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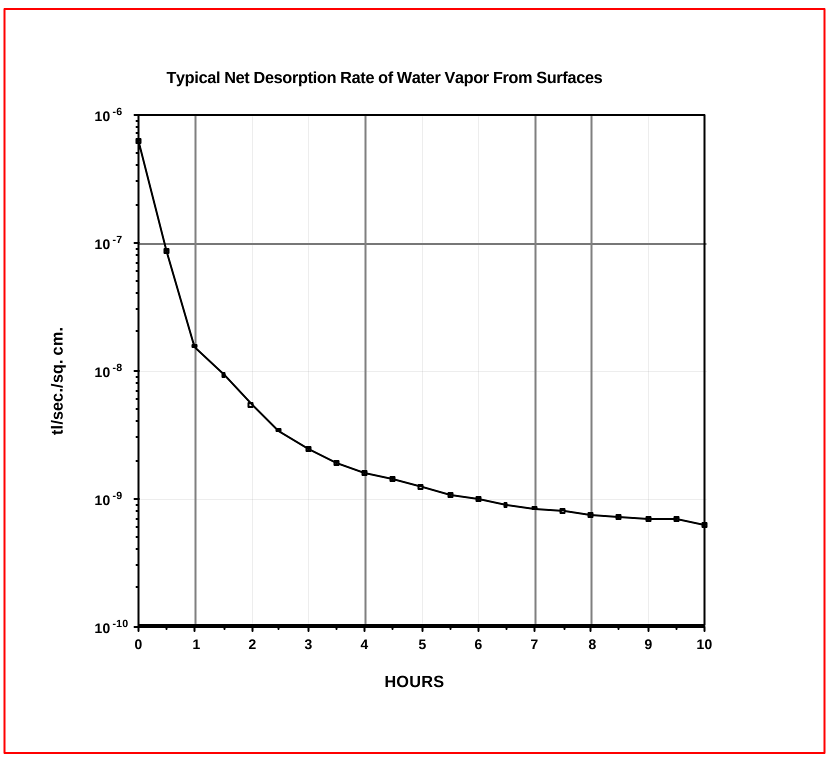
UV Conquers the Drydown Zone

All vacuum systems encounter the drydown zone where the slow desorption of water vapor controls the system's pumpdown performance. Powered desorption by UV radiation can shorten the pumpdown time substantially.

Every vacuum practitioner needs to deal, at some point in their process, with water vapor. Water vapor can be a big enough problem with condensation or pump loading, but when a process requires high vacuum below 10^{-3} torr, we have to face the drydown zone where the partial pressure of water is, overwhelming, the main residual gas. When we attempt to traverse the drydown zone, we encounter a complex process that cannot be avoided if we intend to achieve a particular pressure.

Water molecules will have adsorbed on all internal surfaces in layers that can easily reach several hundred monolayers in thickness during air exposure between pumpdown cycles. Adsorption rates of 1.5-2 monolayers per minute are common. When the pumpdown cycle reaches about 20 torr, the molecules begin to desorb easily, but that's only the beginning of the drydown process. Almost all of the desorbing molecules will strike another surface, and then they will either bounce or resorb. The time, following initial desorption, that a desorbing molecule will spend in the chamber before being pumped will average about 6 hours.



At this point, we have to realize that there are two desorption rates to consider. The rate at which water molecules leave a surface is called the *intrinsic* desorption rate, but this can be misleading since almost as many molecules are arriving at a surface as are leaving it, and the difference is the small number of molecules being removed by the pump. We need to concern ourselves, instead, with the *net* desorption rate. This is the rate at which the water molecules are being removed.

The Drydown Process

The drydown process is an inevitable phenomenon that must be dealt with somehow. A certain amount of water vapor will need to be pumped away before a low enough net desorption rate can be achieved to allow a given pump to produce the specified pressure. Looking a the fundamental vacuum relationship Q=SP, we can state it as Net Desorption Rate = Pumping Speed x Pressure. Initially, during the pumpdown, the net desorption rate is very high because the bed of adsorbed water molecules are weak water-to-water bonds with microsecond-to-millisecond sojourn times. As desorbed molecules are pumped away, the desorption rate declines steeply until the last few adsorbed layers remain, and these have sojourn times that are on the order of 24 hours before initial desorption. Since a certain amount of net desorption has to occur as we traverse the drydown zone to whatever point is required, we have two choices: to either wait long enough or to provide some energy to accelerate the drydown process.

Energy, imparted to the sorbed water molecules, will raise their internal energy to a high enough level to exceed these weak bonds and allow the molecules to desorb. The two most common energy sources are heat and UV. Heat, the traditional energy source, will result in rapid desorption but it has the disadvantages of heat-up and cool-down time along with thermal pyrolitic degradation problems with some vacuum materials such as O-rings.

UV, though, is essentially a non-thermal effect where the UV energy is imparted directly from the UV source to the sorbed water molecules and thusly requires no heat-up or cool-down time penalty. For systems that will need to operate in the ultrahigh vacuum hydrogen zone below the drydown zone, heat is more effective since it can drive both adsorbed gases from surfaces and absorbed gases from the material's bulk. UV will only be effective on surface-sorbed gas or gas already released from its original source. UV, then, should be viewed as a pumpdown enhancement tool instead of a replacement for a 250^0 C bakeout with metal seals.

