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From THE VACUUM LAB

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Matching Cryopumping Techniques to Application

Cryopumps and cryopumping have become fairly ubiquitous in vacuum technology. There are many variations within the category, and it is necessary to understand the variations in order to achieve the best practical results.

The only answer to the frequently asked question, “What’s the best pump?”, is another question. “What are you trying to do?” That’s because each type of pump has its own inherent strengths and weaknesses, and the right pump is the one that does the job your particular application requires. The only way to successfully make the right match is to look into each type of pump deeply enough to understand how it’ll perform within the parameters of your application. Although there’s no such thing as a universally acceptable vacuum pumping technique, cryopumping meets a large percentage of the most common vacuum processes and applications.

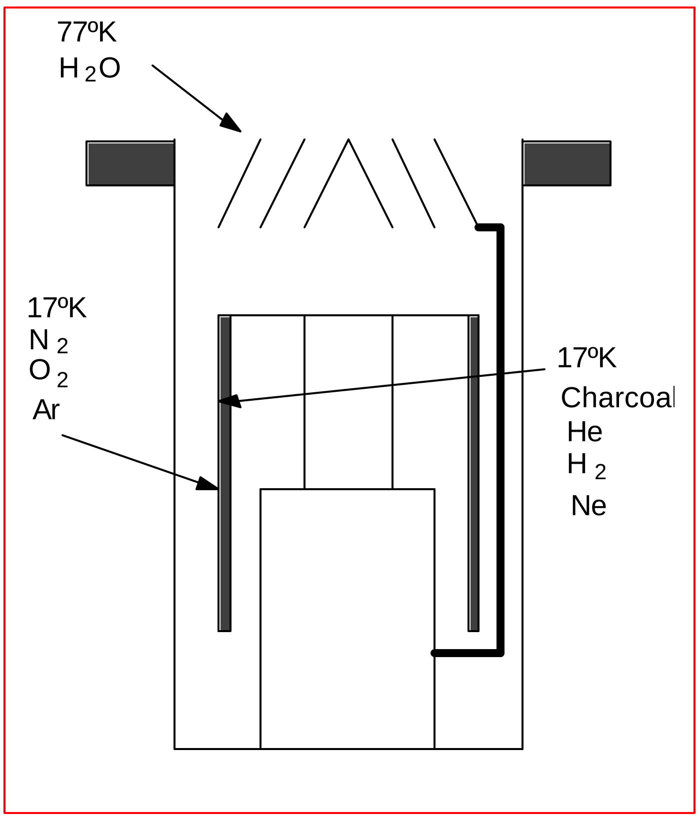
Vacuum pump types can be divided into two main groups; momentum transfer pumps such as turbomolecular, molecular drag, and diffusion pumps, and capture pumps such as cryopumps, sputter-ion pumps, and getter pumps. Capture pumps, true to their name, operate by capturing and holding gas molecules. Sputter-ion and getter pumps remove active gases by a chemical reaction between the gas and a reactive getter metal and hydrogen by dissolving it in the metal as a solid solution. Sputter-ion pumps have the additional ability to pump inert gases by ionizing and accelerating them into the getter material to essentially bury them. Cryopumps, on the other hand, condense or absorb gases onto a sufficiently cold surface(s) to capture and hold the gases. Capture pumps, then, all share a common problem, and that is one of capacity. When a certain quantity of gas or of distinct gases have been captured, the pump will need to be regenerated, reactivated, or replaced *in toto* or in part. Cryopumps, once they have reached their capacity, only need to have their cold surfaces warmed up to release the condensed gases. There are many types of cryopumps with differing applications and configurations that need to be sorted out, but they all share the technique of the use of cold surfaces condensing gases.

Cryosorption Roughing Pumps

Cryosorption pumps are used to provide entirely hydrocarbon-free pumping from atmospheric pressure to the low millitorr range. Sorption pumps are essentially metal cans filled with molecular sieve and provided with some internal means of heat transfer such as fins to allow the heat of sorption to be removed. When the pump body is chilled with liquid nitrogen (L/N_2), the molecular sieve absorbs the chamber's gas and keeps it trapped as long as the pump is cold. Since there is obviously a finite amount of gas that can be sorbed, multiple pump installations are common where the pumps are used sequentially.

