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From THE VACUUM LAB

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GAS LOADS IN VACUUM SYSTEMS

Vacuum Technology Ain't for Sissies!

The practice of vacuum technology requires extreme care throughout a sometimes bewildering list of details that start with the original design of a particular vacuum system and extend through the actual day-to-day operation of the system when carrying out the process for which the system was originally designed. This is why vacuum technology is considered to be so unforgiving. Simply put: you can do everything else right, but if you make one mistake, it won't work. As daunting as that sounds, you have to face up to it if you want to work with vacuum. Since the average human mind is patently incapable of considering a list containing a myriad of important details all at the same time and with essentially equal import, you really need some sort of simple thinking technique to tie the details together while allowing you to constantly consider the system as a whole.

Developing the Concept

There's a single overall relationship that governs and explains the performance of all vacuum systems that can't be avoided:

$$Q = SP$$

Gas Load = Pumping Speed x Pressure

You can easily see that if a system has a given pumping speed, which is usually the case, the pressure in the system will be dependent upon the relative size of the gas load. For example, an air leak will provide a larger than usual gas load which will result in a higher than usual pressure. It's that simple, and it can be made even simpler. Look at it this way:

In any vacuum system, you're trying to reach some specified pressure and that's a result of the relationship between the gas load and the pumping speed. Now take pumping speed. In general, the pumping speed of a pump that's working properly is a one-time decision. Once it's chosen and installed, it's fixed. That leaves gas load consideration as the key thinking concept we can use to work our way through that list of myriad details that are so crucially important.

The Gas Load Concept

The Q = SP relationship only considers a total Q, or gas load. That is to say, all the gas entering the system's volume per unit time. The reason that the gas load concept is so useful as a thinking tool is that the total gas load is made up of a number of smaller contributions. Since each and every contribution has a source, you can begin to think about all those details by considering all the possible sources of gas load(s) and what they mean. This, then, is the handle you need to allow you to work your way through the whole system or process without bogging down in conflicting details.

If you follow the gas load thinking process, you can easily break down the major sources of gas loads and then break those down into a chain of smaller and simpler gas load sources until the whole system concept becomes clearer. An oversimplified example is air leaks. What part of the total system gas load is from air leakage, and is that part from a single large leak or from a number of smaller air leaks? Or both?

This mode of thinking can be applied equally well to any vacuum system or process, but first we need to understand the source(s) of the gas load(s.)

Sources of Gas Loads

Since a system's gas loads can come from many sources, those sources need to be considered separately before they can be considered as a whole. Gas loads can be fixed or varied depending upon the various stages of pumpdown cycle or various stages of actual process. Each requires its own criteria and degree of importance depending upon the actual system or process, but we can start at the simplest and most universal and work our way through to the most complex.

Pumpdown

Volume Gas

Every system or process will start off, at some point, at atmospheric pressure. That means that the volume of gas enclosed by the vacuum chamber or envelope will need to be removed until some specified pressure is achieved. This type of gas load is probably the simplest to deal with in that the total volume and the target pressure are the only two major considerations that need be taken into account to determine the required pump size and the attendant pumpdown time.

The pumping of volume gas is usually accomplished with one of the many types of mechanical positive displacement pumps on the market. The pump manufacturers usually provide curves or formulae to allow easy and straightforward pumpdown time vs. volume determinations.

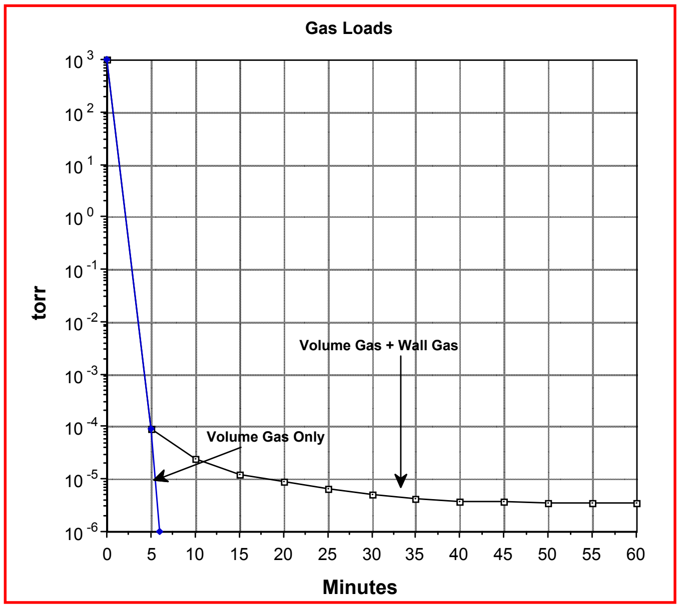

Figure 1.

