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From THE VACUUM LAB

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HOW TO ASSESS GAS LOADS IN VACUUM SYSTEM DESIGN

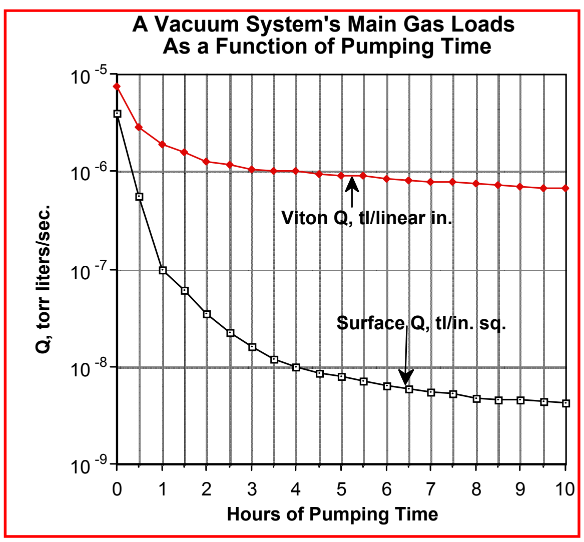
The performance of all vacuum systems is governed by the fundamental relationship Q=SP (gas load in torr liters/sec. = pumping speed in liters/sec. x pressure in torr).[1] It is obvious, when we look at the equation, that the pressure will be lower if either pumping speed is increased or the gas load is decreased. The pumping speed of a pump can be easily checked in the manufacturer's specifications and the effective pumping speed at the chamber can be calculated fairly easily. The total gas load, though, is a little more elusive. This is due to the fact that each chamber design or process will have its own specific gas loads that will combine to make up the total that the pump is required to deal with. Although it's important to assess and control these gas loads in the design phase, it's also important to know and understand them in an already existing and working system. In an overall sense, gas loads can be divided according to their sources as either volume gas or wall gas.

Volume gas is the easiest to understand and deal with. This is nothing more than the amount of gas trapped within the chamber volume at the onset of the pumpdown process. Volume calculations are easy to do in either the design phase or on an existing system. The importance of the system's volume applies only to the roughing segment of the pumpdown process. The manufacturers of roughing pumps usually provide a simple means of calculating pumpdown performance based on volume and pumping speed. This makes it a fairly simple matter to design in the right sized roughing pump and roughing line to achieve the expected or specified pumpdown performance. Once the pumpdown proceeds past roughly 1 torr, though, the volume begins to slowly lose importance. By the time the total pressure falls to 1 millitorr or so, the gas in the original volume is almost gone. In the low10^{-4} torr range, volume gas no longer plays a part in the total gas load, but wall gas does.

Wall gas is something of a catchall term in that it includes a number of specific gas sources that are surface related. It's convenient, though, since once the volume gas has been pumped away, it seems as though the pumpdown rate has "hit the wall." This apparent slowdown is due to the fact that we are no longer pumping the permanent gases contained in the chamber's volume, but we are now pumping gas that is slowly desorbing from the system's internal surfaces.

This means that the pumpdown rate (pressure vs. time) will be controlled by the rate at which the gas leaves the surface to be subsequently pumped away. This rate is called the rate of desorption and is commonly given in units such as torr liters/sec./in.^{2} of surface area exposed to the vacuum.

In a practical process system that is frequently exposed to ambient air for loading/unloading, this desorbing gas will be essentially all water vapor. When the system is open, the water vapor in the air will contact the clean surfaces that had been under vacuum and fairly water vapor-free prior to air-release. The polar nature of the water molecule allows it to establish weak bonds to the clean surfaces and to other water molecules. As the water molecules bond to each other, they can form a bed of sorbed water vapor that is hundreds of monolayers thick at the onset of the next pumpdown cycle. The layers of water that formed last are very weakly bound due to the disorder in the bed and they will accordingly desorb and be pumped away quickly and easily. The layers closest to the chamber's surface will be more strongly bound and will desorb much slower since desorption will only occur when the water molecule has absorbed enough energy to overcome the energy binding it to either the surface or the next water molecule. The total amount of water sorbed during air exposure will depend upon humidity, temperature, and exposure time. Obviously, the lower the amount of water vapor exposure in terms of both time and humidity will result in lower sorption, and lower sorption will result in lower desorption during the pumpdown. Water vapor desorption can be broken into two separate sources in most practical systems. These are chamber surfaces and elastomer O-ring surfaces.



