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From THE VACUUM LAB

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Anatomy of a Pumpdown

Dividing a pumpdown curve into zones that reflect the actual gases being pumped within the zones is a useful technique for sorting out problems and solutions.

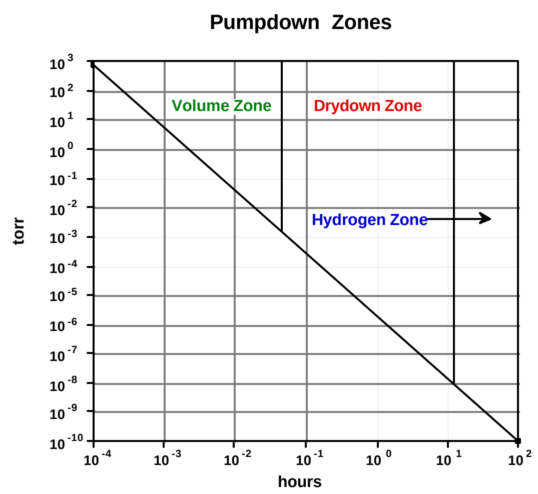
The pumpdown process is something that's shared by all practitioners of vacuum technology. Vacuum chambers of all sorts and descriptions are pumped from atmospheric pressure to any and all ultimate pressures that are within the realm of practical possibility. Usually displayed as a pressure vs. time curve, the pumpdown would appear to be a continuous process that is fairly easy and straightforward to work with and understand. Since the graph is usually plotted with total pressure measurements, the fact that there are continual and drastic changes occurring constantly within the process are easily missed. An appropriately applied residual gas analyzer (RAG) will quickly show the changes in the residual gas makeup that aren't apparent when we look at total pressures. It's all too easy to totally bog down in trying to understand a continually changing situation that covers a wide range, but it's practical to look at overall changes if we break a pumpdown curve into a limited number of categories that we can look within.

Pumpdown Zone

There are a number of ways to break down the pumpdown process. It might be by total pressure such as rough, high, ultrahigh, and extreme high vacuum, or it might be by gas flow regime such as viscous, transition, and molecular flow. These breakdown methods work, and they've been applied many times. In many ways, though, a breakdown method that reflects the overall categories of the system's residual gases as found in segments along a typical pumpdown curve can be much more useful. This gives us a workable look at the residual gases and allows us to think through the various techniques, gas sources, and hardware that would apply most within these zones. We can then break down a pumpdown curve that extends from atmospheric pressure to extrmehigh vacuum into three overall zones; volume, drydown, and hydrogen. As with all categorical-type separations, the boundaries have enough fuzziness and overlap that the lines of demarcation are arbitrarily set and are not to be taken as absolutes.

The Volume Zone

If we assume that the starting point of any pumpdown is a chamber at atmospheric pressure that has been opened to ambient air, it's obvious that the chamber is filled with a volume of a gas mixture that has fixed components, primarily nitrogen (N_2) and oxygen (O_2), with the exception of water vapor which will vary with humidity. At this pressure, we have viscous flow conditions where the gas molecules are constantly colliding with each other and the chamber's walls so the gas will act like a fluid as we begin the pumpdown process.



A pumpdown curve from air shows the three major zone divisions based on residual gases: the volume zone dominated by air, the drydown zone dominated by desorbing water vapor, and the hydrogen zone dominated by hydrogen.

If we start to evacuate the vessel with a positive displacement pump such as an oil-sealed rotary vane pump, each time a vane passes the pump's inlet a fixed volume of gas will be trapped, compressed, and expelled back into the atmosphere. The gas within the chamber will immediately expand to refill the chamber's volume due to the constant molecule-to-molecule collisions. When the pump's next vane passes the inlet, the same volume of gas will be trapped, but it will contain fewer molecules than the first-trapped volume. This volume-after-volume removal, then, will continue as the pressure falls within the chamber with ever fewer molecules being trapped and ever fewer molecules left within the chamber. This process of removing the gas within the chamber's volume is called volume pumping since the pumping process makes no real changes in the makeup of the gas and the rate of gas removal in terms of volume/time is predictable based on the pump's swept volume and the rate of rotation.

