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The Use and Misuse of O-Rings

Elastomer O-ring seals are commonly used to provide demountable vacuum seals. The proper choice of material, installation, and handling are key to a successful vacuum design

The sealing integrity of vacuum systems is, undeniably, a crucial aspect of vacuum technology, and demountable seals are an important segment. A demountable seal can be considered to be any seal that is capable of being opened or closed as opposed to permanent seals such as welded or brazed joints, which includes important components such as flanges and valves.

Any discussion and consideration of these components leads us directly and inexorably to the subject of gaskets and gasket materials, which can be readily broken down into two main groups: metal and elastomer. Metal seals are inherently cleaner and more reliable, but their use has the overall disadvantage of being more expensive and more time and labor intensive than elastomer gaskets. Consequently, elastomer seals are used whenever possible in most applications, and they are usually applied in the form of O-rings.

Defining materials

Elastomers, in general, are organic polymers that exhibit an elastic resilience that allows them to deform slightly when under compression but with enough elasticity to prevent permanently deforming or flowing. In an O-ring seal, the material can form a seal between two smooth surfaces, such as flanges, by flowing slightly into microscopic imperfections in the flange and still retain an internally stored force to maintain the seal when opened and closed time after time. It is helpful to picture a “rubbery” material as opposed to materials such as Teflon that will flow into a different shape upon compression and retain that shape when the compressive force is removed.

O-ring materials are difficult to characterize since they are not clearly defined chemical compounds. To add to the confusion, there are a number of possible variations that are encountered within a single material category. What this means is that they are “compounded” of a number of component materials such as the basic resin, fillers to promote resilience, plasticizers, and curing agents. Within a particular generic category, the actual compounding and the molding processes will have a number of variations and many of these variations will be considered proprietary. For example, the filler might be carbon black or it might be diatomaceous earth. What this tells us is that any properties of the materials will have wide variations, and that it’s necessary to take this into consideration when using them or designing them into vacuum systems and processes.

The most commonly applied generic groups of O-ring materials are nitrile such as buna-N, butyl, fluoroelastomers such as Viton and Fluorel, and perfluoroelastomers such as Chemraz and Kalrez. Each of these groups has widely different vacuum related properties that make it impossible to make a generalized statement of which is the best material. Instead, it is necessary to try to find the best material for a particular application where the specific properties of the elastomer will make it a better choice.

Vacuum Properties of O-Ring Materials

	Permeation Rate. H_2O tL/sec/lin. cm, 23°C, 50 % r.h.	Permeation Rate, He, tL/sec/lin. cm, 23°C	Outgassing Rate, tL/sec./lin.cm., 23°C	Temp-erature Limit, ° C	Relative Cost
Butyl	5×10^{-9}	3×10^{-8}	1×10^{-5}	86	Lowest
Nitrile	1×10^{-7}	9×10^{-8}	1×10^{-6}	135	Low
Flouro	6×10^{-9}	5×10^{-8}	$3 \times 10^{-8.}$ Pre-baked	150	Medium
Perflouro	2×10^{-8}	1×10^{-6}	3×10^{-8}	200	Highest

Cross-comparing the vacuum properties of the four commonest O-ring materials allows the proper tradeoff selection for any particular application. Source: Phil Danielson

