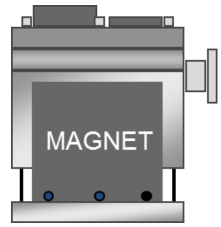
The Helium Leak Detector

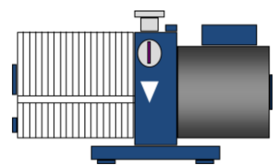
Helium Leak Detector Main Components

The main components of a helium leak detector are:



1. The analyzed, which enables to separate the tracer gas from other gases inside leak detector. The most common type is a magnetic deflection type analyzer or a quadrupole type in the event of testing multi-gasses. (As used in the refrigeration industry). This devise allows to measure the partial pressure of helium. (See later in this document)

2. A high vacuum pump, which is able to reduce the pressure in the analyzer down into the 10^{-6} mbar pressure range. Most leak detectors today are equipped with either a turbo molecular pump, a molecular drag pump or a pump that includes the combination of both. These pumps are ideally suited for contra-flow operation, where the lighter gas molecules, such as helium, can contra flow through the turbo back into the analyzer. This contra flow principle provides the opportunity to start testing at high system pressures, which is ideal for finding larger leaks as common in industrial leak detection.



3. A backing pump to support the turbo pump. This pump can be an oil sealed rotary vane pump. For hydrocarbon free applications, one can select a screw pump or a scroll pump.

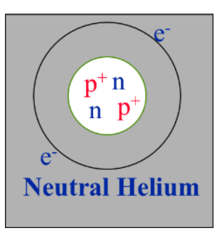
Matter

All elements helium, carbon, silicon and molecules (multiple element substances, such as water, oil, and alcohol) consist of protons (+), neutrons (neutral) and electrons (-)

With helium being the most important for leak detection applications, we will focus on this gas and explain how the ionization process is takes place.

Helium example,

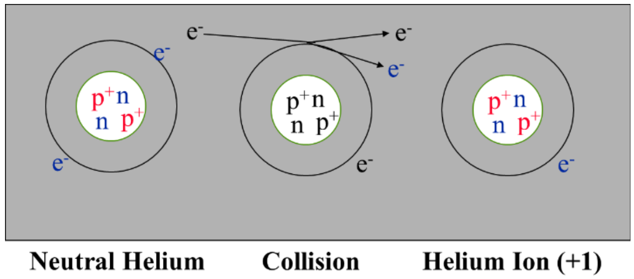
- 2 electrons
- 2 protons
- 2 neutrons,



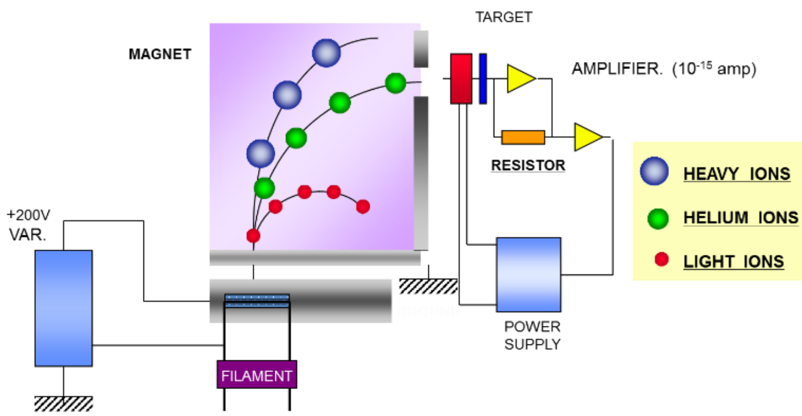
Ions

Ions are elements or molecules that have gained or lost electrons, resulting in a charge imbalance. Once ionized, electric and / or magnetic fields are used to control the speed and direction of the gas molecules.

Example of helium ionized by e^- collision



A 90 degrees Deflection Magnetic Analyzer



As an example for a magnetic analyzer, please look at an analyzer with 90^0 deflection as shown on the left. In this drawing, we see all ionized gases accelerated out of the ionization chamber into a magnetic field.

Only the selected gas (helium) will reach the target plate through the different “lenses” and consequently reach the pre-amplifier (represented by the green dots).

All light gases such a hydrogen will follow a smaller curvature (blue dots), while all heavy molecules will follow a larger curvature and can be collected on a different target plate to be collected for pressure measurements.

