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From THE VACUUM LAB

By Phil Danielson

Choosing the Right Vacuum Materials

An in-depth review of each and every material exposed to the vacuum system is absolutely essential to ensure a successful system design.

It's no secret to its practitioners that vacuum technology is a demanding discipline. The technology is unforgiving to the point that you can do almost everything right, but if you make one mistake, the chamber might not pump down to it's required level. This means that a lot of decisions need to be made. Crucial decisions. When you consider that the total complexity of a vacuum system is greater than the sum of the complexity of its parts, the message comes home to you in dire clarity. Each part interacts with every other part, and that's why a mistake can kill the project. Worse yet, a few really small mistakes can be worse than one big one. Although this can be daunting, it's not really as daunting as it sounds.

A little detailed thinking within the basic vacuum relationship Q (Gas Load) = S (Pumping Speed) x P (Pressure) will provide the guidance and technique. A low value for Q will result in a lower P with any given S. If, then, we try to keep the total gas load as low as possible, we have to realize that the most important gas load(s) in most vacuum systems emanate from the materials exposed to the vacuum. The gas within the chamber prior to pumpdown has to be removed of course, but this is a much simpler process than dealing with the gas from the materials. All engineering solutions are a series of successive compromises, and the choice of vacuum materials is no exception. Choosing the materials to use in a vacuum system design is not just a case of finding the materials with the lowest gas loads, but to also consider the various physical or chemical properties that

Approximate outgassing rates to use for choosing vacuum materials or calculating gas loads

(All rates are for 1 hour of pumping)

Vacuum Material	**Outgassing Rate** *(torr liter/sec/cm^2)*
Stainless Steel	6×10^{-9}
Aluminum	7×10^{-9}
Mild Steel	5×10^{-6}
Brass	4×10^{-6}
High Density Ceramic	3×10^{-9}
Pyrex	8×10^{-9}

Vacuum Material	**Outgassing Rate** *(torr liter/sec/linear cm)*
Viton (Unbaked)	8×10^{-7}
Viton (Baked)	4×10^{-8}

will fulfill the process's requirements.

The universal materials problem that runs through any and all vacuum technology is the vacuum chamber itself. The material(s) of construction is required to provide as little gas load as possible while still being strong enough to withstand the forces exerted by the external atmospheric pressure. The strength issue is easily dealt with by making the walls thick enough or by adding additional bracing or supports either internally or externally, but the main problem is found in assessing the possible gas loads. Chambers are commonly constructed of metals, glasses, ceramics, or plastics. All of these materials have in common consideration that the internal surfaces will be covered with layers of sorbed water molecules which will have to be desorbed during the pumpdown. Since most of the water molecules are sticking to themselves in a bed, the base material doesn't matter very much until enough water has desorbed to leave only a single monolayer on the surface. At this point, things change. You need a material that doesn't bond too strongly to the water molecules. This starts ruling out a lot of plastic materials, but more importantly, you have to start thinking about gas coming out of the material's bulk. This, along with surface desorption, is what we call outgassing. Coupled to this effect is permeation of gases from the atmosphere through the chamber's walls, and this includes sealant and/or gasket materials such as elastomer O-rings.

Other than the consideration of strength and permeation, the same criteria should be applied to any material exposed to the vacuum. Permeation occurs with most materials, but is often too small an effect to be of concern. For example, the small amount of atmospheric helium that permeates into Pyrex bell jar through the glass's tiny micropores is too small to be of concern at 10^{-6} - 10^{-7} torr, but might be a real problem in a Pyrex system that is expected to operate at 10^{-11} torr. In general, though, we can look at materials exposed to the vacuum by mainly assessing the outgassing rate. Additionally, gas loads can arise by vaporization of the material itself or from components of the material. High vapor pressure materials are an obvious problem in terms of contamination of the vacuum space or the process.

