

THE VACUUM CHRONICLES

Volume 4, Number 9

Critical Pumping Speed and Water Vapor in Production Systems

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Vacuum systems that are used in production environments are plagued with the same problem of pumping water vapor that is endemic to all vacuum systems, but the intensity of the problem is increased due to the need to push product throughput to a maximum. This means that there is a need to shave as much time off the pumpdown process as is possible without affecting product quality. This problem is especially intense in chambers that are constantly cycled back to atmospheric pressure such as batch systems or load locks.

The source of the problem encountered by such systems is pumping away the water vapor desorbing from the internal surfaces. Backfilling the chamber with dry nitrogen, etc. will help reduce the amount of water that enters the chamber when at atmospheric pressure for reloading, but some water vapor will always enter the chamber and a percentage of that water vapor will sorb on the internal surfaces. Once sorbed on a surface, its subsequent desorption will produce a pumpdown rate that is affected by the desorption rate from the surfaces.

HOW CAN WE SPEED UP THE PUMPDOWN?

The first thought is usually to increase the pumping speed for water vapor, since we accept the $Q = SP$ relationship where gas load is equal to pumping speed

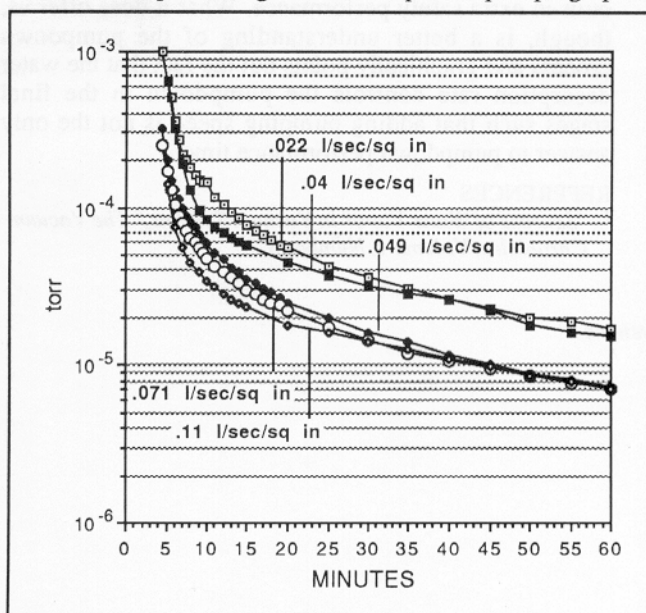


Figure 1. Critical Pumping Speed Experiments.

times pressure. At first glance, it seems that the solution to achieving a lower pressure is to merely increase pumping speed.

Based on this concept alone, the decision to increase water vapor pumping speed by using a bigger pump, a type of pump with higher water vapor speed, or adding a dedicated water vapor pump is an easy decision to make, but will it necessarily provide a faster pumpdown time to your target ultimate pressure specification?

Figure 1 shows the results of a series of experiments with varying water vapor pumping speeds. Since the source of the water vapor to be pumped is the inner surfaces, the data is shown in liters/second/Inches². This should allow you to relate the pumpdown curves in Figure 1 to any other chamber you might be considering for comparison. Just multiply your system's total internal surface area by the system's pumping speed at the chamber after you've considered the conductance losses of the tubulation between the pump throat and the chamber and you've got a direct comparison to Figure 1.

WHAT HAPPENS WHEN YOU INCREASE PUMPING SPEED?

Referring to Figure 1, we can see that increasing the pumping speed in steps from 0.022 to 0.11 liters/sec./in.² does indeed produce a better pumpdown rate during the first part of the pumpdown cycle. However, later in the cycle, the higher pumping speed curves seem to merge. This wouldn't appear to make sense since increased pumping speed would have to produce a lower pressure if $Q=SP$. It does, but this is a practical system with a focus for short term results with a series of tests aimed at practical knowledge.

We need to look at the molecular scenario now.

THE SCENARIO

What you have is chaos. You start out with a bed of sorbed water molecules on the system's internal surfaces that is often several hundred layers thick; so when you start pumping, you have large numbers of water molecules leaving the internal surfaces. Some go to another surface and stick, some bounce, and some are pumped away, and this goes on ad nauseam.