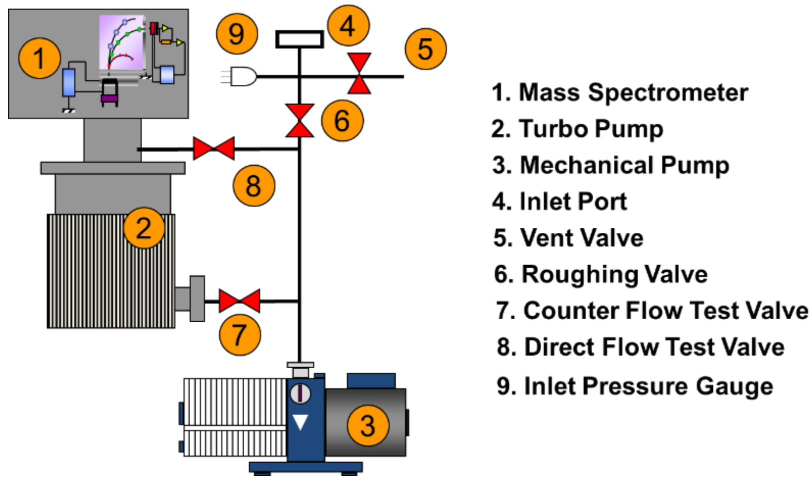
Quadrupole Analyzer

A quadrupole mass spectrometer consists of an ionization chamber, an ion accelerator and a mass filter. The later consists of four parallel metal rods. Each opposing rod pair is electrically connected and a direct current voltage is then superimposed on the RF voltage. Ions will travel down the quadrupole between the rods and only ions of a certain mass-to-charge ratio will reach the detector. Other ions will collide with the rods and will be filtered out.

Stand-alone Helium Detector

This diagram shows all components required to build a stand-alone helium leak detector.

This arrangement offers the capability to firstly evacuate the part to be tested to a vacuum level compatible with the critical fore line pressure of the turbo pump.

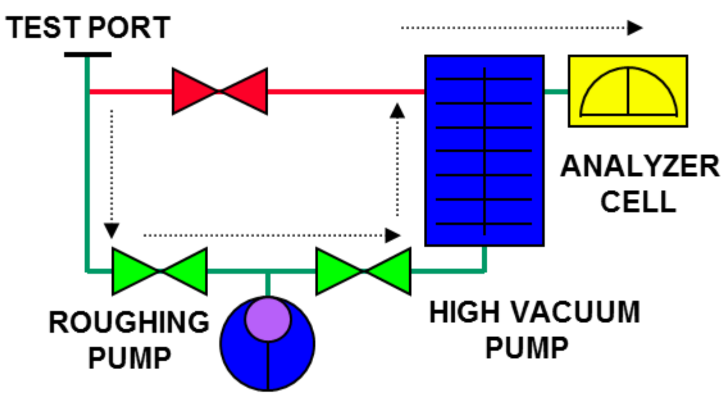


Flow Principles

Helium can contra flow through the turbo pump back into the analyzer. Therefore, the inlet port of a leak detector can be connected to either the exhaust or an intermediate port of the high vacuum pump (mostly a turbo pump).

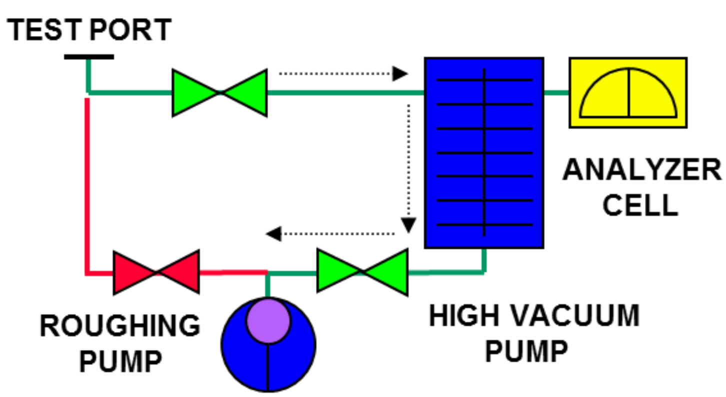
By doing so, the leak detector system can start testing at higher test pressures. If the pressure drops to levels that are comparable with the required analyzer pressure, the machine can then switch to a "direct" flow mode for higher sensitivities. In this situation, all molecules will reach the analyzer directly.

The advantage / disadvantages are shown with each flow mode below.



CONTRA FLOW

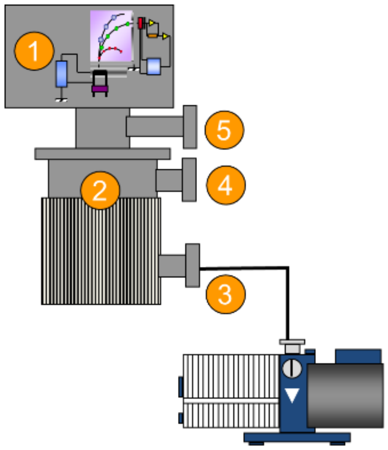
- Shorter test cycle
- Lower sensitivity
- Slower response
- Maintains a clean analyzer



DIRECT FLOW

- Longer test cycle
- Higher sensitivity
- Faster response

Industrial “Component” Helium Leak Detector



1. Mass Spectrometer
2. Turbo Pump
3. Full counter flow port
4. Mid-stage port
5. Direct flow port

Required fore pump and connection line

When a leak detector is used in a large leak detection system with additional pumping systems, the integrator will be best served by receiving a helium leak detection module without valves and auxiliary parts. Most of the time such a module will include a recommended fore-pump to assure the provided module characteristics.

