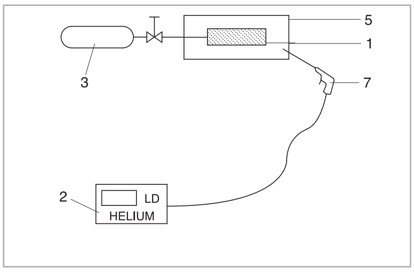
This method permits the detection of the lowest leak rates and is used mainly in automatic industrial leak testing especially when it is not possible to fill the parts with gas in any other way.

Key to the Figures

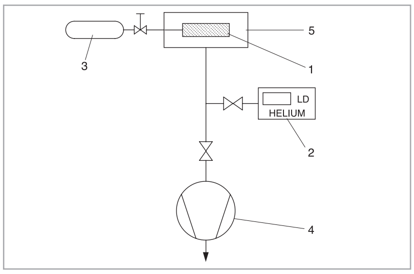
1 Test object
2 Leak detector
3 Search gas cylinder
4 Vacuum pump
5 Hood
6 Spray gun for search gas
7 Sniffer probe



Leak detection –
Search gas overpressure in the test object



Integral method (search gas accumulation)
Search gas overpressure in the test object



Integral methode –
Search gas overpressure in the test object

Operating Principles of the Helium Leak Detectors

Operating Principle

A helium leak detector permits the localization of leaks and the quantitative determination of the leak rate, i.e. the gas flow through the leak. Such a leak detector is therefore a helium flow meter.

In practice the leak detector performs this task by firstly evacuating the part which is to be tested, so that gas from the outside may enter through an existing leak due to the pressure difference present. If only helium is brought in front of the leak (for example by using a spray gun) this helium flows through the leak and is pumped out by the leak detector. The helium partial pressure present in the leak detector is measured by a sector mass spectrometer and is displayed as a leak rate. This is usually given in terms of volume flow of the helium (pV-flow).

Important Specifications

The two most important features of a leak detector are its measurement range (detection limits) and its response time.

The measurement range is limited by the lowest and the highest detectable leak rate. The lowest detectable leak rate is defined by the sum of drift and noise in the most sensitive measurement range. Usually the sum of noise amplitude and zero drift per minute is made to be equivalent to the lowest detectable leak rate. With leak detectors the amount of drift is so low, that the noise amplitude alone determines the detection limit.

The highest detectable leak rate depends strongly on the method employed. Especially the counterflow method and partial flow operation (see description below) permit the measurement of very high leak rates even with a sensitive helium leak detector. In addition the multistage switchable high impedance input amplifiers of the leak detectors also permit the measurement of high leak rates.

In practical applications, especially in the localization of leaks the response time is of great significance. This is the time it takes from spraying the test object with helium until a measured value is displayed by the leak detector. The response time of the electronic signal conditioning circuitry is an important factor in the overall response time. In the case of leak detectors the response time of the electronic circuitry is well below 1 s.

The volume flow rate for helium at the point of the test object is of decisive significance to leak detection on components which are pumped down solely by the leak detector. This volume flow rate provided by the leak detector takes care of the helium entering through a leak and it ensures quick detection by the leak detector. On the other hand the volume of the test object delays the arrival of the helium signal. The response time can be calculated on the basis of the following simple equation:

Response time for helium $t_A = 3 \frac{V}{S_{He}}$

(for 95% of the final value)

with V = Volume of the test object

S_{He} = Volume flow rate for helium at the point of the test object (or at the inlet of the leak detector, if it alone pumps down the test object).

Leak Detecting Instruments

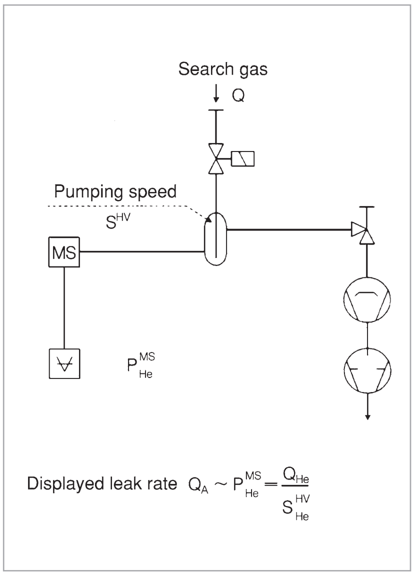
Main Flow Method

The classic operating principle of helium leak detectors is based on the main flow method. Here the entire helium flow passes through the high vacuum system of the leak detector, where the mass spectrometer measures the partial pressure of the helium. In this, the use of a liquid nitrogen cold trap is essential to remove water vapor or other condensible gases in the vacuum system which impair the operation. Moreover, the use of a cold trap permits the low operating pressures for the mass spectrometer to be reached (below 10^{-4} mbar) despite the directly connected (and possibly contaminated) test object.