Although you can't actually pull molecules off the surface by pumping, you can affect (decrease) the total desorption rate by pumping away some of the molecules that would otherwise have gone to another surface to stick for awhile before desorbing again. This is all you are doing in any normal pumpdown once you've pumped

away the permanent gases, and once you're into the 10^{-5} torr range almost all of the gas load is water vapor. You just keep removing molecules from the chamber until the desorption rate is low enough to provide a low enough molecule population within the chamber volume to meet your target pressure.

EXPLAINING FIGURE 1

During the first half of the pumpdown shown, the desorption rate is extremely high. The first layers of water molecules to desorb are very weakly bound, but the water-to-water bonds of the newly exposed layers steadily increase as subsequent layers desorb and are pumped away. Figure 2 showing the desorption rate of water with time will clearly demonstrate that the desorption rate drops off in a very steep curve for the first half hour and then begins to decline. As the desorption rate declines as shown in Figure 2 during the second half hour, the rate of reduction of the pressure of water vapor in the chamber begins to decline as well. Fewer and fewer molecules are entering the chamber and since the pump will only remove a percentage of the molecules present, increasing the pumping speed will only remove a slightly larger percentage of the molecules desorbing.

As desorption continues and water-to-water bonds increase in strength, the bond strength begins to become more and more important. Slight changes in the percentage of molecules being pumped also become less and less important. Obviously, molecules are still being removed during the second half of the pumpdown shown in Figure 1, so pumping is continuing as the pressure drops.

The $Q=SP$ relationship holds, but the differences are too small to show up on Figure 1.

THE PRACTICAL VIEW

A practical view of a production vacuum system is of actual performance in producing a fast pumpdown and this all has to occur during the early stages of the desorption rate as shown in Figure 2. Figure 1 shows us that, in a practical sense, there is a critical pumping speed beyond which further increases will not provide measurable practical results in pumpdown performance.

This leads us to the concept that the only further improvement in pumpdown performance is to pump more molecules away during the first part of the pumpdown, and this can only be accomplished by raising the desorption rate during that period to increase the steepness of the desorption rate vs time relationship beyond

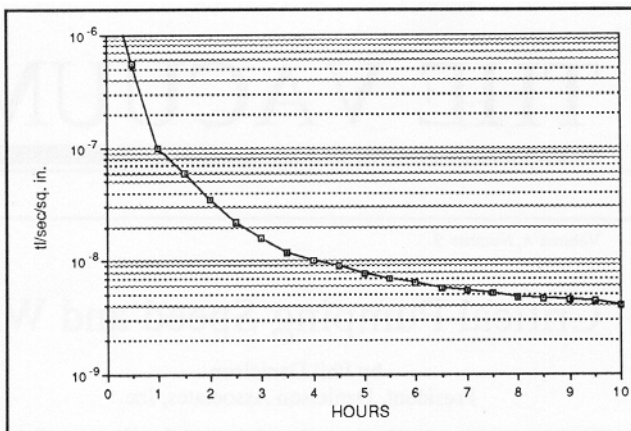


Figure 2. Natural Desorption Rate of Water.

that shown in Figure 2. This can be done by using the forced desorption provided by Phototron irradiation during the first part of the pumpdown.

With increased desorption, it is necessary to consider another critical pumping speed to match the increased desorption. Pumping speed and desorption rate must always be considered together.

CRITICAL PUMPING SPEED

The critical pumping speed shown in Figure 1 indicates that a pumping speed of about 0.071 liters/sec./in.² is about as high as you need to go in pumping speed before you're not accomplishing much more in terms of pumpdown time in a practical production system where a fast pumpdown is important. This number should not be taken as an absolute target number. There will be variations under other humidity and exposure time conditions¹ as well as variations due to system and chamber geometry.

This number is also merely aimed at pumpdown time under these practical conditions and does not take into consideration pumping speed for process gas loads or any of the other process related parameters. It also indicates a bare minimum for pumpdown time with no built-in extra safety performance. What it does offer us, though, is a better understanding of the pumpdown process and graphically points out the fact that the water desorption rate controls the pumpdown in the final stages such that adding pumping speed is not the only answer to pumpdown performance time.

REFERENCES

- ¹ "Sources of Water Vapor in Vacuum Systems," *The Vacuum Chronicles*, Volume 4, Number 8