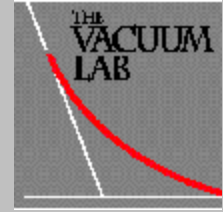


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From



By Phil Danielson

## Pumping Specific Gases in High Vacuum

*There's more to planning and designing a vacuum process pumping system than just maximizing pumping speed. Matching the pumping performance of each discrete gas species encountered will ensure maximum pumping performance.*

All practitioners of vacuum technology share a single requirement in that, at some point, a chamber must be pumped down from atmospheric pressure after being opened to ambient air. This requirement often lulls the unwary practitioner into assuming that the entire pumpdown process is composed of pumping air. This easy to make assumption can lull the soon to be benighted practitioner into assuming that a “big” pump will solve any pumping problem that might arise. It's just not that simple.

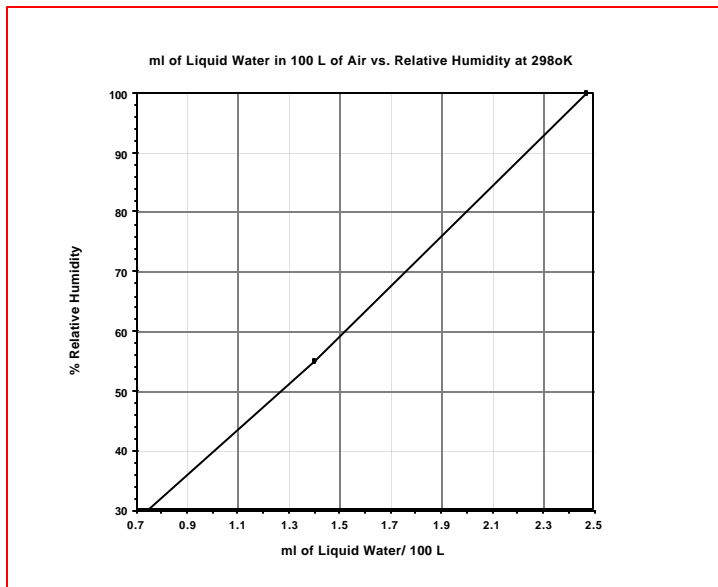
Consider that the pumpdown process starts with a gas called air that's really a mixture of a number of gases with a fixed gas-to-gas ratio. Except, that is, for water vapor which varies widely with changes in relative humidity (rh). For example, 100 liters of air at room temperature and 55 % rh will contain 1.4 ml of water while the same volume at 100% rh will contain 2.47 ml. That's a considerable spread, and it will have an effect on the pumpdown and the pumping system. Variations in the water vapor content is only a single, but obviously important, example of the need to target specific gas pumping in vacuum technology. In general, it's possible to break the subject down into two main areas: pumpdown and process.

### Pumpdown

The pumpdown process can be divided into three discrete zones that span the entire vacuum range from atmospheric pressure to ultrahigh vacuum. A particular vacuum-related process might only require pressures within a single zone, or it might require the traversing of several zones. These three distinct zones, starting at ambient or atmospheric pressure are the volume zone, the drydown zone, and the hydrogen zone.

### Pumpdown in the volume zone

In the volume zone, the pumps must deal with either the air or specific gas that fills the chamber volume. Although pressure reduction in this zone is primarily a function of the pump's volume displacement, the amount of water vapor in the chamber from humidity must be considered to keep the pump from loading with condensed water and inhibiting the pump's ultimate pressure due to the vapor pressure of the water within the hot pump. Trapping techniques are often, then, required to keep the water out of the pump, but water vapor pumping effects can vary widely.



*A pumpdown through the volume zone requires the removal of a large amount of water vapor. A 100-liter chamber will contain a liquid equivalent of ml of water as a function of relative humidity.*

In general, the positive displacement pumps used to reduce the pressure from atmospheric will have essentially the same pumping speed for all of the volume gases at the onset of pumping, but changes in the gas-to-gas ratios can be caused by additional high vacuum pumps that might be used while still within the volume zone. Although the differences in pumping speed for various gases are not usually a problem during pumpdown through this zone, there are

differences that could be important in special cases, so the relative speeds of the high vacuum pumps used should always be kept in mind.

## Pumpdown in the Drydown Zone

In the drydown zone, arbitrarily set at an upper limit of  $10^{-3}$  torr, the specific gas that dominates the residual gases is water vapor desorbing from the chamber's internal surfaces and diffusion from within the bulk of hygroscopic materials. Although the pumping of water vapor is only one of many concerns in the volume zone, the emphasis shifts when the pressure is reduced far enough to enter the drydown zone.

In most cases, the roughing pump used to traverse the volume zone will have reached its ultimate, so it's necessary to use a high vacuum pump that can operate within the molecular flow pressure regime. Condensation ceases to be much of a problem, but for the first time in a pumpdown cycle, a single gas dominates the makeup of the residual gases and needs to dominate our thinking.