Assessment of a system's gas loads is a prime tool in system design since pumping speeds and performance can be predicted before a system is built.

Surface gas loads can be estimated fairly well by calculating the total internal surface area and referring to the desorption rate as a function of time shown in the figure. Calculating the surface area of an empty chamber is straightforward, but chambers are seldom empty. Although it's worthwhile to know the estimated gas load from the chamber alone, tooling can easily double or triple the surface area. For example, coaters are often fitted with internal shielding that triples the area over the area it is shielding. Calculating the surface area of internal tooling and fixturing can be tedious but necessary if the gas load is to be estimated with any accuracy. In this case, the amount of work required will pay off since it only needs to be done once and results in an extremely useful number that can applied over and over in the future.

For example, the desorption rate for surfaces shown in the figure applies to clean surfaces at room temperature. In a coater, the surfaces often become coated with process material that can be spongy or otherwise hygroscopic. Comparing pumpdown curves between a clean system and one that is becoming more and more heavily coated with each process run will provide quantitative numbers for the effect of the coating and will help determine the timing for cleaning or other maintenance.

Elastomer O-rings' gas loads are the second major gas source. Water vapor, desorbing from the surfaces, is often the largest gas load source in a working system. As with internal surface sources, the desorption rate decreases with time as the original heavy coverage desorbs, but the water vapor molecule population on the surface is replaced by water molecules diffusing from within the O-rings' bulk. This can be seen in the figure as the shapes of the desorption rate vs pumping time curves can be compared. Comparison gives rise to some useful ratios. After one hour's pumping, 1 linear inch of Viton O-ring provides an equivalent gas load to 18 in.^{2} of chamber surface while the equivalence is 1 linear inch to 175 in.^{2} after 10 hours of pumping. The gas load from the O-rings can be reduced by using vacuum pre-baked O-rings[1] which removes a good deal of the water vapor trapped within a new O-ring. In fact, the desorption rates shown in the figure are for "conditioned" O-rings that have been pumped on for weeks or months since the desorption rate of new O-rings is too highly variable to quantify.

ISO-KF/MF O-Ring Lengths

NW-10	2.5 inches
NW-16	3 inches
NW-25	4.1 inches
NW-40	5.7 inches
NW-50	7.25 inches
NW-63	9.6 inches
NW-100	19.4 inches

Use these numbers as a shortcut for using the figure

These two major gas loads are not the only ones that can and will occur in a vacuum system, but they are usually the overwhelming majority in terms of relative quantity. This statement, of course, bars atmospheric leaks since they are repairable and not part of the fixed gas load. Since gas loads are additive, the overall expected gas load can be calculated by adding the two main loads which can be easily read from the figure. If these gas loads are considered in the design of a new system, it is fairly straightforward to predict pumpdown performance of a given design in terms of pumping speed through a simple Q=SP calculation. Then, expected performance changes can be modeled by changing gas load or pumping speed at the design stage instead of after it's built and running. Additionally, for existing systems, the effects of changing gas load or pumping speed can be modeled. If, say, better performance is required by a process change, the effect of replacing some Viton O-rings with metallic seals can be calculated. Just replace the expected load per linear inch of the Viton with zero to reflect the missing elastomer gas load.

Using the assessment of projected gas loads can be an invaluable tool in system design through recognition of the major gas loads and application of the simple Q=SP fundamental vacuum relationship.[1]

[1] See "Gas Loads and O-Rings"

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