

How to Establish an Acceptable Leak Rate

Purpose: This Application Bulletin is to provide an overview of how to establish an acceptable leak rate.

Purpose of Leak Testing Parts

- Confirm manufacturing process is performing to specification and making good parts
- Find defective product earlier in manufacturing process so that corrective action can be taken to get production process in control before additional costs are added.
- Reduce total manufacturing cost.
- Assure product will perform function for which it is designed.
- Reduce or eliminate warranty problems.
- Improve customer satisfaction with product.
- Comply with environmental concerns.

What Defines that the Part's Leak Integrity is Acceptable for its Function?

The part does not leak an unacceptable amount of fluid (water, water vapor, oil, fuel, blood, medicine, etc.) that it is designed to contain under operating or static conditions.

Can a Part Leak other Fluids or Gases like Air and still NOT Leak the Fluid for which the Part was Intended to Contain?

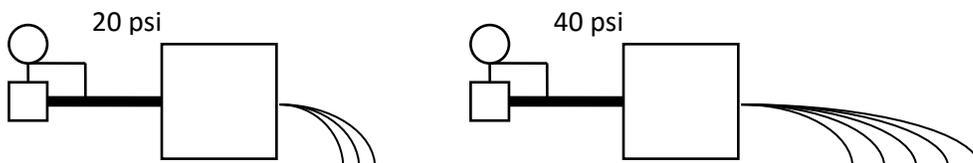
YES

What are the Characteristics of a Hole (Leak) and the Contained Fluid that Make It Difficult or Near Impossible for a Fluid to Leak Out.

If the defect (hole) in the part is small enough or the path length for the leak is long enough, it will be almost impossible for the fluids to flow through the hole (leak).

- The fluid properties that affect flow are pressure, temperature, and viscosity.

Pressure - Greater pressure behind a hole may cause fluid to flow faster or at a greater flow rate.



Temperature - For liquids, higher temperatures change the characteristics of the fluid so that it flows easier and therefore faster. For gases, higher temperatures change the characteristics of the gas so that it flows slower. The examples listed below under viscosity show how temperature causes the resistance-to-flow characteristic of the fluid to decrease for liquids and increase for gases.

Viscosity - Viscosity is the measurement of the internal fluid resistance of a substance. It quantifies the fluid's resistance to flow. Higher viscosities indicate a greater resistance to flow. Low viscosities indicate less resistance to flow or a higher probability of leaking or flowing at a higher rate. Examples of typical fluid viscosities at room temperature (70°F) and at 200 degrees F are:

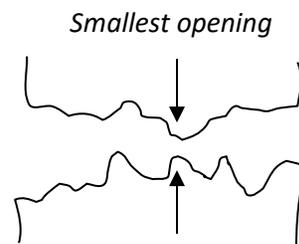
Fluid	70°F	200 °F
SAE10 lube	65 centipoise	5 centipoise
Fuel oil #5 (min)	8 centipoise	2 centipoise
Water	0.95 centipoise	0.3 centipoise
Gasoline	0.6 centipoise	0.3 centipoise
Propane (liquid)	0.11 centipoise	0.04 centipoise
Air	0.018 centipoise	0.021 centipoise
Helium	0.0194 centipoise	
Propane (gas)	0.0080 centipoise	0.010 centipoise

One can imagine that heavy oil or grease will not flow very easily or at all through a small hole where water might flow. The concept of using grease or oil film to seal two mating parts relies on this fact. The ratio of the viscosities between SAE10 lube and water at 70°F is roughly 68:1. In other words water will flow approximately 68 times more units of volume through a hole than SAE10 lube if the lube is able to flow at all.

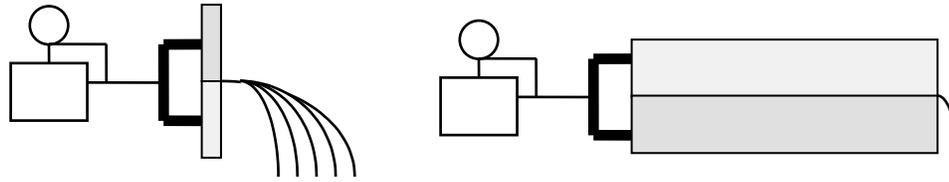
By the same principle when subjected to very low pressure (<1 psig), air will flow approximately 53 times more units of volume through a hole than water if the water is able to flow at all.

