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for good measure

When is a Leak Not a Leak?

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We have all too often heard, when asked for a leak specification, the reply "there must be no leak." But what does that really mean? In this white paper, we will attempt to show that there is no such thing as **"no leak,"** but that leaks are a matter of degree that depends on a number of variables.

No manufacturer wants to deliver products to its customers that do not work as designed since warranty and loss of reputation are costly. However, if testing is not carried out at the correct leak tightness level it can be just as costly. Over testing requires unnecessary equipment and parts making it expensive and good parts may fail the leak test for no good reason. Similarly, under-testing, while not requiring complex test equipment will only find large leaks and allow intermediate leaks through to the customer with the usual warranty and reputation expenses.

Air pressure decay leak detection equipment is possibly the most versatile and offers the most value. Air leak detection systems function in the leak rate flow region known as viscous flow which includes turbulent flow at the higher end, and laminar flow at the lower end.

Flow rates are described by their respective conditions as follows:

Choked Flow:

At very high flow rates, it is possible for the flow to reach the speed of sound, and it cannot exceed this. The condition is reached at a critical pressure where a further increase in pressure difference will not increase the flow rate

Viscous Flow:

Viscous Flow occurs when the mean free path is less than the hole size, and probably constitutes the most common form of leak. In an ideal case, the leak rate is proportional to the difference of the squares of the pressures. The nature of viscous flow can be either laminar, with a Reynolds number below about 2000, or turbulent above this number, with vortices and eddies existing in the flow

Permeation :

This process is not a leak at all, according to the definition given previously, but involves the passage of gas or liquid through a membrane, usually a solid. Molecules are dissolved in the membrane, diffuse through it, and are released at the other surface. As with the flow of any matter there must be a driving force.

The force can be a pressure or concentration difference, for example a mixture of gases for example O_2 in N_2 on one side of the membrane and only one gas, N_2, on the other, giving rise to the permeation of O_2 until the concentration either side of the membrane is the same.

Transitional Flow :

Here the mean free path of the molecules is about equal to the size of the hole. For this kind of flow to occur, the diameter of the circular hole would be in the order of 0.1 mm (100 nm).

Molecular Flow:

This can be considered to be the smallest form of leak. The mean free path of the gas is greater than the hole through which the gas passes. (The mean free path is the average distance travelled by a molecule before hitting another molecule).

The leak rate is proportional to the pressure difference.

Factors affecting leaks

There are many factors that affect leaks, their significance and our ability to detect or locate them. However, the most important factor is the viscosity of the fluid (η) (liquid or gas) contained or excluded from a vessel. For the influence and effect of all the other factors like hole size, pressure difference, temperature, molecular size and material type are dependent on the fluid viscosity.

Viscosity and the Theory of Leaks

Viscosity is one of the important characteristics when handling fluid. Different units are used in different fields. In leak detection we are interested in the dynamic viscosity. The S.I. unit for viscosity is the PASCAL seconds (Pa.s) which may also be expressed as the Newton second per square meter (N s/m^2) or as the kilogram per meter second (kg/(ms)). In France, the Pa is given the name poiseuille (Pl). The corresponding CGS unit is the poise (P); which is not the same as the poiseuille. The commonly used sub-multiple of the poise is the centipose (cP). The imperial units of dynamic viscosity are based on the units of force, length and time.

1 Pa s = 2.088 54 x 10^{-2} lbf b/ft^2
1 Pa s = 5.801 51 x 10^{-6} lbf h/ft^2
1 Pa s = 0.671 969 pdl s/ft^2
1 P = 1 dyn s/cm^2 = 10-1 N s/m^2 = 10^{-1} Pa s
1 cP = 10^{-2} P = 10^{-3} Pa s

In the MKS system, the kilogram force second per square metre (kgf sm^2) is also used.

1 kgf s/m^2 = 9.806 65 Pa s

The poise and its sub multiples, the centipoise and for gases, the micro poise are often encountered in leak detection circles when estimating and comparing leak rates of differing media.

In very simple terms viscosity is a measure of attachment to the neighbouring molecules. The net result is that a more viscous liquid or gas will pass through a hole more slowly than a less viscous one.

There is an associated effect, surface tension, which is that of a liquid tending to reduce its area in contact with the surrounding atmosphere leading to an apparent increase in viscosity.

The viscosity of a liquid or gas is determined by the strength of attraction between molecules. The following equation may be used to calculate the ratio between a liquid and gas:

$$\frac{qv}{qg} = \frac{2\eta g}{\eta v}$$

qv = liquid flow
qg = gas flow
η g = viscosity, gas
η v = viscosity, liquid

N.B. This assumes laminar flow characteristics, which should be verified in practice.