The UV Source

The UV band encompasses a wide range of wavelengths, and not all UV sources will provide effective energy for desorption. The best results are obtained with a hot cathode mercury (Hg) discharge tube of the type used for ozone (O_3) formation. These are bulbs fabricated from ultra-pure quartz and filled with inert gas and a trace of Hg.

When electrically energized, the Hg discharge emits UV light in two major wavelength peaks: 254nm (about 90%) and 185 nm (about 10%). Only the highly energetic 185nm wavelength UV is effective in increasing net water vapor desorption, and it is the wavelength that converts oxygen (O_2) to O_3.

Most UV bulb manufacturers list power output in terms of 254nm output, but the 185 nm output will vary according to proprietary variations in bulb design, filling variations, envelope materials, and manufacture. This can cause some confusion, but all power ratings used in this article refer to the O_3 producing bulbs manufactured by Atlantic

Ultraviolet with vacuum-compatible end connectors. These are linear bulbs that are available in both straight and U-shaped variations.

Since the 185 nm radiation will be adsorbed by the O_2 in air, the bulbs must be operated in vacuum to allow the UV to reach the internal surfaces. This means operating the bulb within the chamber. Since the bulb will be exposed to the vacuum, it's important that they are constructed entirely of vacuum-compatible materials.

The commercially available bulbs are operated with a standard fluorescent light ballast as a power supply. On starting, the bulb will experience a momentary voltage spike of about 400 volts, but will then stabilize at roughly 50 volts at ½ amp. This means that a simple vacuum feedthrough with 600 volt insulation such as a standard instrumentation feedthrough is sufficient.

The Process

Although it would seem to be intuitive that the bulb(s) should be mounted to provide direct line-of-sight to all surfaces, this is really not required. The UV energy will reflect from internal surfaces to spread through the chamber, but direct desorption is only part of the process. With 185 nm wavelength light flooding the chamber, water molecules that are desorbing or already desorbed will be continually energized with the UV, and as they impact other surfaces prior to being pumped away, they will transfer some of that energy to the molecules on the surfaces. Bulbs can even be operated within an appendage nipple as a floodlight with only slightly reduced results.

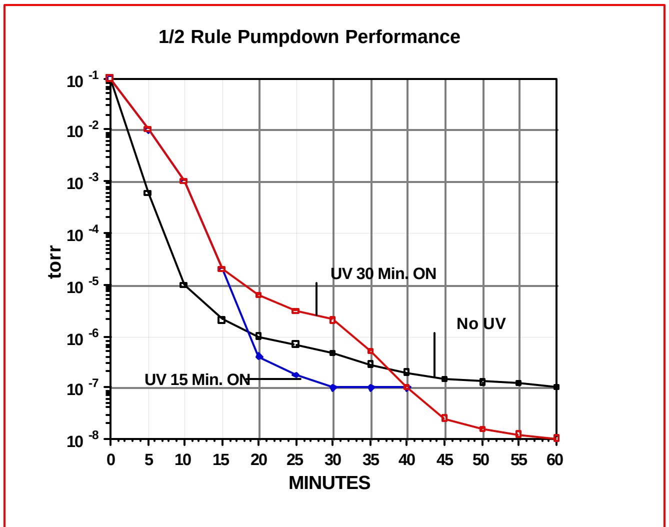
Thusly, the UV serves, directly and indirectly, as an energy pump to maintain a total high energy level of all the water molecules within the system. In essence, this keeps them in motion until they enter the pump and reduces their chance of resorbing on a surface.

Additionally, the 185 nm radiation converts much of the water molecules to the energetic free radical OH[8]. The free radicals also serve to maintain a high energy level. Their effects can be seen in a large increase in carbon dioxide (CO_2) in the residual gases while the bulb is operating. This is caused by oxidation of carbon monoxide (CO) which is always present at 28 amu and the oxidation of hydrocarbons that are always present in trace amounts in the ambient air.

Operation and Results

When used as a pumpdown enhancement tool, UV can accelerate the drydown process in terms of a faster pumpdown. It can also provide a lower ultimate pressure. This can be seen with the example of a working rule-of-thumb that makes use of power level to surface area ratios.

This is called the half-rule, which states that, at a power level of 0.4 mw of UV power (254nm) / cm^2 of surface area, the pumpdown time to a given pressure will take ½ the time it does with no UV if the system is exposed to UV for ½ of the target time. For example, a chamber that reaches 1×10^{-6} torr in one hour will reach that pressure in 30 minutes if the UV exposure is ½ of that time or 15 minutes. The second part of the half-rule is that the same system will reach a full decade lower pressure in the same time if it's exposed for ½ of that time. This would then be 1 x 10^{-7} torr in one hour if the system is exposed to UV for 30 minutes.



Pumpdown performance is a function of the UV power/surface area ratio and total UV exposure time. UV, properly applied, can provide either a faster pumpdown or a lower ultimate pressure.

The half-rule is based upon timing starting at pressures of about 20 torr. Waiting until a lower pressure is reached is inefficient since the time in attaining the lower pressure will be an effect of the slow net desorption rate. In practice, it's usually convenient to turn the UV bulb on at the onset of the roughing process.

Conclusions

UV exposure, then, can become a standard technique in enhancing the system's performance in the drydown zone as long as the UV power and exposure times are properly applied. The performance gains in terms of pumpdown time and/or lower ultimate pressures can result in substantial savings in terms of costs, product thoughput rates, and quality.