The advantages of the main flow method are:

- Highest sensitivity, i.e. low detection limit
- Short response time due to a high volume flow rate at the inlet.

The main flow method is thus especially suitable for stationary leak detection on components. Leak detection on systems having their own pump sets and at higher pressures requires the use of an external throttling valve, i.e. a partial flow with subsequently reduced sensitivity is utilized.



Main flow method

Counterflow Method

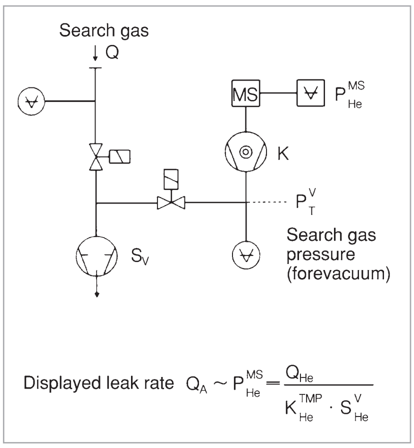
With this method the test object is not connected to the high vacuum. Instead it is connected to the forevacuum (between turbomolecular pump and backing pump), so that the entire gas flow (especially water vapor) does not contribute to the pressure increase in the mass spectrometer. Thus a cold trap is no longer required!

The helium which now enters the forevacuum can still be detected, as it is able to flow against the pumping direction of the turbomolecular pump into the mass spectrometer. This is due to the high particle velocity of the helium. The sensitivity of this counterflow arrangement is equal to that of the main flow principle, provided the right combination of volume flow rate of the backing pump and helium compression of the turbomolecular pump is used.

The advantages of the counterflow method are:

- No liquid nitrogen is required
- High permissible inlet pressures (i.e. pressure within the test object)

This makes the counterflow method especially suitable for mobile leak detection on systems. For leak detection on larger components where a short response time is essential (i.e. high volume flow rate) an additional turbomolecular pump stage is required at the inlet of the leak detector.



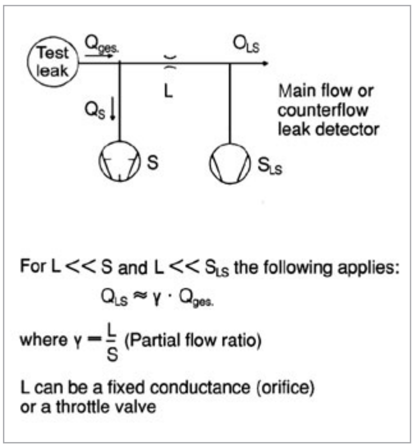
Counterflow method

Partial Flow Method

In order to expand the measurement range in the direction of higher leak rates and for operation at higher inlet pressures, helium leak detectors incorporate a partial flow or a gross leak system. This consists basically of a throttle and a rotary vane pump. At pressures above the normal inlet pressure (main flow: above 10^{-2} mbar, counterflow: above 10^{-1} mbar) or in the case of high helium leak rates, the inlet valve is closed and the main flow is allowed to enter the partial flow pump, whereas only a small part enters the leak detector via the partial flow throttle. Thus the total pressure and the helium pressure are dropped to values suitable for operation of the leak detector.

To obtain correct leak rate readings in the partial flow mode, the partial flow ratio, i.e. the ratio between the actually measured gas flow and the total gas flow must be known and stable.

In all leak detectors this is achieved by a partial flow throttle made of ruby with a precisely machined hole. This ensures that the quantitatively determined leak rates are always correct without calibration, even for gross leaks.



Partial flow method

Calibration of Helium Leak Detectors with Calibrated Leaks

In the process of leak detection one expects that a test object which does not have a leak produces a zero reading on the leak detector. In this any malfunctions are excluded. Thus calibrated leaks, i.e. artificial leaks which produce a known helium leak rate are essential for reliable results.

To obtain a quantitatively correct leak rate reading the sensitivity of the leak detector must also be adjusted. This requires the use of a calibrated leak.

Oerlikon Leybold Vacuum offers calibrated helium leaks of various designs covering the range between 10^{-9} to 10^{-4} mbar x l x s^{-1} as part of the standard range of products. All leak rates are traceable to the standards of the DAkkS Calibration Service controlled by the PTB (Federal Institution of Physics and Technology). If requested each helium calibrated leak can be supplied with a calibration certificate issued by the DAkkS Calibration Service. The calibration itself is performed by the DAkkS Calibration Service for Vacuum which is run by Oerlikon Leybold Vacuum on behalf of the PTB.