Partial Pressure

What is Partial Pressure?

Ambient air is composed of various gases. The pressure “created” by each individual gas is called *partial pressure*.

Under normal ambient condition, we find 5 ppm of helium or 5 * 10^{-4}%.

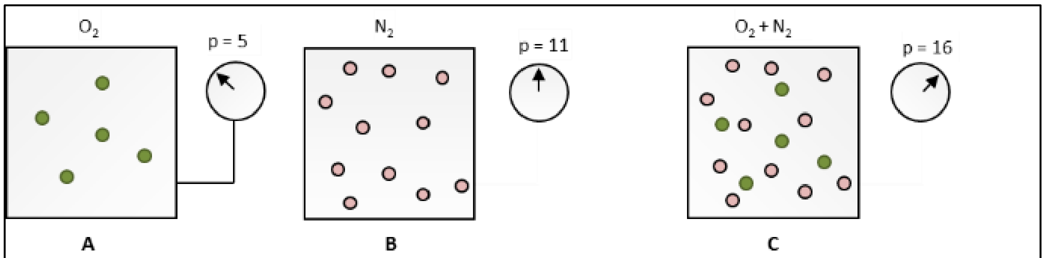
Ambient air composition

The table on the right shows the composition of ambient air by symbol, % by volume and PPM

GAS	Symbol	% By Volume	PPM
Nitrogen	N_2	78.08	780800
Oxygen	O_2	20.95	209500
Argon	Ar	0.93	9300
Carbon Dioxide	CO^2	0.03	300
Neon	Ne	0.0018	1
Helium	He	0.0005	5
Krypton	Kr	0.0001	1
Hydrogen	H_2	0.00005	0.5
Xenon	Xe	0.0000087	0.087
	Total	99.9924587	999924.587

Partial Pressure Influence in an Application

Container A is filled with pure Oxygen at 5 bar.
Container B is filled with pure Nitrogen at 11 bar



The size of the three containers is equal. In container C, the total pressure is the sum of the partial pressures of oxygen + nitrogen.

The total pressure in container C is 16 is bar, being the sum of the partial pressure of oxygen and the partial pressures of nitrogen combined.

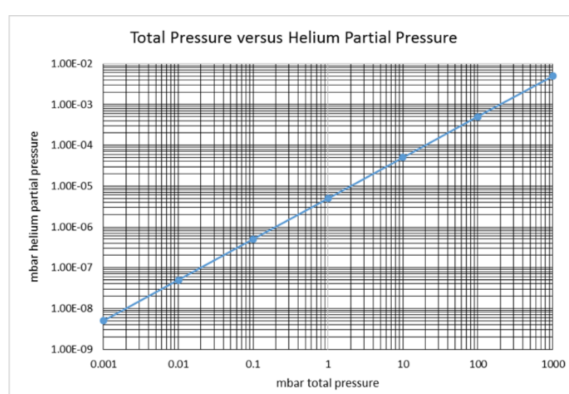
Conclusion: the different molecular types do not affect each other in container C, but will hit the walls as many times per second and with equal force when they are mixed. (Like they would if they were the only gas type present in the container).

What is Helium?

- Helium is a standard element with a molecular weight of 4 amu (atomic mass units).
- Helium is available in small concentrations in the ambient air. This provides for low helium background "noise" in a leak detector and makes helium a very attractive gas for leak detection applications.
- Helium is readily available on a worldwide basis.
- Helium is not toxic.
- Helium is not flammable.
- Helium is an inert gas.
- Helium is available in cylinders of various sizes and it meets the highest standards, as set for the most demanding medical applications. For helium leak detection applications customers should use balloon gas with a accuracy of around 99.99%.

Helium Partial Pressure in Air

To calculate the partial pressure of helium in ambient helium we simply multiply the air pressure in mbar times the concentration of helium in ambient air. (5ppm or 5 *10^{-4}%) Assuming ambient pressure at 1000 mbar, the partial pressure for helium is then calculated to be 5 * 10^{-3} mbar.



“Hard” Vacuum Detection Methods

Why Dynamic Leak Detection?

