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Understanding Minimum Detectable Leak in Helium Testing

Introduction

For most leak testing applications, the minimum leak size that an instrument can detect is unimportant since most users are interested in finding a leak and not necessarily measuring it with a high degree of precision. Typical tests are between 10^{-4} to 10^{-9} mbar·L/s, well above the leak detector baseline sensitivity and the instrument's signal-to-noise ratio. Some users require high sensitivity testing and want to read a leak value as accurately as possible. For applications at 10^{-10} mbar·L/s or below, an understanding of the factors that affect the sensitivity of a modern leak detector are essential.

Sensitivity and minimum detectable leak

The term minimum detectable leak (MDL), while occasionally referenced in discussions of modern leak test, is a misnomer. The term originated in the early days of helium leak detection when analog electronics were used. In those days, there were no CPUs, processing software, or digital noise suppression. The analog signal from the spectrometer was what the user saw as a leak rate display, so leak detector performance was highly dependent on the noise level of the analog electronics. In the absence of a standardized noise benchmark, it was very difficult to understand the true capability of a leak detector. A systematic method was needed to characterize the capability of analog leak detectors to measure small leaks.

Specifications from the International Standards Organization, ISO 3530, and American Vacuum Society, AVS 2.1, were created to provide a defined process to calculate MDL, which was in effect a measure of the "noise floor" of a leak detector. In theory, any signal above the noise floor was a leak rate signal that could be read by the user. That noise floor was comprised of the electronic noise component and the spurious signal from residual helium in the system as measured by the spectrometer.

The MDL evaluation process instructed the user to fully warm up the electronics to minimize electronic noise, and fully pump out the spectrometer vacuum system to remove as much background helium as possible. Keep in mind that a spectrometer measures all the helium present in the system. It cannot interpret if that helium was from a leak, was trapped in O-ring seals, or was desorbed from vacuum surfaces. Any unaccounted background could result in an unstable baseline resulting in a high background "noise component". Once the leak detector was warmed up, the analog output signal was measured using a strip-chart recorder. The resulting strip chart was then evaluated to identify the average noise floor. Again, in theory, any signal above noise was readable by the user. In practice, working at the lowest range of any electronic device, just slightly above the average noise floor is a challenge, and manufacturers therefore had widely varying results in reading small leaks.

Today, sophisticated leak detectors can read signals many decades lower due to extensive computerized signal processing. Modern electronics typically have a noise floor one decade lower than the smallest helium signal the spectrometer can read, and when combined with software signal-to-noise enhancement, electronic noise is effectively removed as a factor in leak detector sensitivity. By the time a user sees a display of background baseline signal, that signal has been amplified, digitized, noise-reduced, and software processed, so MDL in today's world is not a meaningful value. The noise floor is so low in a modern leak detector that a user cannot assume they can read a leak value slightly above that noise floor. The real measure of sensitivity for a modern leak detector is not the MDL value, but rather "what size leak can a system reliably measure and how low is the helium background". Those are determined by the ultimate sensitivity of the spectrometer and, most importantly, how the user configures and calibrates the test system.

All spectrometers have a lower limit of what size leak they can reliably measure under ideal conditions, typically somewhere in the 10^{-11} mbar·L/s range. Being able to "see" a response to a very small leak is one matter; achieving repeatable measurements requires extreme care in the design of the test system. Consider that the "helium background noise" from the test system hardware must be approximately equal to the leak detector helium background discussed above (i.e. very low). Note, however, that the test system hardware does not have computerized processing help to compensate for small variations. Therefore, extreme care must be taken in the system design, calibration, and leak test process to reliably measure extremely small leaks. Depending on the

helium background, and the other variable aspects mentioned below, the signal may be insufficiently stable, and testing to a pass/fail set point may not be possible.

System design

For leak testing at 10^{-10} mbar·L/s or lower, the test system must be designed to optimize the stability of the test process and minimize any source of variation. Helium background variations can cause significant instability, making accurate readings in the 10^{-10} and 10^{-11} mbar·L/s ranges impossible. The two primary system design factors are the leak rate target and the process cycle time target (seconds, minutes, or perhaps hours to measure extremely small leaks).

- To measure small leaks, the system must be extremely leak-tight from atmospheric gas. Air contains 5 ppm of helium (partial pressure of 5×10^{-6} mbar), and since helium is such a small molecule it can readily leak or permeate into the system unless strict precautions are taken to prevent leaks.

- The system volume should be the absolute minimum that is practical for the part to be tested. Water vapor readily condenses on all surfaces. In fact, 99% of gas background in a typical vacuum system is from water vapor. Helium from the atmosphere is trapped amongst those water molecules and will desorb in a varying manner over time, making it difficult to achieve helium measurement stability. In general, the smaller the system, the fewer the problems.

- Some users vent their system with dry nitrogen to prevent the intrusion of water vapor and atmospheric helium. This delivers much faster cycle times since system pump down is not limited by water vapor. Reduced water vapor also means less trapped helium and better leak measurement stability.

- The materials used must be compatible with good helium management; that is, they must not trap helium or allow it to permeate from the atmosphere, both of which would destabilize the measurement process. Stainless steel is the best material, and aluminum can be used in most applications when properly cleaned. The seals for all interconnections must be of very high integrity – metal seals are recommended over O-rings to eliminate permeation. All O-rings permeate helium to some extent and should therefore be kept to a minimum, and where used, Viton or Buna-N are preferred since their rate of helium permeation is lower than other materials. Never use silicone seals.

- The conductance to the leak detector should be as large as possible to make it easier, and faster, for helium to reach the detector and not be slowed by long, narrow piping. This factor is frequently overlooked by users. The best helium conductance will come with short, large diameter pipes.