- The characteristics of the hole (or leak) that determine whether it will leak are the smallest diameter in the hole path, the path length of the hole through the part material, surface tension, and the surface finish of hole (leak).

Hole Size - The smallest opening in the flow (leak) path controls the rate of flow through the path. The small opening tends to dam up the flow path.



Path Length - The length of the flow path through which a fluid must pass will control how much fluid will flow because long path lengths add resistance to flow.



For **Laminar Liquid Flow**, the generalized equation that relates flow rate (Q_L) in ccm to the hole diameter (d) in inches, path length (L) in inches, fluid viscosity (u_L) in centipoise, and pressure across the part wall (dP_L) in psi is the following:

$$\text{Liquid Flow: } Q_L \text{ (ccm)} = 1.66 \times 10^8 \times \frac{(d \text{ inch})^4}{L \text{ (inch)}} \times \frac{P_L \text{ (psi)}}{u_L \text{ (centipoise)}}$$

Note: 1.66×10^8 (used above) is the resistance coefficient constant for liquids.

Ex: Under **Ideal Conditions** what is the flow rate of water through a leak (0.0004 inches diameter) with a path length of 1/16 inch under pressure of 100 psi at 70°F ignoring surface tension and evaporation?

$$Q_L = 1.66 \times 10^8 \times \frac{(0.0004)^4}{0.0625} \times \frac{100}{0.95}$$

$$Q_L = 1.66 \times 10^8 \times 4.096 \times 10^{-13} \times 105.26$$

$$Q_L = 715 \times 10^{-5} \text{ ccm} = 0.00715 \text{ ccm} \quad (\text{This is approximately 1 drop of water with a diameter of } 1/8'' \text{ in 2.5 minutes.})$$

For **Laminar Gas Flow**, the generalized equation that relates flow rate to the hole diameter (d), path length (L), gas viscosity (u_g), pressure across the part wall (dP_g), and average absolute pressure across the leak path (P_a) in psi is the following:

$$\text{Gas Flow: } Q_g \text{ (sccm)} = 1.132 \times 10^7 \times \frac{(d \text{ inch})^4}{L \text{ (inch)}} \times \frac{dP_g \text{ (psig)}}{u_g \text{ (centipoise)}} \times P_a \text{ (psi)}$$

Note: 1.132×10^7 (used above) is the resistance coefficient constant for gasses.

What air flow will occur through a 0.0004 inch diameter leak with a 1/16 inch path length if the part were pressurized with 100 psi air at 70°F?

$$Q_g = 1.132 \times 10^7 \times \frac{(4 \times 10^{-4})^4}{0.0625} \times \frac{100}{0.018} \times \frac{(100 + 14.7)}{2}$$

$$Q_g = 1.132 \times 10^7 \times 4.096 \times 10^{-13} \times 5.555 \times 10^3 \times 57.4$$

$$Q_g = 1.477 \text{ sccm} \quad (\text{This is equivalent to 100 bubbles with a diameter of } 1/8'' \text{ in one minute in a dunk tank})$$

From the formulas it indicates that as the hole size gets smaller, it reduces the flow by a factor to the fourth power. As the path length gets longer it has an inverse proportional effect to reduce the flow.

When comparing liquid and air flow rates, the flow rate increases due to the reduced viscosity and the expansion characteristics of the gas. The following formula which is derived from the two formulas above reflects a comparison of liquid flow to gas flow across a common leak.

$$\frac{Q_g}{Q_L} = 0.068 \text{ Pa} \times \frac{u_L}{u_g} \times \frac{dP_g}{dP_L}$$

This formula reflects the theoretical relationship on flow of changing test pressures between liquid and air applications and the proportional effect of going from a liquid viscosity test media to a gas viscosity test media.