Dynamic helium leak detection got its designation by the fact that leak measurement is obtained in a system that is constantly pumped by a vacuum pumping system. The system includes a helium mass spectrometer. This in contrast to a vacuum decay processes where the pump source is valved off to observe a pressure variation.

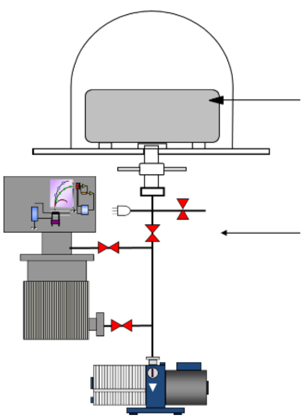
The Units used in Helium Leak Detection

When discussing a leak or flow, the pressure and volume of gas displaced in a particular period must be included. As gas volume is the product of volume * pressure, the gas flow can be expressed as

Error!

The leak rate units used are: Normal.liter/hour, mbar.l/s, atm.cc/s, Pa.m^3/s, SCCM, mm^3/s.

Measuring Total Leak Rate (Inside-Out)



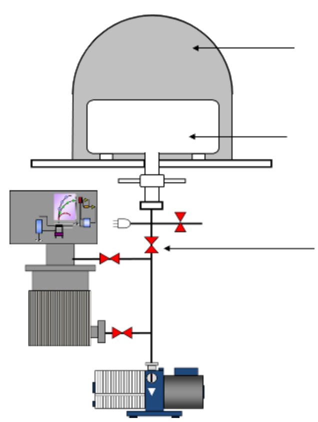
A part pressured at a defined pressure and a known helium concentration is placed in a vacuum chamber pumped by a leak detector or leak detector system.

By using this test method, it is possible to measure the total outflow of helium from the part in a calibrated way. (This technology does not allow to pin point the leak location(s).

Measuring Total Leak Rate (Outside-IN)

The part to be tested is evacuated by a vacuum pumping system. When the appropriate cross over pressure is reached, the leak detector is valved in.

At the same time, the part is covered by an enclosure. Helium is admitted into the enclosure and if there is a leak(s), the helium will enter the part. The detector is now able to measure the total leak value (includes multiple leaks), if the helium concentration and pressure in the enclosure are known.



Also in this method, the location of the leaks will not be known.

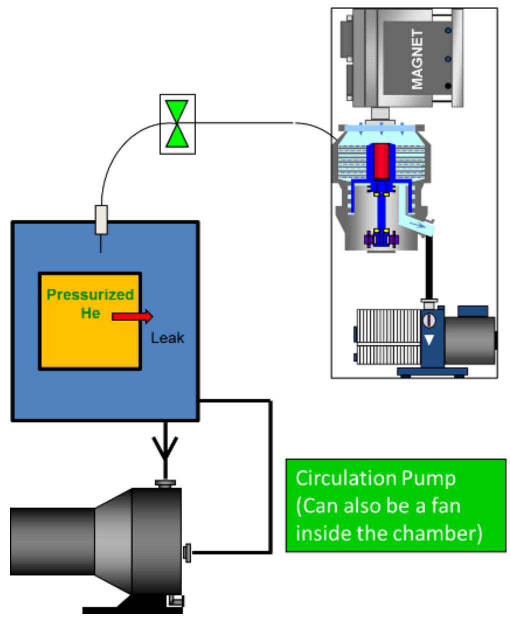
Note:

The leak reading will not be correct if the enclosure does not contain 100% of helium. (The enclosure needs to be pre-evacuated to reach this objective).

After removing the enclosure, the operator can spray helium using a spray probe to “pin pointing" the exact leak location(s).

Accumulation Method

Helium Accumulation Principle



Helium accumulation became a more and more acceptable helium leak test technology that allows for quantitative measurements at a lower cost than a “hard” vacuum method. There is no need for a vacuum pump(s) or a costly vacuum chamber.

- In this technology helium gas or a gas mixture is applied to one side of a containing wall.
- The increase of helium concentration (partial pressure) on the opposite wall in an enclosure is observed over time.

Helium Accumulation Calculations

Error!

