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Technical Note

Vacuum Pump Maintenance and Troubleshooting

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The vacuum pump is an integral part of freeze dryers and is pivotal to the freeze drying process in equipment today. The vacuum pump's primary purpose during primary drying is to evacuate non-condensable gases from the system, thus creating the low pressure environment necessary for sublimation.

In this discussion we will be focusing on the most common vacuum pump found on lyophilizers, two stage rotary vane oil sealed pumps. These pumps are relatively inexpensive (compared to dry pumps for example) and commonly found in most facilities.

Visually Inspect Your Vacuum Pump Oil Before and After Every Run

Maintenance of high quality vacuum pump oil is imperative to continuous operation of the freeze dryer. Most vacuum pumps are equipped with a site glass. You should verify in the pump instruction manual that the site glass is connected to the main oil charge and that it is a true indication of the quality of oil in the pump. As a rule of thumb the more highly refined the oil the more contaminants it can tolerate before having to be replaced. New vacuum pump oil is the same color as vegetable oil—almost clear. As it collects contaminants and breaks down as a result of lubricating the hot vacuum pump it will become darker and darker. Highly contaminated and broken down vacuum pump oil will turn dark brown or black. Ideally, the vacuum pump oil is replaced well before it turns dark brown. By the time it turns dark the integrity of the vacuum pump and its functionality will be compromised and servicing the pump itself may be required. The color diagram below is a general indication of pump oil quality.

Clean Oil

Time to Change Oil

Highly contaminated & pump probably compromised

It is important to note that pump oil that has become contaminated with water will typically turn a milky white color.

When You Are Just Using Water as a Solvent

In a freeze dryer the refrigerated condenser of the freeze dryer is built to trap the vast majority of water vapor that leaves the product. Condensers that are designed well and working properly will trap water in such a way that very little travels to the vacuum pump. However sometimes water will travel to the vacuum pump. These situations include but are not limited to:

- Vacuum is pulled on a system before the system is defrosted and emptied properly
- The load on the condenser is very large due to a product overload or product melting
- The condenser refrigeration system is not working properly

As mentioned earlier, vacuum pump oil that is contaminated with water will often turn a milky white color. The oil charge may possibly be restored in this situation by running the vacuum pump with the gas ballast of the vacuum pump open for a period of time. When operating the vacuum pump's internal temperature exceeds 100C and consequently the water vapor will boil out of the pump. This process can be utilized to restore the quality of the pump oil to a usable state if the pump oil is not highly contaminated. Care should be taken to not leave the gas ballast open for long periods of time. During the time it is open it runs hotter, causing oil to break down faster, and it discharges some oil mist out of the outlet.

When You Are Using a High Vapor Pressure Solvent

In some freeze drying processes there are high vapor pressure solvents such as ethanol and TFA present. Oil sealed vacuum pumps are not meant to handle these solvents with efficiency. Typically, you can accommodate the use of these types of solvents but extra care must be taken. These solvents most likely have a freezing point below that of your condenser and thus will not freeze out on the condenser coil and remain trapped there until defrosting. To mitigate using high vapor pressure solvents care should be taken to first reduce the solvent content by any other means available, making the amount of solvent as little as possible. In freeze drying a solvent will most likely be the very first solvent to leave the product because of its high vapor pressure. We refer to this process as solvent flashing off. You may see the solvent liquefy to some extent on the condenser but ultimately it will travel to the vacuum pump. Running the vacuum pump with the gas ballast open so that the solvent will boil out of the pump when it hits the hot oil is advantageous. In this case it is recommended that a non-restrictive outlet line be installed. Care should be taken to design this outlet correctly so that anything that condenses in the outlet line does not run back into the pump outlet. If this is not feasible it may be necessary to put the vacuum pump under a hood to capture the exhausted solvents. Once the solvents have left the product the pressure in the system will start to go back down and the vacuum pump gas ballast should be closed.

Care Should Be Taken to NOT Leave a Gas Ballast Open

In normal operation of a vacuum pump the gas ballast remains closed. In cases where it needs to be opened the operator should be careful about closing the ballast as soon as possible. Leaving a gas ballast open will cause a vacuum pump to run hotter than normal and causes the vacuum pump oil to break down or "burn". In addition, and open gas ballast will cause additional oil mist to be evacuated out of the outlet. This loss of oil is problematic for anything the exhaust comes in contact with but also, in the extreme, empties the vacuum pump of oil.

Solids in the Vacuum Pump

In some freeze drying applications there is a large amount of fine or powdery solids produced. It is always a surprise for operators to learn that parts of their product are so light that it can be carried by the vapor stream and/or the non-condensable gases to the vacuum pump. Every effort should be made to contain the solids content in product containers. In situations such as this frequent vacuum pump oil changes may be necessary, particularly if the solid is so small that it is difficult to contain.

Troubleshooting Vacuum Pump Performance

Excessive vacuum pump oil loss can be caused by a number conditions. These include:

- A damaged vacuum pump
- Excessive solvent going to the pump and displacing the oil
- A gas ballast left open for extended periods of time
- A leak in the freeze dryer or the pump itself

In freeze drying a good vacuum pump should be able to attain approximately 10mT in a clean, dry and refrigerated freeze dryer. When the freeze dryer is isolated from the pump the leak rate of the dryer should be less than approximately 30 mT/hour. If these conditions cannot be achieved the dryer should be inspected to ensure:

- No water in the drain line
- Drain plug and drain hoses for tight fit
- Vacuum hoses and connections for a tight fit
- Sanitary clamp on top of unit is tight and sealed
- Replace the vacuum pump with another 'known good' pump to test
- Remove manifold (if applicable). Make sure to cap off piping.

System performance should also be checked.

- Perform a leak rate test to determine if the chamber has a leak.
- using the 'Leak Test' in the software Set the vacuum test point to 150 mT and 60 minutes
- if the leak rate is worse than 30 mT/hr then there is a leak in the system that should be investigated further
- If the leak rate is better 30 mT/hr, then the freeze dryer integrity is verified and the vacuum pump is probably damaged, particularly if it does not go to the max low of 10 mT when the system is dry and empty.

Maintaining your vacuum pump may be as simple as frequent oil changes. The frequency of oil changes is dependent on your application and freeze dryer performance. Interestingly we have customers that change their vacuum pump oil once a year and others who have to change their vacuum pump oil after every run. In this case the saying “an ounce of prevention is worth a pound of cure” is very appropriate. There is nothing worse than being half way through a freeze drying run and having the vacuum pump have a catastrophic failure.