Understanding what is a leak as it relates to devices, products and packages

This is an extract from TM Electronics' paper:
Testing 101
Leak, Flow and Package testing
Part 1. Device and Product Integrity

The entire paper can be downloaded from:
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What is a Leak?

Simply and directly, a leak is a hole or a path through which the contents may escape, or through which ambient materials from the environment may enter. There are holes in everything; the issue you face is to decide how large a hole must be to cause a failure, and where that hole is likely to be located. Your answer to these questions will help to determine what kind of leak testing is most appropriate for your product.

There are two common methods of locating leaks:

- Bubble testing,
- Sniffer testing with trace gas.

A very important issue is the definition of the leakage – or leak rate – that must be found to avoid product failure. This definition will vary according to your product and its circumstances.

Everything Leaks

Remember that everything leaks, even if it is the permeation of gas molecules through a metal or plastic, or atoms leaking through a lead shield. It's just a matter of time. The important point is that leakage is relative to a standard or specification.

How Much Leakage is Too Much?

In order to define the specification or standard (how much leakage is too much leakage?), and indeed in order to measure leakage at all, we need to understand one basic relationship:

Leakage (or Leak Rate) = $\Delta V / \Delta t$

where V is the volume of the medium exiting or entering and t is the time period during which you are measuring the change in volume. Leak Rate is therefore the volume of material (air, fluid etc.) that escapes from a closed or sealed containment in a predetermined amount of time.

Various Units of Measure

You may see leak rate expressed in various units of measure, such as cc/min, cc/sec, or ft3/hr. The units will generally reflect whether you are measuring a relatively high or low leak rate; for example, leakage of air from a medical fluid container will be typically in the range of 1×10^{-3} cc/sec (quite small) but air leakage from a water pump may be in the moderately high range of 8-10 cc/min and still be considered an acceptable part based on its use and test specifications.

Leak Measure as a Change of Pressure

Note that some people will use a leak measure as a change in pressure over time (psi/sec, kPa/sec). These measures represent the result of the volume leakage rate for that specific application. However, unless the total volume of the part and measuring system are known, these measurements cannot be standardized against other instruments or measuring systems.

Identifying Good and Bad Parts

Using volumetric or mass measurements provides the best approach to defining leakage in a test system. Using the pressure drop method is most useful when a particular part can be identified as a “good” or “bad” part.

Typical Product Leak Rates

Having developed a very rudimentary sense of the meaning of “Leak Rate”, let us take a look at some practical issues involving actual products. ***Table 1*** demonstrates typical leak rates for a variety of medical products.

Table 1. Typical allowable air leakage for medical applications

Application	Pressure	Leak Rate	Cycle Time
Catheters	30 psig	< cc/min (1.6 x 10^{-2} cc/sec)	1 - 2 sec
Balloon Catheters	200 psig	0.6 cc/min (1 x 10^{-2} cc/sec)	10 - 15 sec
Blood Bags	2 psig	1 - 4 cc/min (1.6 -6.4 x 10^{-2} cc/sec)	4 - 10 sec
Syringes	10 -150 psig	0.1-5 cc/min (0.2-8 x 10^{-2} cc/sec)	3 - 10 sec
Insulin tester containers		1 x 10^{-4} cc/sec	
Medical fluid containers		1 x 10^{-3} cc/sec	

You may note that some items with higher allowable leak rates, such as the syringes, have a relatively short test time. This is related in part to the degree of flexibility of the test part. A less flexible test item such as a syringe may require less time to “stabilize” before the actual leak test begins, whereas a more flexible item such as a blood bag may need a longer “settle” time.

Typical Leak Rates in Industrial Applications

Table 2 illustrates typical product leakage in industrial applications. Note again that variations in test specifications vary depending on the type of part. Several have a relatively high level of leakage to reach the critical point, but others are lower – in particular, the brake cylinders; consequently, a longer test time is needed to detect leakage at the desired critical level (remember our formula).

Size of Part Changes Test Time

Another reason for variations in test time is the size of the part being tested. Even though the critical level of leak to be measured is larger, the volume of the part is larger. Most of these parts are not particularly flexible, as were many of the medical devices, but even these metal parts can be affected by temperature changes in the gas, and still need some stabilization time. In general, we can state that the lower the leakage rate, the longer the test time required.

