Application Bulletin #120

How to Establish an Acceptable Leak Rate

This Application Bulletin provides an overview of how to establish an acceptable leak rate for various product specifications, including IPxx standards such as IP67.

Purpose of Leak Testing Parts

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

Defining Whether 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 Which the Part Is Intended to Contain?

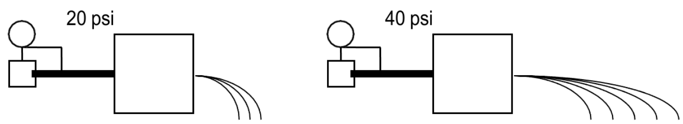
YES. Everything will leak under the right conditions. Either in terms of ingress – penetration by dust or moisture – or egress – the loss of some internal state of equilibrium.

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 and/or torturous 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 to increase for gases.

Viscosity: This is the measurement of the internal fluid resistance of a substance. 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°F are:

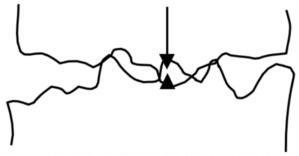
Fluid	70°F	200°F
SAE10 lube	65 centipoise	5 centipoise
Fuel oil #5 (min)	8 centipoise	2 centipoise
Water	0.95 centipoise	0.3 centipoise
Gasoline	0.6 centipoise	0.3 centipoise
Propane (liquid)	0.11 centipoise	0.04 centipoise
Air	0.018 centipoise	0.021 centipoise
Helium	0.0194 centipoise	
Propane (gas)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

A heavy oil or grease will not flow very easily or at all through a small hole where water will 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.

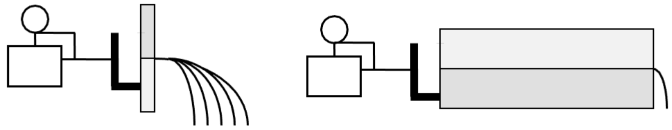
By the same principle, when subjected to very low pressure (<1 psig), air will flow approximately 53 times more units of volume through a hole than water, if the water is able to flow at all.

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 the hole's walls.

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?

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

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

$$Q_L = 715 \times 10^{-5}\ \text{ccm} = 0.00715\ \text{ccm}$$

(This is approximately 1 drop of water with a diameter of 1/8" 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:

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

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?

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

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

$$Q_g = 1.477\ \text{scc/m}$$

(This is equivalent to 100 bubbles with a diameter of 1/8" 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.

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

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: 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:

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

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 show 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 that has a viscosity 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 objective 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 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 scc/m
Valves	50 - 100 psig	0.5 - 20 scc/m
Medical applications		
Fluid catheters	15 - 60 psig	0.5 to 5 scc/m
Angioplastic	200 - 300 psig	0.5 - 2 scc/m
Drug delivery systems	10 - 50 psig	0.5 - 10 scc/m
Filters	3 - 10 psig	1 - 10 scc/m
Automotive applications		
Brake System (brake fluid)	5 - 200 psig	1 - 20 scc/m
Electrical enclosures (water vapor)	1 -10 psig	0.5 – 10 scc/m
Engine components (water, air, oil)	2 - 30 psig	3 - 20 scc/m
Engine coolant system (anti-freeze)	10 - 40 psig	1 - 15 scc/m
Fuel system (gasoline)	20 - 70 psig	0.5 - 10 scc/m
Fuel system (High Pressure)	2000-3400 psig	1x10-4 scc/m
Fuel system (Low Pressure)	Vacuum – 0.5 psig	0.5 – 5 scc/m
Lighting system (water vapor)	0.2 - 3 psi	1 - 20 scc/m
Steering system (steering fluid)	5 - 100 psig	1 - 5 scc/m
Transmission (transmission fluid)	3 - 10 psig	5 - 15 scc/m

(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.