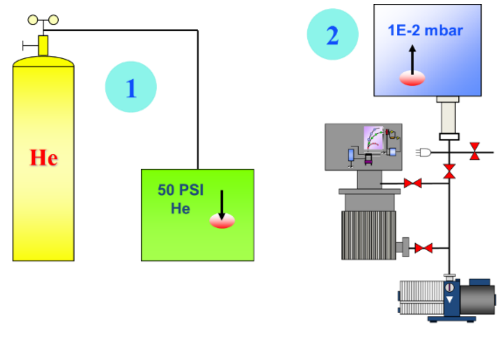
Q = Leak rate in mbar.l/sec
P = Pressure in mbar
C = Helium concentration at the start of the test
C_o = Helium concentration at the end of the test
V = Volume in liters
t = Time in seconds

Example Conditions: C = 25 ppm, t = 35 sec, C_o = 5 ppm, P = 1000 mbar, V = 40 liters

$$Q = \frac{(25 - 5) * (1*10^{-6}) * 1000 * 40}{35} = 2.2 * 10^{-2} \text{ mbar.l/s}$$

Bombing Method

Bombing or Backfilling Principle



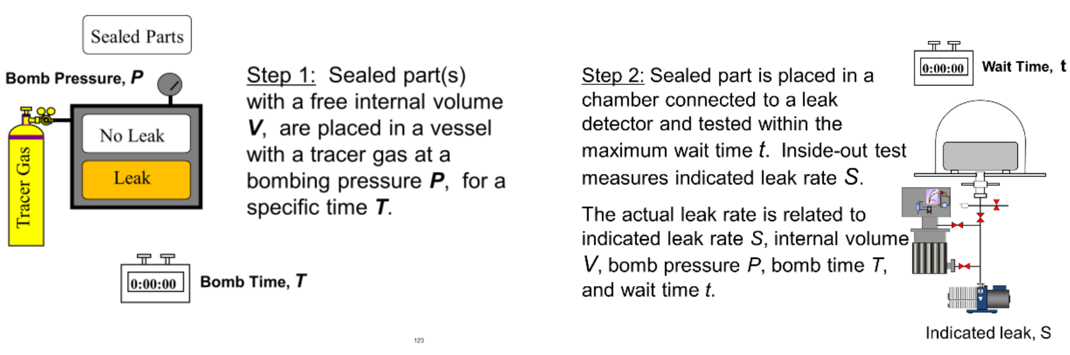
The backpressure method is used when a part is hermetically sealed.

In order to test such a component (electronic packages, relays, transistors), the part is:

- <u>Step 1</u>. Placed inside a so-called bombing chamber, which is pressurized with helium to a defined pressure level. This will allow the helium to accumulate inside the part if there is a leak.
- The part will stay inside this bombing chamber for a fixed period.
- The part is removed from the bombing chamber and will be exposed to ambient conditions for an aeration process. (This is performed, so the helium can escape from the surface avoiding high background readings. (Flushing nitrogen gas over the part will accelerate this process).
- <u>Step 2</u>. The part is placed inside a vacuum chamber that is connected to a helium leak detector. Helium, which entered the part through a leak during the bombing cycle, can now escape and produce a signal on the detector display panel.

Based upon the bombing time, bombing pressure, aeration time and internal volume, a correlation can be calculated between the true leak and the leak indicated by the leak detector.

Bombing Technology Details



Howl-Mann Equation

$$R = \frac{L P_E}{P_0}\sqrt{\frac{M_A}{M}}\left\{1 - e^{-\left[\frac{L t_1}{V P_0}\sqrt{\frac{M_A}{M}}\right]}\right\} e^{-\left[\frac{L t_2}{V P_0}\sqrt{\frac{M_A}{M}}\right]}$$

R =

Measured leak rate of tracer gas through the leak in atm.cc/sec.

L = Calculated leak rate in atm.cc/sec.

P_E = Pressure of exposure in atmospheres (gauge pressure).

Po = Atmospheric pressure in atmospheres.

M_A = Molecular weight of air.
M = Molecular weight of the tracer gas.
t_1 = Time of exposure to P_E, in seconds.
t_2 = Dwell time between release of pressure and leak detection in seconds.
V = Internal volume of the device package cavity in cc.

Indicated Leak versus Actual Leak

Based on MIL STD 883 B the reject level for parts is defined using the Howl-Mann equation. The result is shown in the example on the right.

INPUT

Bombing pressure:	**10**	**ATM (Abs)**
Internal volume:	**0.1**	**CC**
Bombing time:	**5**	**Hours**
Aeration time:	**0.5**	**Hours**
	9.77E-06 mbar.l/s	

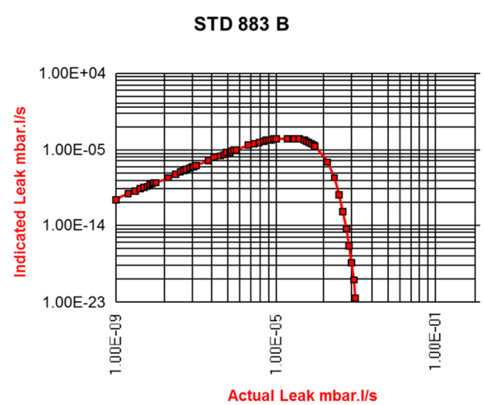
Reject level A2. 10142 (MIL STD 883 B)

The complete ratio range between actual and indicated leaks is displayed in the below graph using the same specifications:

- Bombing at 10 atm (Abs),
- Internal volume of 0.1 cc,
- Bombing time of 5 hours
- Aeration time of 0.5 hours.