Further Discussion: Leak Rate through an Orifice

Leak Rate through an orifice – a hole or a break – is a function of several variables: the pressure differential across the orifice; the diameter or size of the hole; the density of the test medium; the temperature.

The relationships can be defined as follows:

$Q = k * d^2 * Sqrt (P_1^2 – P_2^2 / \rho * T_a)$

where Q is flow rate, d is the diameter of the orifice, P1 and P2 are the pressure on either side of the orifice, ρ is the specific density of the medium, k is a dimensional constant and T is the temperature of the system.

Temperature Must be Constant

To obtain consistent measurements of leak rate, the temperature must be constant. When dealing with gases, most measurements assume it is used in a state where it is considered incompressible.

Obviously, you can relate leakage with hole size, but several empirical factors are tied up in “k”. These factors come from geometry and fluid flow properties like the Reynolds number. Because of this, most leak rates are approximate, unless they are measured directly by mass flow.

As an aside, because matter can flow through an orifice in either direction, in general, leak rates can be assessed using either pressure or vacuum. This is a part-related issue, and in making this decision you need to consider several points: the function of the part, the structural integrity of the part, the degree of pressure change needed to

Table 2. Typical allowable industrial product leak rate

Application	Pressure	Leak Rate	Cycle Time
Water Pumps	15 psig	4 - 6 cc/min	10 - 15 sec
Oil Pumps	30 psig	8 - 10 cc/min	5 - 10 sec
Thermostats	80 psig	1 cc/min	2 sec
Radiators	15 - 40 psig	3 - 6 cc/min	15 - 30 sec
Brake Cylinders	80 psig	1×10^{-3} cc/sec	30 sec
Hoses	150 psig	1 cc/min	10 sec
Tube Sets	15 psig	2 cc/min	5 sec
Faucets	80 psig	5 cc/min	15 sec
Fuel Injection Units		5×10^{-4} cc/sec	
Diesel Injection Units		1×10^{-2} cc/sec	
Gas Filters		3×10^{-3} cc/sec	
Diesel Filters		3×10^{-2} cc/sec	
Gas Pressure Regulators		3×10^{-2} cc/sec	
Gas Tubes		3×10^{-3} cc/sec + high pressure test	

find the leak, and whether the part will “out-gas” in a vacuum, giving false readings.

Leak Rate Conversions

A caveat to keep in mind when considering your test specifications: there are several common units of measure. Table 3 gives leakage and pressure conversion charts that may be helpful to you; note that these are volumetric leak rates at “Standard Conditions” – stated 70 degrees Fahrenheit, 14.7 psia (1 atm).

Table 3. Leakage & Pressure Conversions
All leak rate units at standard atmosphere conditions (70ºF, 14.7 psi)

To obtain →		cc/ss	cc/min	in³/min	ft³/hr	Pam³/min
Multiply	cc/sec	1.000	60.0	3.66	0.127	10
	cc/min	1.67×10^{-2}	1.000	6.10×10^{-2}	2.12×10^{-3}	0.167
	in³/min	0.273	16.39	1.000	3.47×10^{-2}	2.73
	ft³/hr	7.87	471.9	28.80	1.000	78.7
	Pam³/sec	0.10	6.0	0.366	1.27×10^{-2}	1.000

Be careful to note on your specifications – or on specifications from others – what “their” standard conditions are. Many will use 0 degrees Celsius as a reference. The SI units are Pam3/sec (P*V/t). Note also that the following are not leakage measurements (psi/sec, Pa/sec, mbar/sec), but are pressure rates. The actual leak rate is a function of volume. These pressure measurements are only good for one part design, at specific conditions.

The Price of “No Leaks”

We have now developed a sense of the relationship between the size of a leak that is critical and the sensitivity of the test needed to find it. Once you have determined the size of the critical leak for your particular part or device, you can make a determination of your test specifications, and you can begin to research the test method to best serve your needs.

It is important to realize during this specification-setting period that there is a cost associated with instituting this quality control step. The table 4 shows a relative scale of different test methods. There are wide bands around each method to accommodate the different instrument type and the fixturing required to implement the test for your particular part.

As one would expect, the cost associated with greater sensitivity increases. If detection of very low leak rates is essential, the higher cost of equipment may be justified.

Only you can analyze your own best interests.

Table 4. The price of “No Leaks”