As a pumpdown enters the drydown zone, water vapor is desorbing from internal surfaces at a very high rate. Since a portion of the water vapor will resorb after initial desorption, it is necessary to pump away as much as possible to remove it from the chamber. This means that we have to focus our attention on the pumping speed for water vapor instead of the pumping speed for nitrogen ( $N_2$ ) usually listed in vendor specifications. Additionally, we need to think about what happens to the water vapor once it's initially pumped.

Cryopumps, for example, have extremely high pumping speeds for water vapor, but more importantly, they have they have the capacity to hold massive quantities of pumped water vapor as ice. A cryopump will continue to accept water vapor until enough ice is formed to bridge the space from the pumping array to the pump's warm wall and cause a thermal short.

Conversely, turbomolecular, turbo/drag, and molecular drag pumps are intended to allow the pumped gases to pass through the pump into a foreline where they are repumped by a backing pump and expelled to the atmosphere. In general, this is true, but in practice, the large surface areas within the pumps provide resorption sites for water vapor. Water vapor desorbing and resorbing within the pump can cause a reduction in overall pumping speed by changing the theoretical compression ratio. In many cases, enough sorbed water vapor can build up within the pump to allow it to begin to reenter the chamber.

Neither type of pump can be considered ideal for pumping water vapor under all conditions, but it is necessary to think about how much water vapor needs to be pumped and how the system is to be cycled. The point is to focus on the specific gas load within the drydown zone.

### Pumpdown in the Hydrogen Zone

As water vapor is slowly desorbed and pumped away to about  $1 \times 10^{-8}$  torr, the pumpdown enters the hydrogen ( $H_2$ ) zone. Pumping considerations, at this juncture, need to be shifted from water vapor to  $H_2$ . The same kind of single gas thinking that was discussed for water vapor in the drydown zone now needs to be applied to  $H_2$ . In many ways, even more stringency is required since the total pressure is now much lower and smaller amounts of gas released from pumps (memory) becomes ever more important.

The sources, amounts, and rates of  $H_2$  encountered will vary greatly from system-to-system, so each system requires very careful analysis in terms of the system itself and the target ultimate pressure. Although no overall pumping recommendation is possible, cryopumps have a limited  $H_2$  capacity and the turbomolecular and molecular drag pumps have a limited compression ratio and subsequent pumping speed for  $H_2$ . Appendage getter pumps can be a practical solution as a  $H_2$  pumping speed and retention booster in either case.

### Process Gas Pumping

It is often necessary to focus even harder on specific gas pumping when the process is involved than the initial pumpdown. Many present day vacuum applications require gases that are corrosive, noxious, or even lethal that are either statically or dynamically introduced following initial pumpdown. Obviously, these gases require extremely careful pumping considerations, and each one is essentially a single complex subject.

Other common applications are simpler. In sputtering applications, for example, Argon (Ar) and/or reactive gases are dynamically introduced during the process. A pumping system that successfully pumps the chamber down might not be able to handle the process gases. In these kinds of applications specific gas pumping must be focused on both pumpdown and process gas pumping.

In other types of applications, contaminant gases can be released during the process. Water vapor can be desorbed from internal surfaces by thermal radiation from internal sources such as evaporation boats. Plasma processes can also cause water vapor desorption by ion-scrubbing. Since water vapor can be a process killer, it's important to

provide enough pumping capacity to deal with the increased water vapor load. These problems can arise even though the system was pumped down through the drydown zone prior to process initiation.

Vacuum furnace applications can provide large water vapor releases from the workload or the heating arrays in addition to chamber wall desorption sources from thermal radiation. This application is also a good example of unexpected gas loads in that most metals contain large amounts of dissolved H<sub>2</sub> that can be released upon heating. Massive amounts of H<sub>2</sub> can be released, then, as brazing eutectics melt.

## There Are Gases and Gases

Careful attention to all of the various gases encountered in a pumpdown and subsequent process can make the difference between a successful system or process design and relative failure. Taking it step by step and assessing the process in terms of the specific gases simplifies the choice of pumps and method(s) of pumping.

### *SPECIFIC GAS PUMPING QUESTIONS TO ASK YOURSELF*

#### *PUMPDOWN*

- What is the target ultimate pressure requirement?*
- Which pumpdown zones will be traversed?*
- Will the system be cycled and recycled on a short-term basis?*
- Will any specific gas end to load up the pumping system?*
- Will the pumping system's speed match the expected specific gas loads?*

#### *PROCESS*

- What process gases will be added to the total gas load?*
- After pumpdown, will the process gas loads overload the pump's capacity?*
- How many process cycles can be carried out before the pumps are overloaded?*
- What contaminant gases will be liberated by the process?*
- Can the pumps handle any contaminant gas loads liberated during processing?*

#### *GENERAL*

- What didn't I think of?*
- Do I really have the right pump for the gases to be pumped?*

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