Secondary gas load issues are that you are probably pumping down from a volume of atmospheric air which is, of course, a gas mixture that contains a certain amount of water vapor which will condense in the pump as the pumped air is compressed and that a reasonably non-restrictive line between pump and volume is provided.

If the only gas load concern was that of volume gas, it would be easy to see that a pumpdown curve graph showing pressure vs. time would be a straight line much like the straight line shown in Figure 1. However, a pumpdown curve from a real chamber would show the straight line devolving into a curve as is also shown in Figure 1. The actuality of that curve brings us to the second major gas load consideration: surface gas loads.

Surface Gas

The gas load from the chamber's inner surfaces stands in contrast to the simplicity of volume gas loads in terms of complexity. As the pressure drops during a pumpdown, more and more of the volume gas is removed until the gas desorbing from the chamber's surfaces represents the major gas load to the pump. This surface gas load is almost always water vapor. Figure 2 shows the gas load (Q) of water vapor per unit surface area as a function of time. The first obvious relationship is that the smaller the surface area within the chamber, the lower the water vapor gas load. Additionally, note that the gas load becomes lower with time. Also note that the shape of the gas load curve in Figure 2 is the same shape as the curve in Figure 1. This needs further understanding.

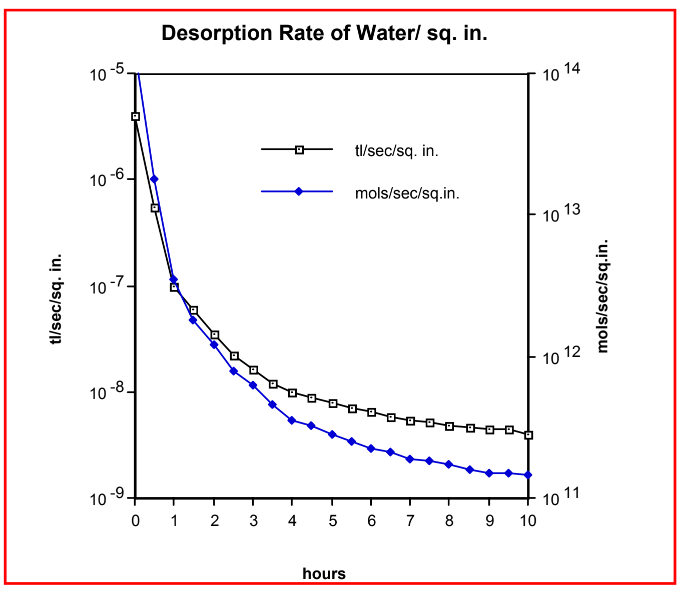

Figure 2.

The source of the water vapor on the surfaces is essentially the water vapor in the air when the system is let up-to-air between pumpdowns. The water vapor, being a polar molecule attaches itself (sorbs) to the clean inner surfaces in layers that can be several hundred monolayers thick when at atmospheric pressure. The bonds between the layers are strongest near the surface, but becomes steadily weaker and more disordered as the number of monolayers grow. The curve in Figure 2 showing a lowering of gas load with time is explained (oversimplified) by the fact that the weak bonds at the top of the layer allow the water to desorb at a higher rate than is shown later when the bed of layers is more highly eroded.

The reason that water desorption gas loads are arguably **THE** problem in today's vacuum processes is the time required to reduce the desorption rate enough to allow a low enough pressure for a process to be carried out. Time is money in an industrial process. These water molecules cannot be pulled off the surface by using more and more pumping speed. They will only desorb when they have absorbed enough energy to overcome the weak bonds holding them to the surfaces. This is usually thermal energy transferred from the walls through the bed to the exposed layer of water molecules. This, then, makes the required desorption totally time dependent unless additional energy is applied. This can be accomplished by either additional thermal energy (bakeout) or by UV bombardment excitation where the water molecules absorb energy from specific wavelengths which couple with the molecules. Raising the desorption rate gas load temporarily erodes the bed enough to provide a lower gas load later.

The behavior of water vapor within a vacuum system is extremely complex and is far beyond the scope of this article.