It is interesting to see that for the same indicated leak there are 2 actual leak readings! The reason is quite simple.

In one case, there is a large leak, so only a small amount of helium at low pressure is left. This low helium pressure/concentration is producing a small signal for a large leak. In the other situation the helium pressure and concentration are higher and consequently it can produce the same signal for a small leak. (See curve to the right)

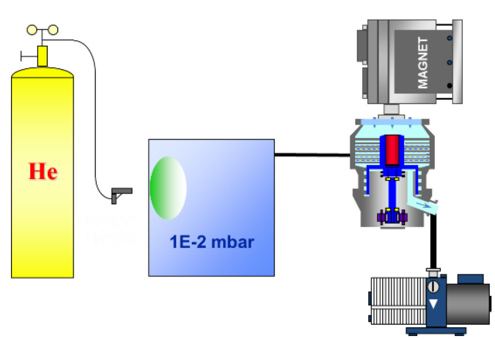


Spraying Technology

Out-side-in Testing

In leak test applications, helium is admitted to one side of a containing wall and is detected through a leak on the other side of that wall.

In the following paragraph, the focus is on technique, where the pressure on the spraying side of the wall is higher than the pressure on the detection side. This is called the "outside-in" test method.



Helium behavior

Admitting or spraying helium is done by using a spray pistol, where the flow of helium can be adjusted to meet the requirements for detecting or pin-pointing a leak.

A part can also be covered with a bag that can be filled with helium. In this case helium can be admitted through a large nozzle.

Helium handling and helium spray control are critical factors for fast, accurate leak detection especially for systems with:

* Multiple leaks
* Multiple elastomers
* Difficult sealing conditions
* High production throughputs

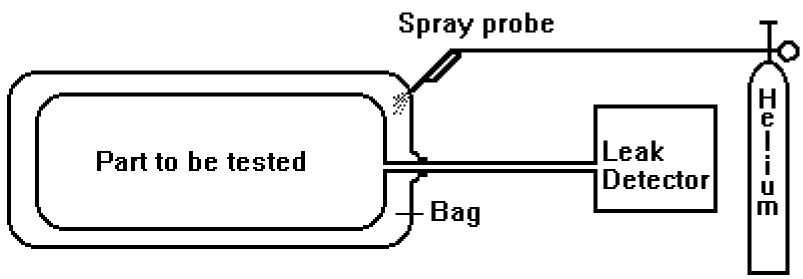
Because helium is a very small, light molecule, which disperses rapidly in the environment and passes easily through any opening or crack, difficult test conditions and false leak indications can occur.

When testing by the vacuum method, there are two specific methods:

1. The "bag" method

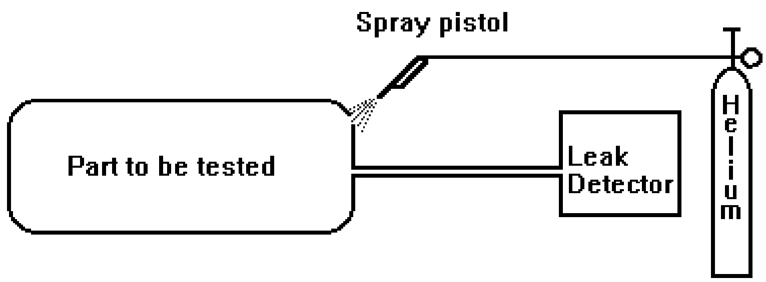
- In this method, a general leak test is performed. The part to be tested is placed completely or partially in a container. (Can be a plastic bag).

- The bag is filled with helium at a pressure => than atmospheric conditions.
  Using this technique, we obtain an overall indication of the system tightness.



Using this technology will not allow the differentiation between a single leak or multiple leaks. Additionally, there is no indication of the leak location(s). The reading is of course affected by the helium concentration created inside the container or bag! (When using a plastic bag, the helium concentration will never be 100% and therefore, the leak detector will never provide a calibrated value of the actual leak rate!)

2. **The "Pinpointing" method**



In this method, the operator can pinpoint the exact location of the leak by spraying a small flow of helium on selected locations. This technique can be applied from the beginning or in combination with the “bag method”. A calibrated reading can only be obtained when 100% helium is present at the leak location.

For both methods, understanding of helium behavior is necessary, as response time, clean up time, and background issues created by helium contamination of the environment have an impact on the test procedure and the results.