$$\frac{Q_g}{Q_L} = 0.068 \times \frac{100 + 14.7}{2} \times \frac{0.95}{0.018} \times \frac{100}{100}$$

$$\frac{Q_g}{Q_L} = 0.068 \times 57.4 \times 52.7 \times 1 = 205$$

Surface Tension of Liquid Flow into Air - In order for a liquid to flow out of a small capillary hole, the pressure of the liquid must be greater than the surface tension pressure. The relationship of surface tension pressure (P) psi to leak (or hole) diameter (d) in inches and the surface tension of specific liquid (a) in lb/in. is:

$$P = \frac{4 a}{d}$$

Pressure required to overcome surface tension increases as the leak diameter (d) gets smaller.

If the diameter gets small enough the surface tension will prevent liquid flow.

Ex. Water has a surface tension of .00497 lb/ft (0.000414 lb/in). What internal pressure would be required to overcome the surface tension on a part with a capillary hole with an approximate diameter of 0.0004 inches?

$$P = \frac{4 \times 0.000414 \text{ lb/in.}}{0.0004 \text{ in.}} = 4.14 \text{ psi}$$

Ex: If a 10" tall container holds water, what is the size of the hole at the bottom of the container where the water head pressure in the container equals the surface tension pressure of water to air. This is the critical dimension where the contained water pressure will overcome the surface tension and shows a visible leak.

$$\text{Diameter} = \frac{4 \times \text{surface tension}}{\text{Pressure}} = \frac{4 \times 0.000414 \text{ lb/in}}{(10 / 27.4) \text{ psi}}$$

Diameter < 0.0045 inches there will be no visible leak.

Leak Path Surface Finish - The conditions of the walls inside a leak path also effect the flow rate and resistance to flow. Smooth walls will resist flow less than more typical rough walls. The leak standards produced by Cincinnati Test Systems for calibrated flow rates feature smooth walls which provide maximum flow with optimal repeatability for calibration. Typical holes or leaks are not designed and usually are rough and irregular. Therefore, it is difficult to get repeatable flow through these types of holes. The rough surface finish of typical holes will increase the surface area and therefore the adhesive characteristics of the hole. This in conjunction with the viscosity of typical contained fluids will prevent or severely restrict the fluids from flowing while lower viscosity air will still flow.

Setting a Leak Rate Standard

The first principle that must be understood is that all materials permit some leakage through them over a period of time. It may leak as little as a few molecules of hydrogen a year to several gallons of fluid per minute. The purpose of establishing a leak rate specification is to define the maximum tolerable leakage that a properly functioning part can tolerate and still meet the customer's expectation. The objective is to test the parts with air or some other low cost, safe fluid whose viscosity is lower than the specified contained fluid and will therefore qualify the holes faster, easier, and more economically.

Although the desire is to manufacture a part that doesn't leak the specified fluid, a specification of "No Leak" does not establish a tolerance for testing the parts and determining their functionality. To inspect the parts there must be a quantitative, measurable value that defines what is acceptable and what is not acceptable. Consider tolerancing for dimensional measurement. The object is to make parts that have the right dimensions. Who would want a specification of "exactly right" or "exactly". What does this specification mean? Does "exactly" mean within 0.1", 0.01", 0.001", 0.0001", etc. Dimensional tolerances are understood. Leak measurement also needs measurable tolerances.

How to Establish a Quantitative Leak Rate Specification

For many products there are industry recognized tolerances for leakage that are used by most manufacturers. In some cases the customer actually defines the leak test specification to the manufacturer. Using those specifications will usually save a lot of time. It is advisable to do some testing to verify that these specifications support the quality, function, and cost standards for your company.

Below are typical ranges for existing test specifications. In addition to the examples below there are many instances where specifications outside the typical ranges mentioned are used. The purpose for summarizing these typical test parameters is to narrow the scope of consideration for a leak rate and test pressure specification.

