KNOW YOUR SYSTEM

Oil Vapor Diffusion Pumps

Vapor diffusion pumps were first conceived about 1915-16, and used mercury as the pumping fluid. A decade later, experimenters found that some oils had high boiling points and low vapor pressures and were good pumping fluids. These oils were useful because they remained in the pump indefinitely and allowed lower pressures to be attained without the use of a cold trap. During World War-II, and again during the 1960's for the space effort, diffusion pumps went through some significant design changes that increased their pumping speed, increased their ability to produce lower pressures, and oils gave way to synthetic pumping fluids. Due to its simplicity, high performance, and low initial cost, the diffusion pump remains the primary industrial high vacuum pumping mechanism. Applications for this type of pump are found in R&D labs, coatings facilities, manufacturing, and space simulation. When diffusion pumps are used with the correct fluid, traps, and baffle, they can produce pressures to approximately 2x10 -10 Torr.

Theory of Operation

Diffusion pumps are vapor jet pumps that work on the principle of momentum transfer. This occurs when a heavy, high speed vapor molecule collides with a gas molecule and moves it in a preferred direction through the pump. The bottom of the pump contains an electric heater which is used to heat the pumping fluid to its boiling point, thus, producing the vapor. This must be done at a reduced pressure. This means that before the diffusion pump is started, it must be "rough pumped" down to an acceptable pressure, typically 100 millitorr. To do otherwise will result in no pumping action and possible damage to the pumping fluid. Once boiling of the fluid has begun, the vapor is forced up the central columns of the jet assembly. It then exits at each downward directed jet in the form of a molecular curtain that impacts the pump body.

The pump body is externally cooled so that the fluid will condense on its inside surface and run back down into the boiler. Pump bodies are typically water-cooled, but some are air-cooled. As gas molecules from the system randomly enter the pump (molecular flow conditions), they encounter the top jet. Some of them are impacted and driven on to the next jet. Subsequently, they reach the foreline where they are exhausted to the atmosphere by the mechanical backing pump.

Compression Ratio

The diffusion pump is similar in character to other compression pumps in that it develops a relatively high exhaust pressure compared to the inlet pressure. For most gases this compression ratio may be one million to one (or greater). For example; for an inlet pressure of 2x10-7 Torr and a foreline pressure of 2.0x10-1 Torr, the compression ratio would be one million. As far as compression goes, in a mixture of gases, each species may be pumped with different effects. It is possible to have different maximum compression ratios and different flow rates for gases having different molecular weights. For example, the compression ratio for hydrogen will differ greatly from the compression ratio for argon simply because their molecular weights are very different. Also, when the pumped gas has a molecular weight different from air the maximum compression ratio will shift, but the tolerable foreline pressure (critical discharge pressure) remains the same.

Critical Discharge Pressure

The critical discharge pressure of a diffusion pump is the maximum permissible pressure at the foreline during normal pump operation. The expected pumping action of a diffusion pump ceases when the critical discharge pressure is exceeded. That is, the vapor of the discharge stage of the pump does not have sufficient energy and density to provide a barrier for the air in the foreline, thus, this air will flow through the pump in the wrong direction carrying with it the pumping fluid vapor. For most modern diffusion pumps, the maximum allowable foreline pressure is about 0.5 Torr. Diffusion pumps cannot function at all unless the foreline pressure is held below this limit by the backing pump. The most important rule of diffusion pump operation is: Do not exceed the critical discharge pressure! If this single most important rule is observed, then most difficulties associated with diffusion pump operation can be eliminated.

Back Streaming

Back streaming can be defined as the passage of the pumping fluid through the inlet port of the pump and in the direction opposite to the direction of desired gas flow. However, back streaming must not be limited to the pump, but must include the trap, baffle, and plumbing as well because all affect the transfer of pumping fluid vapors from the pump body to the chamber. There is a multitude of conditions that can cause back streaming.

The most common are; exceeding the critical discharge pressure in the foreline, exceeding maximum throughput capacity for long periods of time, and incorrect start-up or shutdown procedures. Back streaming of pumping fluids into your work environment is always considered catastrophic. I know of very few vacuum related processes in which oil contamination is not a disaster! My suggestion to system operators is to know their equipment thoroughly and learn proper operating techniques. Ninety-nine percent of costly back streaming problems are due to operator error. Finally, equip your system with the appropriate interlocks that will prohibit valve cycling above a specified pressure. This will protect your system whenever it is left unattended.