Issues with the Out-side in Method

- When admitting helium into a container, sealed bag, as discussed above, the helium will need to be dispersed inside the enclosure and a uniform concentration must be built up. This concentration build-up will depend on the helium flow into the bag and on the volume of the enclosure. For small volumes, a significant difference in concentration between the various locations within the volume cannot be noticed, but in large spaces, a higher concentration at the top of the volume may be observed, as helium will rise.
- Leak testing in an environment without proper venting will cause an increase in ambient helium concentration in the room. This can result in a high detector background since helium can permeate through elastomers (see permeation below). Further, helium can back stream into the vacuum system and leak detector through the exhaust of the fore pump due to the contra flow effect, resulting in a higher helium background.

In general:

1. Use a controlled helium spraying technique to minimize helium in the area
2. Using proper venting to remove spent helium from the work area
3. Exhaust the fore pump of the leak detector outside the room, so helium cannot back stream into the detector

Tips for Spraying Technology

To pinpoint leaks or to test smaller systems, just use a few bubbles per second, this;

- Helps minimize background helium
- Improves instrument cleanup following gross leak
- Improves instrument sensitivity
- Improves instrument stability
- Helps avoid misidentification of leak location

In windy environments consider:

- Testing from downstream of the system upstream

- Using a wind barrier while fine testing
- Isolating nearby fittings with a barrier, such as a rubber glove while spraying the fitting under test. It is also possible to isolating the fitting under test with a barrier and introducing helium inside the barrier

To obtain correct readings:

- Displace air at the leak location with 100% helium
- Apply helium long enough to reach a full stable signal (see response time calculations see later in this document)
- Have knowledge of the split flow ratio if a second pump is active on the vacuum system (see split flow operation for details)
- Helium gas is very light and rises quickly. For that reason, it can surprise an inexperienced leak test technician looking for a leak at the bottom of a system. He can get a false leak indication signal from helium coming through a leak at the top of the system.

Corrective action:

- Careful spraying
- Use a minimum amount of helium (see helium flow below)
- Use protective shielding if necessary
- Avoid draft and turbulence
- Start at the top of a system or installation and work down

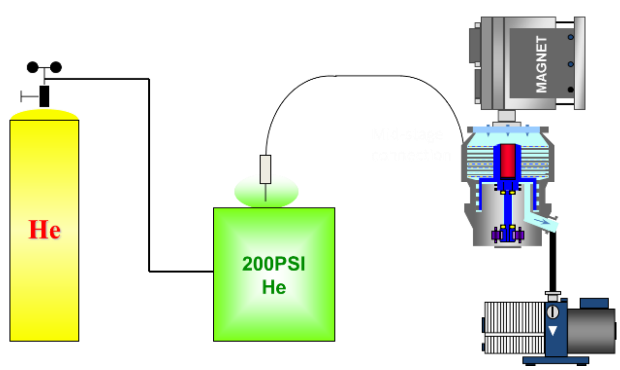
Adjusting a spray probe

To pinpoint a leak, it is not necessary to use a large flow of helium. In fact, that might lead to many of the difficulties as listed above. An appropriate flow is established by inserting the spray probe in a cup with water and adjusting the helium flow to obtain 2 to 5 bubbles per second.

- ✓ If a flow is too small, a leak can be passed over without a recognized response
- ✓ If a flow too large, it can result in false indications and long clean up times if a large leak is discovered

Sniffing Technology

Inside Out or Sniffing Technology



In this technique, the part is pressurized with helium or with a mixture of helium and air or nitrogen. A sniffer probe connected to a leak detector is used to sample the helium escaping through a leak.

To obtain a general indication of a leak, the part under test can be covered with a dome or just a simple plastic bag. By reducing the dead volume of the dome or bag to a minimum, the signal will increase more rapidly. (It is important that the cover or bag does not touch any part of the item to be tested that might be subject to possible leaks). The sniffer probe must be inserted into the bag or dome at the highest point to follow the concentration increase more quickly and accurately.

In a next step, the operator can remove the cover and manually scan the surface of the part with the sniffer probe. This will allow to "pin-point" the leak the location(s).

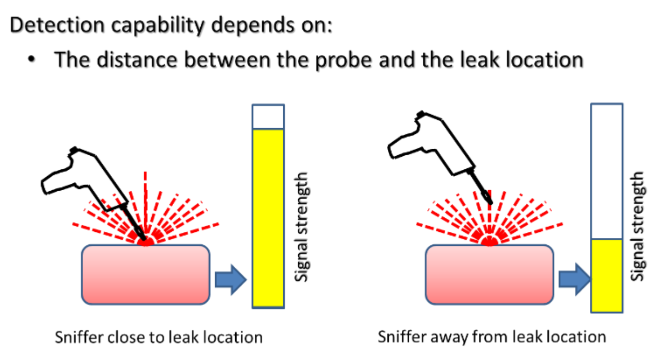
Helium Background in Sniffing

Sensitivity for helium sniffing is limited because of the 5 ppm of helium in ambient air. With this in mind, the smallest leak that most manufacturers of helium leak detectors advertise is $1 * 10^{-7}$ mbar.l/s. This number is not very practical for industrial applications, as it requires working in a non-drafty environment and all helium escaping through a leak needs to be captured by the leak detector. For this reason, the advisable specification for industrial applications is set at $5 * 10^{-6}$ mbar.l/s.