Application	Typical Pressures	Typical Leak Rates
Appliance Applications		
Household appliances (dishwashers, washing machines, water filters, etc.)	20-30 psig	3 – 10 sccm
Valves	50 - 100 psig	0.5 - 20 sccm
Medical applications		
Fluid catheters	15 - 60 psig	0.5 to 5 sccm
Angioplastic	200 - 300 psig	0.5 - 2 sccm
Drug delivery systems	10 - 50 psig	0.5 - 10 sccm
Filters	3 - 10 psig	1 - 10 sccm
Automotive applications		
Brake System (brake fluid)	5 - 200 psig	1 - 20 sccm
Electrical enclosures (water vapor)	1 -10 psig	2 - 20 sccm
Engine components (water, air, oil)	2 - 30 psig	3 - 20 sccm
Engine coolant system (anti-freeze)	10 - 40 psig	1 - 15 sccm
Fuel system (gasoline)	20 - 70 psig	0.5 - 10 sccm
Lighting system (water vapor)	0.2 - 3 psi	10 - 50 sccm
Steering system (steering fluid)	5 - 100 psig	1 - 5 sccm
Transmission (transmission fluid)	3 - 10 psig	5 - 15 sccm

(Usually the lower pressure matches the lower leak rate.)

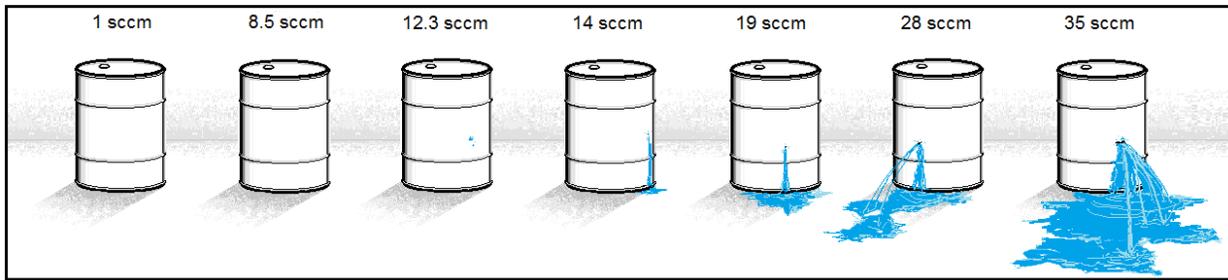
Establish New Standards

To establish new standards, the parts should be analyzed for their function. A practical expectation should be established as to how to verify that the part does not leak the contained fluid over a defined time period.

For instance if the part were pressurized to 100 psi with water and no water drops were detected in 1 hour or some agreed upon time period, than everyone agrees that the part “doesn’t leak”.

Caution: *Selecting too tight of a reject leak standard may require the use of expensive leak testing technology. It is, therefore, important to establish realistic expectations for what is considered a “no leak part”.*

The next step is to test a large sample of production parts with an air leak tester at the same part working pressure. This air test must be done before any liquid is introduced into the part. An initial air leakage tolerance of 1.0 sccm should be used so that all parts with leakage greater than 1 sccm will be rejected. The reject parts should be marked with the measured air leak rate and set aside for further testing. Once a variety of parts with a wide range of leak rates from 1 sccm to 100 sccm or higher are identified, arrange the parts by the magnitude of the measured air leak rates.



Then pressurize the parts with water (or the typically contained fluid) at the same working pressure and observe them for the agreed upon time cycle established for a part that “doesn’t leak.” If the parts had a wide variation in air leak rates, they will exhibit different magnitudes of liquid leak. There should be a leak rate value below which the remaining parts will show no signs of fluid leakage.

This experiment identifies the approximate hole size (measured by air leak rate) that does not allow the fluid to flow through it. The part’s resistance to fluid flow is defined by the hole diameter, path length, hole surface finish, the fluid viscosity, and the surface tension. Now there is hard data which indicates that parts with an air leak rate less than some amount “do not leak” the contained liquid. With this data you can set the reject leak rate at some amount close to but below the highest air leak rate that did not allow the fluid to leak. The final leak rate tolerance should be stated as a “specified air leak rate (sccm) at a specified test pressure.” If field returns or other production testing indicates that the newly established air leak rate is not tight enough, the reject rate can always be lowered with discretion at a later date.

Many formulas used in this bulletin taken from, “A Treatise on Leakage” by Guy Jolly, 2005.