They have the potential drawbacks of cool-down, heat-up time, the possibility of sieve material being blown into the chamber by misvalving, and the inability to pump light gases such as neon (Ne) and helium (He). Care in operation can deal with the first two potential problems. The Ne and He problem is related to the partial pressures of 1.4×10^{-2} torr of Ne and 4×10^{-3} torr of He in the atmosphere, but there is an old trick of valving the first pump in for only a single whooshworth of time before valving it out again. The Ne and/or He is easily entrained in the high pressure flow and remains trapped in the first pump.

Cutaway View of a Cryopump



The various cold arrays within the cryopump body show their specific pumping capability. The chevrons in the pump inlet are positioned to pump the main gas load in most systems, water vapor. Other gases pass though the water pumping array, and are then pumped according to their degree of possible condensation.

Cryopumps

The term cryopump is most often used to refer to the single high-vacuum pump using the Gifford-McMahon refrigeration technique. This type of pump, connected to an external He compressor, will produce a two-stage cooling effect with internal arrays cooled to 17°K and 77°K. Located within a single pump body, the 77°K array will pump large quantities of water vapor, and the 17°K array will pump nitrogen (N_2), oxygen (O_2), and argon (Ar) on its surface. These gases are pumped by simple condensation on the cold surfaces. He. Ne, and hydrogen (H_2) are pumped by absorption within a charcoal coating on part of the 17°K array. With these, essentially three, separate pumping arrays, a single pump is able to trap (pump) all the gases encountered in a normal evacuation process.

As with all capture pumps, capacity is important. Capacity is generally specified in torr Liters of gas. For example, the 77°K chevron array can condense massive amounts of water vapor, but under extreme gas loads, an ice bridge can form between the array and the pump body to constitute a thermal short. This is a rare occurrence, but it can happen. The light gases such as H_2 and He are the main concern. When too many torr Liters of either gas has been absorbed in the charcoal, absorption stops. This results in a slowly increasing pressure rise which manifests itself in a higher thermal conductivity between the array and the pump body that results in heat flow into the array and a slight temperature rise. Since the charcoal capacity is a function of temperature, the temperature rise causes the charcoal to release gas, and this condition soon results in a runaway thermal/pressure excursion that will result in all of the pump's condensed gas being released. Monitoring the pump's internal temperature indicator will give ample warning, barring sudden accidentally large gas loads, in time for a regeneration cycle to be planned.

Regeneration of a cryopump is accomplished by warming it to room temperature and allowing the pumped gases to escape. This can be done simply by waiting, or the time can be shortened by heating with warm gas or internal heaters. Once warm, it is re-evacuated with a roughing pump before starting the compressor to re-chill it to operating temperature. This cycle can take several hours or more to complete. It is also possible, with care, to regenerate a cryopump without completely warming it up. This is the cold regeneration technique that requires the pump's drive to be turned off just long enough to allow the saturation level He or H_2 to escape from a slightly warmer charcoal bed. This can only be done if the pump's pressure is kept below 1 millitorr by a close coupled turbomolecular pump during the process.

The limited capacity for light gases can cause some problems when extended He leak checking is required or large H_2 gas loads are encountered in metallurgical or evaporation processes. Such applications have led to another approach; selective pumping. A pumping surface only cold enough to pump water vapor is coupled with a small momentum transfer pump such as a turbo to handle the non-water gas load. Since water vapor is, by far, the major gas load in most systems, the turbo only needs to be fast enough to handle the initial pumpdown load of volume gases and the cryosurface handles the water. There are several commercial methods, including L/N_2, to produce these temperatures quickly. This approach also sidesteps another potential problem.

Most applications require the chamber to be opened to air periodically, and this means that the cryopump needs to be isolated by a valve during the up-to-air cycle. The water vapor gas load is a function of internal surface area and the valve's surface area then comes into play. For example, a 100-liter chamber with an appropriately sized pump can require a gate valve that supplies 1/3 of the system's total surface area. A cryosurface within the chamber that can be thermally cycled quickly can be operated without recourse to a valve. Additionally, this type of installation produces a maximum conductance of gas to the pumping surface. The major caveat is only that the cryosurface be at ambient temperature before the chamber is let up-to-air. The amount of water vapor released upon warmup is less than the amount of water in the air as humidity.

In Perspective

Cryopumps have become a major part of the vacuum practitioner's pumping options, but they, like all pumps, need to be applied correctly and matched to the process. No single type of pump will ever do everything and do it well, but cryopumps have already come pretty close. New ways of applying cryopumps and cryopumping will certainly evolve as vacuum technology applications become more and more complex and stringent.