Metals are arguably the most prevalent vacuum chamber materials, with stainless steel (SS) far ahead of other metals such as mild steel (MS) or aluminum (Al) alloys. Since MS is usually used only for systems that require moderate vacuums above 10^{-6} torr, it would seem that a choice between SS or Al would be sufficient, but this is only the beginning of the selection process. For example, deciding to use SS doesn't mean any and all SS alloys. Free-machining alloys such as 303 SS contain sulfur (S), but the vapor pressure of the S is too high for high vacuum systems. 304 SS, though, is the most common choice. This helps narrow things down, but ultrahigh vacuum (UHV) usually requires the low-carbon 304L alloy. What we're describing here is the process of picking down through the layers to merely define the overall description of the material, but we have to get deeper yet. The final choice of material will also depend upon the surface finish to minimize surface area with its resultant lowest desorption rate per unit area. Then the surface cleaning needs to be evaluated to ensure that organic contamination is removed and that no porous welding scale remains. All of this seemingly tiresome detail work is absolutely required to assure that the minimum gas load is presented by the material. For example, if Al had been chosen, you'd have to make sure the surface hadn't been anodized since the oxide film absorbs large quantities of water vapor and then slowly desorbs them into the vacuum space.

Sealing materials and gaskets are another extremely important consideration. Total gas loads emanating from elastomer O-rings can be greater than those from the chamber's surface. So, if you're going to use O-ring seals, you have to do everything possible to reduce the gas loads. This means using vacuum-baked O-rings that have been carefully handled with lint-free gloves and haven't been solvent cleaned since the solvents are absorbed and cause swelling. Swelling increases outgassing and atmospheric permeation. When analyzing the expected gas loads, then, it might be feasible to consider using metal gaskets and avoiding the O-ring's gas loads entirely.

There are a number of other materials that will probably be used in a vacuum system for very specific applications that are process dependent. This overall category includes ceramics and glasses that might be used as thermal or electrical insulators, components of internal arrays, or even plastic substrates. In each case, the same careful assessment is required to ensure that the gas loads are as small as possible. For example, ceramics are considered to be good vacuum materials, but only if high-density sintered materials are used. This differentiates between the insulator in a UHV-rated feedthrough and a piece of firebrick. Porous materials contain massive amounts of gas. Even normally acceptable metals such as Al need to be looked at carefully. Household Al foil is often found in systems where it is used as a chamber liner. This material is coated with peanut oil used as a lubricant in its manufacture, and it is virtually impossible to remove with solvent cleaning.

QUESTIONS TO ASK YOURSELF WHEN CHOOSING VACUUM MATERIALS

1. Have I added up the total gas loads from all the materials?
2. Have I defined each material well enough?
3. What would happen to the total gas load if I substituted for any single material?
4. Does any single material's gas load dominate over the others?
5. Have I compromised too far or too many times?
6. Am I really sure that I've looked at every material?
7. Have I made any mistakes?

In addition to gas load effects, the physical properties of materials need consideration. Internal arrays are often assembled with SS nuts and bolts that are likely to become heated by the process.This results in extreme surface galling that can make it impossible to disassemble the pair, but a thin coating of Milk of Magnesia (unflavored) brushed on the threads before assembly makes disassembly easy. Sliding surfaces can also cause galling or sticking problems with pairs such as SS-to-SS, but a coating of molybdenum disulfide can act as a vacuum-compatible lubricant. These are only a few of the many examples of the materials problems that need to be considered, and a successful system requires a full analysis.

There are a number of materials that need to be avoided whenever possible. High vapor pressure metals can be a problem, and they can sneak in easily if close attention isn't given. Zinc and cadmium-plated nuts and bolts are a prime example. If these materials become heated during the process, they can sublime within the system to cause metallic contamination. Additionally, they can form thin oxide coatings that sorb large quantities of water vapor. The zinc content of brass is often a problem in any but the most non-stringent requirements. Any material, then, that might vaporize under vacuum needs to be treated with suspicion. This includes many plastic materials.

Although vacuum technology is unforgiving of mistakes, a careful analysis, in depth, of the materials that will be exposed to the vacuum system will help avoid those dire mistakes that can kill a design. Any process will require a number of successive compromises, but adding up the many gas loads will allow a sensible series of compromises. This is one of those cases where "the devil's in the details" really makes sense.