- Helium, being such a small gas molecule, can migrate backward through any type of vacuum pump, and eventually reach the spectrometer. In a facility where helium is in constant use, the residual background in the atmosphere can be many times greater than the normal 5 ppm. It is not uncommon to have helium levels above 100 ppm or even several thousand ppm. Helium can flow from the helium-enriched atmosphere backward through pumps resulting in a difficult-to-diagnose background instability in the spectrometer. Some users purge their vacuum pumps with a low, constant flow of nitrogen between the test system and the pumps. The constant flow of relatively large nitrogen molecules through the pumps prevents helium from migrating to the spectrometer, thereby creating a more stable test environment. This method can be highly effective in stabilizing a system for low leak rate measurements.

- In general, it is difficult to measure small leaks in an area with a high concentration of helium. For measurement of extremely small leaks, users should consider locating the leak detector and test system in a room with a low and well-controlled helium background. In addition, rather than continuously venting helium into the work area after each leak test and creating an unstable background, helium should be vented outside the test area, either into another well-ventilated room, or outside the building.

Calibration

The accuracy of a helium mass spectrometer leak detector is dependent on numerous factors, most of which are outside the control of the instrument (i.e. atmospheric helium) and are not considered when calibrating with an internal calibrated leak. The effect of these other factors are often viewed as inconsequential by users, but correct calibration of the test system is critical for any precision leak rate measurement. The leak detector is usually connected to a volume with a significantly different environment than the leak detector itself in terms of surface conditions, gas entrapment, or material outgassing conditions. Test system factors typically introduce helium background far greater than that present in the leak detector. These factors all contribute to the helium signal the leak detector measures. For precision leak measurement, the user must implement an accurate and repeatable external calibration process with a helium source that is part of the user's test system. The external calibration must be performed with careful attention to correct zeroing of the test system background. A few key points with respect to calibration:

- The system must be fully pumped down and the helium background correctly zeroed before attempting a leak rate measurement or calibration. Making a measurement or zeroing the instrument while the helium background and vacuum pressure are still decreasing can introduce an error greater than the size of the leak being measured.

- The time it takes to achieve an accurate measurement depends on the integrity and condition of the system – volume, presence of water vapor on fixture surfaces, residual/background helium, conductance, type and condition of vacuum pumps, etc. Under ideal conditions, the leak detector can make a measurement in milliseconds. Achieving the correct test conditions to do so however may take a very long time when measuring extremely small leaks.

- The external calibration must account for variations of ambient temperature. To demonstrate that point, while reading a 10^{-10} mbar·L/s calibrated leak in the leak detector test port, hold your hand around the leak for 30 to 60 seconds; the leak rate will increase significantly as a result of that slight temperature change. For precision leak testing, temperature management is critical. The test process must measure the temperature of the system calibrated leak. Compensation must then be made for the leak value based on the current temperature. The certificate of calibration typically will indicate the percent change per °C.

- Manufacturers of calibrated leaks are typically certified only to the 10^{-9} mbar·L/s range. Leaks smaller than that are established only by calculation. For a 10^{-11} mbar·L/s leak, manufacturers calibrate to a 10^{-9} mbar·L/s standard, then reduce the helium pressure and/or concentration and scale the value; even the calibrated leak manufacturers cannot directly measure such a small leak.

- Depending on the helium background, and the other aspects mentioned above, the signal may be too variable, and testing to a specific pass/fail set point may not be possible.

For detailed information, see the Agilent document Calibration for Precision Leak Testing.

Process design

To ensure success, a well-designed test fixture, an accurate calibration, and having a documented process are equally important. Typically, for a precision leak test, the user has strict set point objectives and is performing high sensitivity testing to read a leak value as accurately as possible. In the 10^{-10} and 10^{-11} mbar·L/s ranges, each step of the test process must be logically planned to optimize the test environment for an accurate repeatable measurement. Each of the following factors comes into play:

- Test fixture design, pump system design, cycle time requirement, helium background management, and appropriate venting.
- Appropriate conditioning of the test fixture –pumped to remove water vapor and vented to nitrogen for rapid pump down when testing begins. Nitrogen pump purge flowing if used.
- Proper leak detector warm-up and stabilization.
- Internal calibration of the leak detector, and external calibration of the entire test system.
- Zeroing of small background signals after the background fully stabilizes.
- Sufficient overall system stabilization time to make quantitative measurements.
- Sufficient measurement duration to reach a stable helium signal. If the system is vented too soon, an incorrect leak measurement can result.

Conclusion

In summary, a precision leak test in the 10^{-10} mbar·L/s range is done in factories around the world daily. A rare few companies even work in the high side of the 10^{-11} mbar·L/s range using extreme care and with the correct process design. The key for success is to understand and design for the factors that can affect measurement of such small leak rates. The leak detector uses sophisticated hardware and software to accurately detect helium signals above the electronic noise and helium background. The user must design a test system with great care and attention to small details to succeed.

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Conversion tables

Pressure

	Torr	mbar	micron	psi	atm	Pa
Torr	1	1.33	1000	0.0193	0.00132	133.32
mbar	0.751	1	750	0.0145	0.000987	100
micron	0.001	0.00133	1	0.0000193	1.32e-6	0.133
psi	51.72	68.96	51710	1	0.07	6894.76
atm	760	1013	760000	14.7	1	101325
Pa	0.0075	0.01	7.5	0.000145	9.87e-6	1

Leak rate

	atm·cc/s	mbar·L/s	Torr·L/s	Pa·m³/s	sccm
atm·cc/s	1	1.013	0.759	0.101	59.8
mbar·L/s	0.987	1	0.75	0.1	59.2
Torr·L/s	1.32	1.33	1	0.133	78.9
Pa·m³/s	9.87	10	7.5	1	592
sccm	0.0167	0.0169	0.0127	0.00169	1

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