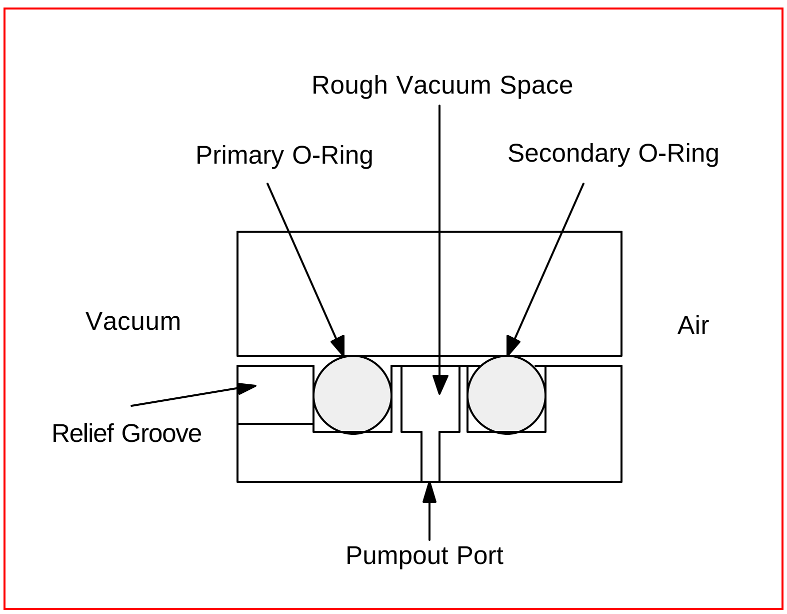
Resistance factor

Today’s vacuum processes often require the use of specialized gases that can attack or, at least, modify the properties of the elastomer seals. This means that no particular compound will be best for all applications. Instead, it’s necessary to use the chemical resistance tables obtained from the manufacturers to find the best material. At the same time, it’s also necessary to compare other vacuum properties that might affect the application. In most cases, though, perfluoroelastomers turn out to be the most resistance to chemical attack.

Many processes also require or generate high temperatures that can easily attack or degrade the O-ring materials. Although perfluoroelastomers also generally lead in thermal resistance, fluoroelastomers will withstand reasonable amounts of heat. For this concern, it's necessary to consider whether the heat will be short term, such as bakeout, or continuous such as in ovens. Fluoroelastomers are often rated at 200°C even though they start to slowly break down at 150°C. Short excursions, then, don't affect the material all that much.

Gas loads

All elastomers will add to the gas load entering the system by outgassing. Outgassing is defined as a combination of the desorption of surface adsorbed gas and gas from the bulk of the material that diffuses to the surfaces, adsorbs, and then desorbs. They are combined because it's virtually impossible to separate them experimentally. Although most outgassing is water vapor adsorbed and absorbed when the O-ring is exposed to outside air, other gases such as solvents and plasticizers absorbed into the bulk also add to the gas load. In general, the outgassing rate will be high during the first part of the pumpdown cycle as the bulk of the surface adsorbed water desorbs, but then will slowly decline to some quasi-equilibrium rate that will appear lower but steady. In truth, the outgassing rate will continue to decline, but the increased time-base will make it appear to be fixed.



The relief groove allows trapped volumes of gas to be pumped out of the O-ring groove and the rough vacuum space with pumpout reduces the primary O-ring's permeation rate. Source: Phil Danielson

As the outgassing rate declines, a secondary gas load mechanism, permeation, will come into play. All elastomers are permeable to some extent, and this means that various gases from ambient air will pass through the O-ring into the chamber. Most vacuum practitioners will have observed an example of permeation when leak checking with helium (He). If the He flow is held on an O-ring for a minute or so, a signal will be picked up by the leak detector that can be erroneously assumed to be a leak. A real leak will give a sudden increase, but permeation will slowly rise and then fall as the He flow is moved away.

Permeation occurs as gas travels in a random walk along the surfaces and spaces of the long and twisted elastomer molecules. This process should not be confused with porosity where the size of the gas molecule and the size of the pore set the rate. Instead, each specific gas will have its own permeation rate through each specific O-ring material. This is due to the electronic interaction of the gas molecule and the elastomer molecule, and it is driven by the partial pressure differential across the O-ring and the temperature. Since the partial pressures of the ambient air are fixed, the permeation rate of these gases will remain constant. Water vapor is the only real variable since higher humidity or temperature will greatly increase the total water vapor permeation rate. Permeation problems, especially on large door or end flanges, can be defeated by using two O-rings, mounted concentrically or an outer inflatable seal, with a groove between them that can be pumped on. Maintaining a rough vacuum in the groove will reduce the permeation rate to a negligible rate. Usually a pressure of 1-10 torr will suffice, and this means that a small diaphragm pump is all that is required.

O-ring grooves often provide dead volumes that can trap gases and become virtual leaks. This is especially true where dove-tailed grooves are used to retain the O-ring in large vertical flanges such as doors that are opened frequently. A simple radial groove or grooves extending from the vacuum side of the flange to the O-ring groove will usually avoid gas trap volumes.

Do's and Don'ts of O-ring maintenance

Although O-rings can be used as a convenient re-usable vacuum seal, they can also be a good way to introduce contaminants into an otherwise clean system. Handling and installing them with bare fingers can introduce skin oils, so they should always be handled with lint free gloves. Plastic gloves can transfer plasticizers to the surface and should be avoided. Never clean O-rings with solvents since they will absorb the solvent and then cause swelling that, in turn, greatly increases permeation. Ultrasonic cleaning will cause water absorption. The best thing to do is merely wipe them with lint-free tissue unless mold-release powder is detected and then a damp tissue will suffice. Never grease O-rings unless there is an actual need that cannot be avoided such as a scratched seal surface, but dressing the scratch with a stone or Scotchbrite is a much better solution.