Product Note, PN 435
Quantifying Bubble Tight

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Introduction:
Manufacturers of fluid handling components often use the term “bubble tight”. However there is limited consistency in its meaning and application. ASTM Standard ASTM E515-11 as well as ANSI/FCI 70.2, and IEC 60534-4[1] provide some guidance on testing methodology, but do not establish consistent or industry-wide acceptance levels. Most would agree that bubble tight is a rough indication of the leak integrity of a component or system, but more qualitative than quantitative. So, how can the term bubble tight be quantified?

Simple Leak Detection Methods:
Most simple leakage tests are Go, No-Go (pass/fail) testing only, that is; there is no quantification of the leak, just determination of whether there is a leak or not. Each of the cited techniques involves internal pressurization of a component or system with a gas. Gases, pressures, test temperature and time may vary significantly from test to test.

Name	Method	Sensitivity	Advantages	Limitations
Bubble Test, Submersion	Submerge device or outlet, count bubbles/unit time	Gross leaks	Easy and inexpensive	Difficult to quantify. Mechanics under water bubble formation / surface adhesion have impact. Highly subject to tester experience and skill. Results can vary depending on test conditions. Hydraulic pressure can impact test results. Components may be exposed to fluid contamination. Difficulty in accurately assessing bubble size and formation. Tester cannot normally perform other tasks during test. Cannot easily be performed on large systems or assemblies.

[1] For control valves *Class VI* (to *FCI-70-2* and/or *IEC 60534-4* standards)
For on-off valves compliant to *Table 5* of *API 598* standard

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Name	Method	Sensitivity	Advantages	Limitations
Bubble Test, Soap	Apply soapy solution, watch for bubble formation	Gross leaks	Easy and inexpensive, test in place	Not quantifiable. Soapy fluid must be applied to all potential leak zones and they must be visible. Components exposed to fluid contamination. Results can vary depending on test conditions and methods. Large leaks can be difficult to identify due to blowout.
Ultrasonic	Direct sensitive microphone to device, instrument amplifies / identifies inaudible gas leaks	Gross to moderate leaks	Moderate cost, test in place	Not quantifiable. Vulnerable to sound contamination in environment. Results subject to correct microphone position.
Pressure Decay	Isolate device, record initial pressure, record final pressure after wait period, calculate dP/dt	Depends on test time, instrument accuracy, system volume	Easy and inexpensive, test in place, quantifiable	Testing time may be long. Test requires accurate instrumentation. Device under test must be well understood. Environmental factors can impact test results.

Of the low to moderate cost leak detection methods surveyed, only one can lead to repeatable, quantifiable results; the pressure decay method. While pressure decay is not specifically a "bubble tight" test, detectible leaks are in the same orders of magnitude. Simple average pressure decay can be easily converted to a standardized average volumetric leak rate by simple calculation.

Assumptions:

- Gas behaves ideally
- Gas is dry with no vaporizable liquids
- Containment volume is known and fixed
- Temperature is stable and constant

Convert Pressure Decay to Standard Volumetric Leak Rate:

The average pressure decay:

$$\frac{dP}{dt} = \frac{P_1 - P_2}{t_1 - t_2}$$

The initial mass of gas contained in the system at t_1 is:

$$m_1 = \frac{P_1 \times V}{R \times T_1}$$

The final mass contained in the system at t_2 is:

$$m_2 = \frac{P_2 \times V}{R \times T_2}$$

When $T_1 = T_2$, the mass exiting the system is:

$$m_1 - m_2 = \frac{P_1 - P_2}{R \times T} \times V \therefore \frac{dm}{dt} = \boxed{\frac{dP}{dt} \times \frac{V}{R \times T}}$$

The ideal gas equation at standard conditions:

$$P_{st} \times V_{st} = m \times R \times T_{st} \therefore P_{st} \times \frac{dV_{st}}{dt} = \frac{dm}{dt} \times R \times T_{st}$$

By substitution, the average (non-instantaneous) standard volumetric leak rate is:

$$\frac{dV_{st}}{dt} = \frac{V \times T_{st}}{T \times P_{st}} \times \frac{dP}{dt}$$

System or component volume	V
Temperature, absolute	T
Pressure, absolute	P
Time	t
Mass	m
Atomic mass unit	AMU
Gas constant (gas specific)	R
Initial conditions (subscript)	$_1$
Final conditions (subscript)	$_2$
Standard conditions [2] (subscript)	$_{st}$

Example 1
A component has an internal volume of 0.670 cubic inches (11 cc) including fittings. The test apparatus connecting the pressure source to the inlet is 0.161 cubic inches (2.64 cc) and is leak-free. A pressure decay test is performed at 62°F (16.7°C) nitrogen gas (N_2) and 100.00 psig (6.89 barg). The N_2 source shut off valve is closed and 5 minutes later the pressure has dropped to 99.53 psig (6.86 barg), final temperature is 62°F.