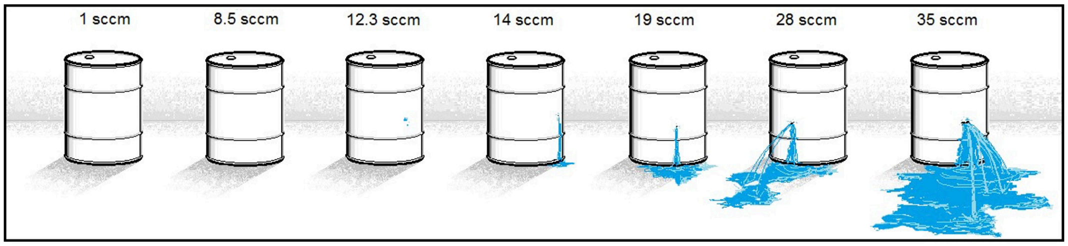
For instance, if the part were pressurized to 100 psi with water and no water drops were detected in one hour, or some other specified period, then everyone agrees that the part "doesn't leak."

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 at the same part working pressure.

Testing non-sealed parts with air

This air test must be done before any liquid is introduced into the part. An initial air leakage tolerance of 1.0 scc/m should be used so that all parts with leakage greater than 1 scc/m 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 scc/m to 100 scc/m 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 cycle time 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 (scc/m) 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.

Testing sealed devices for IP67 and beyond

All these considerations around leak path and fluid characteristics also apply with establishing and testing for an acceptable leak rate with sealed devices.

The most popular IPxx rating is IP67. Devices that meet this rating are considered dust tight and withstand up to 30 minutes of submersion in water up to 40 inches (or one meter) in depth.

International Protection System Marking (IPxx)

Protection Against **Solid Ingress**		
	0	Non-protected (not rated)
	1	> 50 mm gap for entry
	2	> 12 mm gap for entry
	3	> 2.5 mm gap for entry
	4	1.0 mm gap for entry
	5	Dust protected
	6	Dust tight

Protection Against **Liquid Ingress**		
	0	Non-protected or rated
	1	Vertically dripping water
	2	Dripping water tilted at 15 deg
	3	Splashing water at any direction
	4	Jets of water from any direction
	5	Heavy seas or powerful jets of water
	6	Powerful water jets with increased pressure
	7	Harmful ingress of water when immersed between a depth of 150 to 1000 mm (5.9 – 40 in)
	8	Continuous immersion in water
	9K	Powerful high temperature water jets

Example:

IP 6 7

- Ingress Protection
- Solids
- Liquids

IP67 = 6 dust tight + 7 protection from liquids immersible to specification.

An IPxx rating for a sealed device or component is not in itself a "leak rate." It is an "attribute" of the part in question. A selected leak rate should be validated by correlation/validation testing, to prove a non-liquid leak rate as a measurable value.

To determine what is an acceptable leak rate for a desired IPxx rating in scc/m, we need to set a benchmark under controlled environmental conditions.

In North America, we use the benchmark of atmospheric pressure at sea level and an ambient temperature of 20 degrees C. In Europe, it's common to use 0 degrees C. But context matters. If the device or component will be used under conditions that are notably colder, hotter, wetter or of different pressure, the leak rate that passes muster for a desired IPxx rating under controlled conditions will no longer be relevant.

For example:

- Enclosures with sight windows or used in certain environments may require water vapor leak rate ranges of 0.5 to 3.0 scc/m. That's because operating conditions make it more likely that moisture will be forced through a leak path.

- Enclosures that are thick walled, large, that don't see altitude changes or that are subject only to low pressure spray or drips, may be able to accommodate a higher leak rate, such as 3.0 –10.0 scc/m. That's because these factors make it less likely that unwanted moisture or dust will be able to find its way through a leak path.

The distinction between watertight vs. vapor tight is also important. Vapor can penetrate where liquid cannot. But again, determining if a device or component is vapor versus watertight at a given leak rate is dependent on the combination of all those factors related to design, manufacture, and operating conditions.

For a more in-depth focus on IPxx leak testing, and how achieving a desired rating impacts product design and manufacture, please refer to these CTS companion ebooks:

- **A Beginner's Guide to IPxx Ratings and How They Affect Leak Testing**
- **Leak Test of a Sealed Part for an IPxx Rating**

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

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