Specific Gas Loads

OUTGASSING

The term outgassing is an unfortunate carryover from an earlier time when the complexities of gas loads were not nearly as well understood as they are today. In fact, the term includes a number of specific gas loads and gas load sources that can be broken down and looked at separately. To many people, the gas loads from surface gas are included, but it is often clearer to think of surface gas as a separate subject.

Vapor Pressure of Materials

Any material used with or within a vacuum system will have an intrinsic vapor pressure. This really means that the gas load will emanate from evaporation of the material itself. When using gas load thinking, we need to avoid as many sources of high vapor pressure materials as possible in order to reduce their evaporative gas load to an acceptable minimum.

For example, greases and lubricants, and pump fluids that are exposed to the vacuum environment, will evaporate at a fixed rate that depends upon the surface area of the material exposed and the temperature. Worse yet, they'll continue to evaporate until they are gone, so the total amount in terms of weight or volume becomes important. This concept can be exemplified by the fact that a tiny droplet of mercury will have a vapor pressure of a few millitorr which will halt the pumpdown process while it is evaporating but will pass out of the system fairly quickly when compared to a grease with a lower vapor pressure that will evaporate for an extended period.

Metallic materials that have high vapor pressures can also be avoided. Screws with zinc or cadmium plating are often mistakenly used within chambers, and the high vapor pressure of these elements cause a residual pressure of the metals themselves within the system causing not only a gas load but material transfer that can easily result in cross contamination of a process. Easy machinability of materials such as brass, which contains zinc, or 303 stainless steel which contains sulfur can tempt the practitioner to use problem materials as well.

Gas load thinking will provide a fairly simple tool to analyze the list of details that is required to avoid problems in a system's performance caused by the system itself.

Permeation of atmospheric gases through the various materials making up the vacuum chamber itself are often overlooked in gas load thinking because they are relatively constant and do not decrease with time. A good example is the permeation of air through elastomer O-rings. Although the permeation rate per unit length is low enough to achieve a reliable vacuum seal, the constant permeation of air through the seal material can result in a substantial gas load when the total length of material used on a given working chamber is considered. This gas load, for example, is often dealt with by substitution of metal seals to eliminate the elastomer permeation completely.

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Desorption from Materials

The materials used in construction of vacuum chambers, seals, and internal arrays will all contain at least some gas in the bulk. When the system is evacuated, this gas will tend to diffuse out of the bulk material and enter the chamber where it will become a gas load to be dealt with by the pump.

When using gas load thinking, then, it is obvious that materials should be chosen that contain small amounts of sorbed gases that can be quickly and easily desorbed. A good example would be choosing to use glazed ceramic insulators instead of plastic. As in vapor pressure considerations, the greater the total bulk of material to be desorbed, the greater amount of desorption will occur. A little here and a little there will quickly add up a greater than expected gas load.

If the gas load from each and every material to be used is carefully considered and pared down to a minimum, the lower the total gas load will be along with attendant improvement in expected system performance.

Virtual Leaks

Virtual leaks aren't really leaks. They just, sort of, act that way. A common gas load in systems is from trapped volumes of gas that show up by a slow and seemingly steady influx of that gas into the chamber. These gas loads are often mistaken for leaks from the atmosphere and result in fruitless and frustrating periods of leak detection. Gas load thinking will result in avoidance of as many trapped volumes as possible and the provision of pump-out holes to allow gas to easily escape in those cases where total avoidance is impossible.

Leaks

Leaks are an obvious source of gas loads, and are obviously to be avoided. Since total avoidance is impossible, the possibility of leaking welds, seals, etc. should always be considered and avoided as much as possible by careful consideration of seals, welding techniques, and general careful handling of demountable seals. If a system is designed, assembled, and tested to have a leak rate that allows it to fall within performance specifications. It is easily possible to use gas load thinking to spot the possibility of a suddenly appearing leak by reference to $Q = SP$ where the pressure is suddenly higher than would be expected under normal conditions.

Process Gas Loads

In any system, the gas loads that will affect the pumpdown time to the specified or desired pressure and the ability to reach this pressure at all must be considered first. An additional consideration is required in processes where a process gas is introduced at some flow rate and to some pressure. This gas load will be in addition to the system load. An example would be the argon gas flow introduced into a system during a sputtering process.

The Rest of the System

If careful attention is paid to the gas loads from and within the system, there is a clear path in thinking to the other equally important considerations such as speed and type of pump to meet the gas loads. Gas load thinking is a useful handle to work your way through a system without losing sight of all the details necessary. It will allow you to clearly assess the other details in their own time in the thinking process.

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