Pressure decay = *dP/dt* = (100.00 - 99.53)/5
= 0.09 psi/min = $\underline{1.57 \times 10^{-3}}$ psi/sec = (1.08 × 10^{-4} bar/sec)

Standard volumetric leak rate = $dV_{st}/dt = dP/dt \times (V \times T_{st}) / (T \times P_{st})$
= 1.57×10^{-3} psi/sec × (.670 + .161 inch^3 × 520°R) / ((62°F+460°R) ×14.696 psi)
= 8.8×10^{-5} standard inch^3/sec = $\underline{1.44 \times 10^{-3}}$ sccs N_2

Example 2
The allowable time for a leak test is 5 minutes per component. The available N_2 gas source is 100 psig (6.89 barg). Internal volume is 0.20 cubic inches (3.28 cc) and the pressure instrumentation and associated test apparatus add another 0.10 cubic inch (1.64 cc). The pressure transducer stated accuracy is 0.05% of full scale throughout the 100 psig range. The transducer is therefore capable of measuring differences of 0.05 psi (0.0034 bar) with high repeatability. One decade of instrument accuracy overhead

[2] Standard conditions assumed: Pst=14.696 psia (1.01 bar), Tst= 520°R (15.6°C)

gives 10 X 0.05 = 0.5 psi (0.034 bar) detection limit. Bubble-tight is determined to be a leak of < 1×10^{-3} sccs. Room temperature is constant 72°F (22.2°C). Can pressure decay testing be used?

Detectible standard volumetric leak rate = $dV_{st}/dt = dP/dt \times (V \times T_{st}) / (T \times P_{st})$
$= (0.5\ \text{psi}/300\text{sec})\times((0.20+0.10)\text{inch}^3\times 520°\text{R})/((72+460°\text{R})\times 14.696\text{psi})$
$= \underline{3.3 \times 10^{-5}\ \text{standard inch}^3/\text{sec} = (5.4 \times 10^{-4}\text{sccs})}$

Since the detectible leak rate is < 1×10^{-3} sccs, pressure decay can be used.

Example 3
In the example 2 above, what pressure drop is necessary to determine failure?

Rearranging the volumetric leak rate equation:
$dP > (dV_{ST}/dt \times (T \times P_{ST}) / (V \times T_{ST})) \times dt$
$> (1\times 10^{-3}\text{sccs}\times 0.061\ \text{inch}^3/\text{cc})\times((72+460°\text{R})\times 14.696\text{psi})/((0.20+0.10)\text{inch}^3\times 520°\text{R})\times 300\text{sec}$
$\underline{> 0.92\ \text{psi} = (0.06\ \text{bar})}$ to exceed specification.

Example 4
In example 2 above, what is the biggest volume that can be accurately tested?

Rearranging the volumetric leak equation:
$V_{valve} + V_{test\ system} = dV/dt \times dt/dP \times (P_{ST}/T_{ST}) \times T$
$= (1\times 10^{-3}\text{sccs}\times 0.061\text{inch}^{3/}\text{cc})\times(300\text{sec}/0.5\ \text{psi})\times(14.696\text{psi}/520°\text{R})\times(72+460°\text{R})$
$= \underline{0.55\ \text{inch}^3 = (9.0\ \text{cc})}$

The biggest volume that can be accurately tested is 0.55 - 0.10 = $\underline{0.45\ \text{inch}^3 = (7.4\ \text{cc})}$

Summary:
When specifying a bubble tight component, it is useful to understand the options and tradeoffs for leak testing methods. Several simple and low cost tests were summarized and the advantages and limitations[3] were listed. Pressure decay leak testing is an economical leak test method that has one significant advantage over other tests surveyed. The pressure decay rate can be converted to a standard volumetric leak rate when enough test information is known. Therefore, the term "bubble tight" can be quantified.

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[3] An additional caveat is related to the test gas. Small molecule gases like helium are better at identifying small leaks. From molecular kinetic energy theory, root mean square molecular velocity $v_{rms} = (3 \times R \times T)^{1/2}$. It follows that small diameter molecules move faster and traverse smaller holes more readily than larger ones. Tests using large molecule gases should be de-rated for sensitivity due to these differences if comparing to helium leak rates. That is, a 1×10^{-3} sccs nitrogen leak is a bigger leak rate than an identical helium leak rate. Leaks tested with nitrogen are not as sensitive as those tested with helium. Based on kinetic theory, $(AMU_{gas} / AMU_{He})^{1/2} = 2.6$ for nitrogen. Therefore, for molecular flow (not viscous), to convert to an equivalent helium leak rate, multiply the nitrogen leak rate by 2.6.