During the pumpdown, the relative ratios of the N_2 and O_2 will remain unchanged, but when the chamber reaches a total pressure of between 10-20 torr, we are probably in the transitional gas flow region and water vapor begins to desorb from the chamber's surfaces, but it is only a trace amount in the total pressure. As the air gases are pumped away, though, the desorbing water vapor begins to assume a higher and higher percentage of the total gas makeup as it steadily desorbs into the chamber's volume. At the point where the water vapor becomes the predominant partial pressure, we enter the drydown zone.

The Drydown Zone

The boundary between the volume zone and the drydown zone can be arbitrarily placed at 10^{-3} torr. When the pressure reaches this point, the partial pressures of the air gases are dropping to the apparent vanishing point and the water vapor begins to make up at least 98% of the total pressure. As the volume gases vanish, so does the simplicity of the pumpdown process. We are no longer pumping away the gas originally found in the chamber's volume but water vapor that's desorbing from the chamber's internal surfaces. Water molecules traced to atmospheric humidity will impact the surfaces and form weak bonds with the chamber material, elastomer seals, and with itself until a virtual bed of molecules are present when the pumpdown first begins.

When the pumpdown enters the drydown zone, the water molecules will slowly desorb and some of them will be pumped away. Most of the desorbing molecules, though, will impact a surface and many will resorb. Since the drydown zone is within the molecular flow regime where, by definition, a molecule will impact a surface before it will impact another molecule, only random trajectories allow a molecule to enter the pump. The process of desorption/resorption constitutes a game of molecular musical chairs where only a small portion of the desorbing molecules are pumped away. Added to this problem is the bond energy of the water molecules to surfaces where the sojourn time at a particular sorption site is over 24 hours at room temperature. Taken together, it's easy to see why it takes so long the traverse the drydown zone unless desorption energy is added to the water molecules by heat (bakeout) or low wavelength UV to increase the desorption rate enough to accelerate the pumpdown process.

Although the desorption rate will slowly fall as the bed of sorbed water molecules are pumped away, a secondary water source then appears in the form of water vapor permeation through any O-rings used to seal the system, and the permeation rate is usually high enough to ensure that the chamber will stay within the drydown zone. These molecules will also enter the molecular musical chairs game and take even more time to be pumped away since they will tend to sorb on the already cleared surfaces. It's not necessary to traverse the entire drydown zone to reach a low enough partial pressure of water for the majority of high vacuum processes, In those cases, some water will remain on the surfaces, and care must be taken to be sure that the process, such as thermal radiation or plasma scrubbing, doesn't stimulate its release into the chamber. If the process requires even lower pressures, the transition into the hydrogen zone is arbitrarily set at 1×10^{-8} torr.

The Hydrogen Zone

The hydrogen zone covers the pressure ranges usually called ultrahigh and extremehigh vacuum. At these pressures, we are no longer thinking about beds of sorbed molecules on the surfaces. The only significant partial pressure remaining, with the exception of gases formed by the gauge and RGA filaments, is H_2. Since elastomer gaskets are pretty much ruled out for use in this zone, the main source of this H_2 is from the material of the chamber. The exact source and mechanism for the introduction of the H_2 is still being debated. It might be diffusing directly from the bulk of the chamber wall, or it might be water vapor from the bulk reacting with the thin oxide film inside the chamber wall, or it might be water vapor dissociating on the outside film to form atomic H which diffuses through the wall, or it might be a mixture of all three. The final answer will come from future work.

Thinking Zonally

The point in using the zone approach is to help focus your thinking in terms of the specific gas loads within each zone and to help make it easier to communicate when problems and solutions are discussed. Each zone has its own pumping considerations and problems along with its own hardware and material requirements, so thinking zonally helps focus our thinking within a fixed set of parameters.