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From THE VACUUM LAB

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GAS LOADS AND O-RINGS

The key to understanding vacuum system performance lies in a full awareness of the relationship of gas loads and pumping speed to pressure. This relationship is usually written as:

$$Q = S\,P$$

Gas Load = Pumping Speed x Pressure

torr liters/sec. = liters/sec. x torr

Obviously then, with a fixed pumping speed, the pressure attained will depend upon the magnitude of the gas load. In most systems, the predominant gas load during pumpdown at high vacuum is water vapor. Most of this water vapor comes from a combination of water molecules desorbing from the system's inner surfaces and from the O-rings sealing the system. There's a simple rule-of-thumb to determine which source is the greater for any given system. It's rough, but it's simple and effective. Just compare the ratio of the total internal surface area to the total linear inches of O-ring. Since both buna-N and Viton[1] O-rings are commonly in use, we need two ratios to reflect the differing water desorption rates of each:

1 linear inch of buna-N = 45 square inches of internal surface area
1 linear inch of Viton = 18 square inches of internal surface area

What these ratios mean is that, for example, multiplying the total linear inches of Viton O-ring by 18 will give you the equivalent gas load to what would arise from that many square inches of surface area. If the calculated number is much lower than the actual surface area, the water desorbing from the surface of the chamber is the predominant gas load. If, however, it's much higher, the O-rings are the predominant source of gas. More often than not, the O-rings are the major source. It depends on the system. You'll want to be careful, though, about the actual surface area. For example, a set of chamber liners will triple the chamber's surface area, and tooling such as a planetary can easily have as much or more surface area than the empty chamber. If you're not sure whether you've got buna-N or Viton, here's a quick and easy test. If you tap them with something like a screwdriver handle or a wrench, the Buna-N will give you a nice rubber-like bounce while Viton will produce a dull thud.

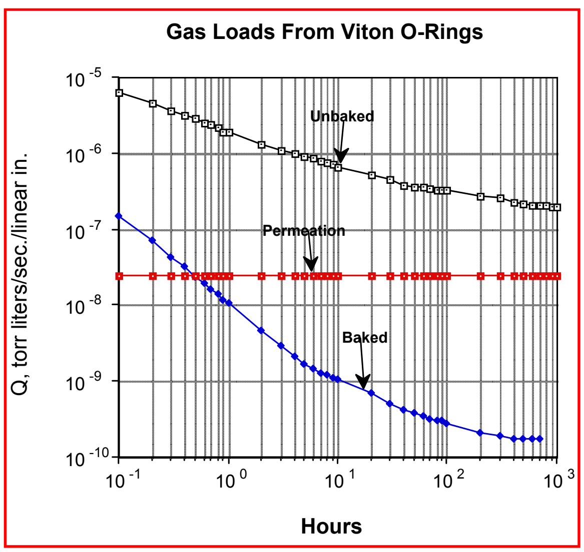
As can be easily seen by the ratios, the gas loads from Viton are much lower than those from buna-N. This explains why Viton is has become the most common of the two materials. Other O-ring materials such as silicones or perfluoroelastomers have little to offer over Viton in terms of pure vacuum performance, but they are often applied in cases where high temperature or chemical resistance is of importance. Viton's overall importance to general vacuum applications requires a detailed focus.

What Is Viton?

Viton is a fluorocarbon resin that is mixed with a filler such as carbon black, acid acceptors such as MgO, and curing agents before being cured into a fluoroelastomer material in forms such as O-rings and sold as Viton O-rings. This process is known as compounding. The O-ring that's bought as Viton from a distributor might contain Viton itself, or it might contain the equivalent Fluorel[2]. It might, and probably does, contain varying percentages of the constituents listed above in addition to proprietary inclusions. It might be cured in one process, but the next O-ring might be cured by another process. The point here is not to point fingers or hint at unscrupulous suppliers, but to show that when we think of Viton, we are not thinking of a specific chemical product but a wide category of products instead. Within that wide category we find a number of variations that produce differing performance parameters.

Viton Gas Loads

Any and all gas loads emanating from something like an O-ring are often erroneously referred to as "outgassing." In the case of elastomer seals, there are two distinct types of gas load. The first is outgassing which is composed of gas, usually water vapor, desorbing from the vacuum-side surfaces and diffusion transport from the bulk to the same surface where it also desorbs. The second is permeation of gas from the outside ambient atmosphere directly through the O-ring into the vacuum. These two distinct types of gas load must be looked at separately since they are two entirely different mechanisms with differing performance. Outgassing gas loads are usually variable since outgassing tends to decrease with pumping time as gas is removed. Permeation, on the other hand, is constant and will not change with pumping time.