Baffles and Traps

Baffles have one particular purpose: to reduce the back streaming of pump fluid into the vacuum chamber. Most baffles are "optically opaque" which implies that their internal geometry is such that light cannot pass directly through them. This insures that a molecule will collide at least once with a surface regardless of the incoming direction.

Baffles do impede the flow of pumped gases, but well designed units can retain about 60% of the pumping speed. Baffles are installed directly above the pump inlet and are often used in conjunction with a trap. Water-cooled baffles can reduce the rate of re-evaporation of condensed fluid thereby reducing the density of vapor in the space between the baffle and the trap.

Cryogenic or refrigerated traps serve two purposes. They act as barriers against the flow of condensable vapors from pump to system; and they also serve as cryopumps for condensable vapors (primarily water vapor) emanating from the system. In typical unbaked systems, water vapor may constitute about 90% of the remaining gas after initial evacuation. Chilled traps increase the pumping speed for water vapor and therefore can in many cases lower the base pressure of your system. I know of two distinct varieties of liquid nitrogen traps. One is a trap that is placed anywhere within the vacuum chamber. This may be a cryopanel, a sphere or cylindrical bottle, or a tubular arrangement acting as a "cold-finger" on which condensable gases will be trapped. The other is of the optically opaque design and is placed between the chamber and the pump inlet. These traps insure that gas molecules collide at least once with a cold surface.

Fluids

Many of the pumping fluids used today have been developed within the last 30 years. Up to about 1960, most fluids had a vapor pressure of 10-7 Torr or 10-8 Torr and the base pressure of the system was limited to that range.

Operational characteristics of low vapor pressure silicone fluid (DC704) were also found to be excellent. The use of either of these fluids will permit base pressures of 10-9 Torr or 10-10 Torr to be achieved. More recently, fluorinated oils have been developed for use in diffusion pumps. These have the added advantage of compatibility with corrosive gases used in some processes.

Ultimate Pressure

Two distinct observations can be made regarding the ultimate pressure of a diffusion pump. Ultimate pressure may be considered to be a gas load or a pressure ratio limit. The pressure ratio limit is usually associated with light gases (hydrogen, helium, xenon). The pumping action of the vapor jets does not cease at any pressure, however low. The ultimate pressure of the pump depends on the ratio of pumped versus back-diffused molecules, plus the ratio of the gas load to pumping speed. Also, the pump itself can contribute a gas load either through back streaming of pump fluid vapor and its cracked fractions or the outgassing from its parts. In practice, then, the ultimate pressure of a pump is a composite of several elements. The first limit of the ultimate pressure is usually due to the vapor pressure of the pumping fluid, although this limit may not be observed at pressures below 10-8 Torr.

Operating Procedures

The operation of high vacuum, diffusion pumped systems requires certain care and attention to several items. General cleanliness is extremely important, especially in smaller systems. Remember, if a drop of oil were to be trapped somewhere in your vacuum system, it may take days or weeks to evaporate that drop from your system.

Humidity and temperature can be important in view of the constant presence of water vapor in the atmosphere. When your system is opened to the environment, pump down time is significantly longer if the air is humid. The time of exposure is also significant. If possible, the backfilling should be done with nitrogen or argon. For short exposures, this appears to reduce the amount of water vapor adsorption in the vacuum system.

It is extremely important to develop good habits in valve sequencing operations, especially in systems with manual valves. It is useful to have a "map" or schematic of your system on your control panel that shows valve locations and functions. A single wrong operation can result in very costly maintenance to the system. Automatic valve sequence controllers have been used widely for many years, and they all have built in interlocks to prevent accidental opening of the wrong valves.

During the evacuation of a vessel, the question arises regarding the proper time to switch from the roughing pump to the diffusion pump. In other words, when should the high vacuum valve be opened? There is no general answer to this question because each system is different with different gas loads and different volumes. In practice, the transfer from roughing to the diffusion pump is made between 50 and 150 millitorr. Below this pressure region, the mechanical pump rapidly loses its pumping effectiveness and the possibility of oil back streaming increases. Although the throughput of a diffusion pump is nearly constant when inlet pressures are in the 1 to 100 millitorr range, the initial surge of air into the pump when the high vacuum valve is opened will overload the diffusion pump temporarily. We recommend that the period in which pump inlet pressure is above 150 millitorr be kept as short as possible; i.e., just a few seconds! Without a doubt, you'll have questions on proper diffusion pump operation.