<u>Note:</u>

A sniffer probe must be seen as a defined leak connected to the helium leak detector. Assuming this leak to have a value of $1 * 10^{-2}$ mbar.l/s (This value shows up if we would spay helium at 100% concentration at the probe inlet). The ambient reading on the *calibrated* helium leak detector may be measured as:

$1 * 10^{-2}$ mbar * $(5 * 10^{-4})$% helium concentration = $5 * 10^{-8}$ mbar.l/s. (Please be advised this value is never the value of the leak that is being measured!)

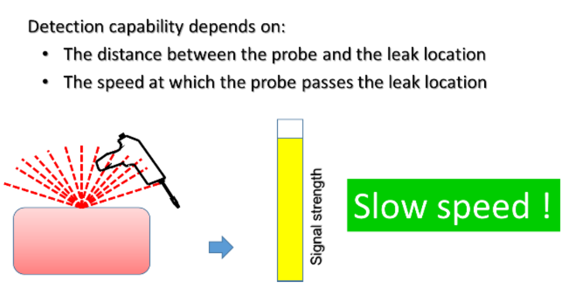


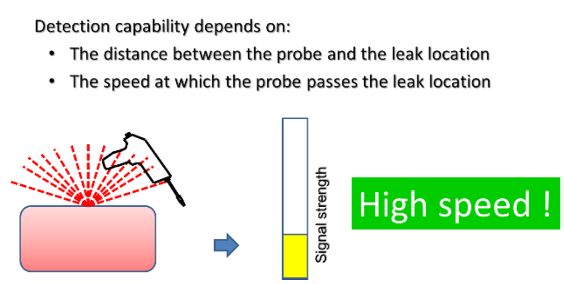
Sniffer Probe Technology

The signal strength that can be obtained using a sniffer probe depends on two major elements:

- Probe distance to the leak.
- Probe speed when passing a leak location. (See illustrations below)

.

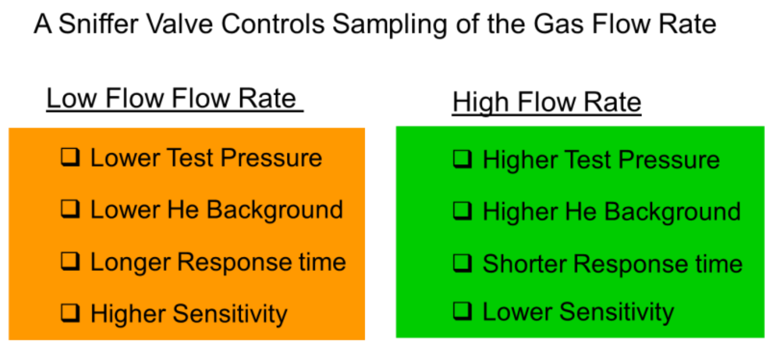




Sniffing Technology Details

Regarding sniffing technology, the following additional information might be important for the user:

- The operator needs to find all individual leaks and to combine their values to determine the total leak specification.
- If there is no true tracer gas leak in front of the probe, the test gas concentration in the suction gas flow equals the ambient concentration (Co). A stable and clean environment is necessary for operations, where stable high sensitivities are required.



- Probe flow conditions have a major effect on the sniffing capabilities and even the slightest change in probe flow conditions (for instance caused by contamination) has an impact on the system accuracy and performance.
- The sniffer probe can be used to perform quantitative measurements is by applying accumulation technology. (See accumulation technology).

Where Helium Detection Methods are used

Spray Probe

- Vacuum systems
- Testing objects able of withstanding one atmosphere pressure differential

Sniffer Probe

- Systems that can be pressurized (e.g. gas delivery lines and pressure vessels).
- Systems with poor vacuum conductance or containing high vapor pressure materials (e.g. water cooling lines)

Outside-in Testing / Inside-out Testing

- Components capable of withstanding 1 bar or 14.7 psi pressure differential
- Components able to withstand minimal pressure differential using specialized pumping technology

Bombing

- Small sealed devices (e.g. ICs)

Accumulation

- Sealed components not capable of withstanding one atmosphere pressure differential
- Components or systems too large for inside-out testing