Outgassing

Outgassing mechanisms and the outgassing rate are complex and dependent upon the recent and long-term history of the material. This is especially true when we consider new O-rings.

Virgin O-Rings

An unused O-ring direct from the distributor is an unknown quantity in regard to performance. As discussed above, there are wide variations in the makeup of O-rings from source to source and even from lot-to-lot. A new O-ring contains such things as unreacted monomer, solvents, volatile curing agents, and water vapor. The curing process is also a water factory since HF is formed during curing and acid acceptors such as MgO are included to react with the HF. This reaction produces incredible amounts of water that is trapped within the bulk of the material.

When a new O-ring is placed on a system, it takes long-term room temperature pumping periods to remove or reduce the amount of water outgassing into the system. Since the water that's trapped within the bulk must slowly diffuse to the surface and then desorb, it can take weeks or months to "condition" a new O-ring. Obviously, baking the O-ring in place would speed the transport of the water vapor and other volatiles through the bulk to the surface, but the temperature required (180-200^{o} C) to do this would also drive out the unreacted monomer and other contaminants which would then condense within the system. A surprising amount of this sort of stuff comes out during the first vacuum bake, and it could leave your system's internal surfaces coated with contaminants. Although this doesn't always happen, due to the variations in material, it only has to happen once to produce a full scale clean-up problem. The best move is to pre-bake the material in a vacuum oven where any contaminants can be cold-trapped. Vacuum baked O-rings are also commercially available.[3,4] Air baking can be helpful in removing some of the water and volatile solvents, but heating periods of days are required, and air baking can still only be considered to be a partial solution toward lowering the outgassing rate.

Outgassing Rates

The figure shows the outgassing rate of Viton as it decreases with pumping time. Although there will be slight variations in exposed O-ring surface area from seal to seal, these variations will be unimportant when compared to length. For this reason, it is both convenient and handy to normalize rates to a per linear inch basis. Note the difference between the outgassing rates of baked and unbaked material. These rates are only "representative" because of the common variations in material already discussed. In a practical sense, the low outgassing rate shown in the figure will not be achieved on a system. Water vapor will be added to the surfaces and the bulk close to the surface as a process system is cycled continually up-to-air. A practical outgassing rate will be somewhere between the two curves. It does show, however, the benefits of using vacuum baked O-rings.

Permeation

O-ring permeation has been observed by anyone leak checking a system by probing with helium. The slow but steady increase in signal on a helium leak detector when the helium is kept on a flange for a while is caused by helium permeation. Most elastomers have a higher permeation rate for helium than for air. While a real leak will show up in seconds, permeation can take a minute or more and a lot longer to drop to a previous background level once the gas is within the O-ring.

Permeation, as a gas load, is often considered to be low enough to be ignored, but this is far from the truth. The steady air-permeation shown on the figure indicates that it is low when compared to an unbaked O-ring's outgassing rate, but that it is a major gas load in the case of a baked O-ring. Remember that gas loads are additive, so the permeation rate can be the major gas source in many applications. Permeation is something that has to be, and can be, lived with for small flanges, but it can be a major source of gas in long O-rings such as might be found on full opening doors or sputtering targets. In these cases, a solution is to use two concentric O-rings with a channel between them. This is often called "double pumping" because the channel is connected to an auxiliary pump to reduce the amount of gas available to permeate through the inner O-ring. A vacuum of only 10 torr or so is sufficient in the channel or "guard vacuum" to reduce the permeation rate to a negligible amount. A small diaphragm pump is usually sufficient, and it will maintain oil-free cleanliness.

Conclusion

The gas loads from elastomer O-rings are often considered to be acceptable when viewed against the simplicity, time, and convenience of using an O-ring instead of a metal gasket. Improvements in performance can still be achieved by using vacuum-baked Viton without losing the convenience. Careful consideration and understanding of gas loads from O-rings is important in understanding the behavior of a vacuum system. This is true whether the O-rings are the largest contributor to gas load or not. Still, it's only one of the many gas loads in a practical working system.

[1] Du Pont Trademark
[2] 3M Trademark
[3] Duniway Stockroom
[4] U-C Components

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