Air Leak Testing for Liquid Leak Sites

Leak test specifications for liquid filled parts have been developed over the last 40 years and many have become standards. For example, all water filled parts in the automotive industry are air tested at the working pressure with a reject level of 4 cc/min of air. This application note is concerned with how to correlate air to liquid leaks and will assist in the establishment of meaningful leak test specifications for liquid containing vessels.

The Hagan-Poiseuille law is often referred to as a representative theoretical equation to explain the behavior of fluids through a very narrow opening. According to this law, if the opening is sized such that the flow of fluid is within a range of viscous flow (laminar flow), and the ratio of the hole’s length vs. the hole’s diameter is large enough, the following equation can apply for gases:

\[
Q_a = \frac{\pi R^4 (P_1^2 - P_2^2)}{16 \eta_a l P_2}
\]

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

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

Where a volumetric flow rate \(Q_w\) representing non-comprehensive fluid such as water, oil, etc., this equation below applies:

\[
Q_w = \frac{\pi R^4 (P_1 - P_2)}{8 \eta_w l}
\]

Where:
- \(Q_a\): Volumetric flow rate of a compressible fluid (air) under a pressure \(P_2\) (when a negative pressure is used, a pressure \(P_1\))
- \(Q_w\): Volumetric flow rate of a non-comprehensive fluid (water)
- \(P_1\): Primary (test) pressure (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)
- \(\eta_a\): Viscosity of compressible fluid
- \(\eta_w\): Viscosity of non-comprehensive fluid
The two equations can be used to relate and compare the flow rate of gaseous and liquids through the same orifice at any given test conditions. The following equations show how the two media can be compared.

Volumetric leak rate with different gaseous and liquid pressures:

\[
\frac{Q_a}{Q_w} = \frac{\eta_w}{2\eta_a} \times \frac{x(P_{a1}^2 - P_{a2}^2)}{P_{w2}(P_{w1} - P_{w2})}
\]

Volumetric leak rate when pressures are the same:

\[
\frac{Q_a}{Q_y} = \frac{\eta_w}{2\eta_a} \times \frac{P_1 + P_2}{P_2}
\]

The equations have limitations; they are only true for viscous flow conditions and therefore cannot be used to determine when a flow ceases to exist. For example, when water would stop flowing to determine the leak test parameters for an air test rig. Here we need to be a bit more pragmatic.

Leak test specifications for liquid filled parts have been developed over the last 40 years and many have become standards. For example, all water filled parts in the automotive industry are air tested at the working pressure with a reject level of 4 cc/min of air (this would correspond to a virtual leak path of 22 micron diameter x 1 mm long hole when tested at 1.4 bar).

Recent work by a car radiator manufacturer re-asserted the 4 cc/min test criteria. In this study they had a number of radiator assemblies laser drilled with increasing hole diameters. The radiators were tested dry by a pressure decay test system. This was then followed by filling the radiators which a coolant mix of water and glycol and running the radiators on a life test rig. The life test showed that the range of hole sizes were leak tight up to the hole size that leaked on the dry test rig at 22 cc/min, and after 24 hours this hole revealed the presence of a leak by showing a 15 mm diameter wet mark around the leak site. The conclusion drawn was that 4 cc/min of air specification gave a safety margin of x 5 and, being readily detectable in the test process, was re-affirmed as the correct level to be working at.

Note: As test volumes increase or cycle time constraints become limiting it may be possible to increase the detection limit accordingly without loss of product leak integrity.