Theoretical Equation of Leak Volume

As a representative theoretical equation to explain the behaviour of fluids through a very narrow opening, the Hagen-Poiseuille law is often mentioned. According to this law, if the opening is so small that the flow of fluid is within a range of viscous flow (laminar flow), and the ratio of the holes length vs. the hole's diameter is large enough, the following equation can apply;

$$Qa = \frac{\pi R^4 (P_1 2 - P_2 2)}{16 \eta w \ell P_2}$$

Where Qa is the volumetric flow of the outlet side pressure (atmospheric pressure) converted from a compressible fluid such as air.

However, if P1 is negative, the leakage volume is expressed in terms of the state of atmospheric pressure; the P_2 in the denominator in equation is replaced with P_1.

With a volumetric flow rate Qw representing non-compressive fluid such as water, oil, etc., this equation below applies:

$$Qw = \frac{\pi R^4 (P_1 - P_2)}{8 \eta w \ell}$$

Where Q_a: a volumetric flow rate of a compressive fluid (air) under a pressure P_2 (when a negative pressure is used, a pressure P_1)
Qw: a volumetric flow rate of a non-compressive fluid (water)
P_1: Primary (test) pressures (when a negative pressure, atmospheric pressure)
P_2: Secondary (atmospheric) pressure (when negative pressure, the test pressure)
R: Radius of the opening (pipe)
ℓ: Length of the opening (pipe)
ηa: Viscosity of compressive fluid
ηw: Viscosity of non-compressive fluid

How does this theory apply in reality?

Like most laws there are limits, and this is the case certainly in leak testing where the ideal leak and leak path never exists. Holes are never round, channels are never straight, surfaces are never smooth or clean and the environment is seldom tightly controlled. In theory therefore, a leak may not exist where our trusty formula, which assumes that all leaks are viscous, says there should be one or to put it another way **"a leak is not a leak"** in all cases.

In nearly all leak testing situations in a manufacturing environment, the fluid used for leak testing is not the fluid to be contained by the part or assembly when it is put in use. Common mediums are air, helium and a hydrogen/nitrogen mixture of which air is the most common because it is cheap, clean, dry and easy to handle. Air also has a relatively low and consistent viscosity which makes it suitable for finding most leaks of significance in our manufacturing endeavors in a short time. Smaller leaks are identifiable too but at the expense of extended test time or the adoption of a more expensive medium such as helium and the added cost of the necessary equipment

Some industries such a food and pharmaceutical packaging are concerned with very small leaks that may allow bacterial contamination. These leaks are in the order of 5um or less (consider at this point that the diameter of a human hair is roughly 100um) and under typical differential pressures generated in food package (up to 34.5 kPa) a liquid leak will never start through a 2um defect[1]. At this level surface tension of the liquid and evaporation will effectively block the leak. A package is considered leak tight when the gas leak rate is so small that no liquid will pass through. Then no microorganisms will be able to pass through either. With this frame of thinking the lowest leak rate that could allow microbial penetration would be close to 10^{-5} Pa.m^3 (0.001 sccs = 0.06 sccm) .Of course, most leak rates in industrial and other products are many orders of magnitude larger than the example above and so their detection is often easier and air leak testing by gauge decay, differential pressure, mass flow or laminar flow will find most of them.

Therefore given that air leak testing is the most popular method of leak testing, we need to be able to correlate air leak rates with practical examples in order to establish leak rate specifications. The automotive industry, for example has performed extensive research over many years and concluded that for reservoirs containing water, an air leak rate of less than 4 ccm at component design pressure is effectively leak tight. In fact, this level of leak provides the user with a confidence factor of 5X. The medical device industry frequently adopts 2 ccm which provides the user with a 10X confidence factor.

Conclusion

To strive for a "no leak" specification using the Hagen-Poiseuille law is unrealistic because the law will never resolve to zero. In reality, the law is not 100% reliable because it assumes that holes are perfectly round and that the length of the leak path is bigger than the diameter of the hole. When leak paths are very small the rate of evaporation may be equal to the leak and therefore we will see no leak, the deposits left behind by evaporation will block the leak, and in certain circumstances corrosive oxidation will block the leak.

It is therefore more desirable to adopt a realistic leak rate specification based upon the intended function of the component or assembly and apply a reasonable confidence factor. A correctly chosen specification will identify leaking parts in an acceptable time, reliably and repeatedly, and at an affordable cost.

For readers interested in the calculation of leak test cycle times Uson has created a calculator for iPhone and Android devices. It may be downloaded at http://www.uson.com/

1.(Abstract from "Prediction Package Defects: Quantification of Critical Leak Size. By Matthew Joseph Gibney IV).