While vacuum issues alone are not among the top contributors of unscheduled downtime, vacuum system performance is a critical factor in achieving process repeatability and optimizing overall tool operation. Proper maintenance of the vacuum pump, the key element of the vacuum system, is necessary to sustain desired performance.

The objective of this paper will be to discuss general maintenance and practical steps that can be taken to troubleshoot vacuum diffusion pumped systems, minimizing unscheduled downtime and helping to ensure optimal performance in a production environment.

The discussion that follows includes a brief diffusion pump overview, discussion of safety and a basic troubleshooting guide.

Please note that it is always best to follow procedures and processes established by the equipment manufacturer, and that the operation manual for a particular diffusion pump should be consulted. It is always critical to review the operational manual for vacuum equipment, as different manufacturers may specify more detailed operational settings.

DIFFUSION PUMP BASICS

The diffusion pump is the most common type of pump for use in high vacuum applications. These vapor jet pumps are one of the oldest and most reliable ways to create a vacuum with an operating range down to $10^{-8}$ mbar at 25 °C.
A vacuum diffusion pump is basically a stainless steel chamber containing vertically stacked cone-shaped jet assemblies. Typically, there are three jet stages of diminishing size, with the largest at the bottom. At the base of the chamber is a pool of a special type of fluid having a low vapor pressure. The fluid is heated to boiling by an electric heater beneath the floor of the chamber. The vaporized fluid moves upward and is expelled through the jets in the various assemblies. Cooling water is circulated through the top and sides of the pump to recondense the fluid and allow it to return to the boiler area for reuse.

Exiting from the jets, which have fairly large diameters, the high-energy vapor travels downward in the space between the jet assemblies and the chamber wall at speeds up to 750 mph. The capture efficiency of the vapor jet depends on its density, velocity, and molecular weight. The high-velocity jet collides with gas molecules that happen to enter it due to their thermal motion. This imparts a downward motion on the molecules and transports them toward the pump outlet, creating higher vacuum. At the base of the chamber, the condensed molecules of atmospheric gases are removed by an ejector stage and forepump, while the condensed fluid begins another cycle. The effect of removing molecules is to create a high vacuum in the upper portion of the chamber. It is this part of the chamber that is connected with the application where a high vacuum is needed, in an electron microscope, for example.

The temperature at the base of the chamber, where the fluid is vaporized, ranges from approximately 190 to 280 °C. Several types of fluid, based variously on silicones, hydrocarbons, esters, perfluorals, and polyphenyl ethers, can be used (typically referenced by the pump manufacturer).

Since the chamber itself has no moving parts aside from the fluid droplets, a vacuum diffusion pump can operate with stability over long periods. In all diffusion pumps, a small amount of backstreaming occurs. Backstreaming is the migration of minute levels of fluid that move in the opposite direction—toward the inlet of the pump and into the process stream, which may be the stage of an electron microscope or a welding chamber. In some applications, minor backstreaming has no impact; in others, where the purity of materials is critical, backstreaming cannot be tolerated. For this reason, system
designers typically add an optically dense baffle of varying design to intercept fluid particles before they can reach the process stream. In many applications, the use of polyphenyl ethers minimizes backstreaming.

Pump and jet designs have evolved over the years and synthetic fluids have advanced, enabling higher levels of vacuum to be achieved. A vacuum diffusion pump cannot begin its work with full atmospheric pressure inside the chamber. Instead, an ancillary mechanical roughing pump (or fore pump), capable of a modest level of pumping, first lowers the pressure inside of the vacuum diffusion chamber to approx. $10^{-2}$ mbar or lower. At this point, the vacuum diffusion pump takes over to create a vacuum ranging from $10^{-3}$ to $10^{-9}$ mbar. Since the diffusion pump cannot exhaust directly to atmospheric pressure, the fore pump is used to maintain proper discharge pressure conditions.

Although they have been replaced in some applications by capture pumps or turbomolecular pumps, vacuum diffusion pumps are still in wide use because they have several advantages: They are reliable, simple in design, operate without noise or vibration, and are relatively inexpensive to operate and maintain. In fact, diffusion pumping is still the most economical means of creating high-vacuum environments. These pumps also tolerate operating conditions such as excess particles or reactive gases that would destroy other types of high-vacuum pumps.

**SAFETY**

Because diffusion pumps typically run for extended periods of time without the need for any intervention, it is important to emphasize the need for safety. There is tremendous energy stored in vacuum systems, and there can be risks of catastrophic failures. *The following conditions increase the risk of explosion in a system:*

- **Air leaks into the system.**

- **Roughing through a hot diffusion pump, which can cause hot hydrocarbon fluids to ignite or explode when exposed to air.**
Air release or the admission of air to a pump with a hot boiler (permitting a strong oxidizer to contact the hot pump fluid)

Insufficient (or low level of) pump fluid.

Operation of a diffusion pump without circulating cool water to the main body cooling coils.

Operating pump with water trapped in (optional) Quick Cool coil.

Foreign matter in the pumping fluid, which changes its viscosity and obstructs flow passages.

Some Basic Rules to Follow:

Do not turn on the heater without fluid in the pump. This may ruin the heaters and damage the pump.

Do not air-release the pump while the boiler is hot. Most diffusion pump fluids break down under these conditions.

Do not operate the pump heater unless cooling water is circulating. Doing so causes the pump and fluid to overheat.

Do not operate without a foreline baffle in the pump. This can cause a greater than normal fluid loss.

GOOD GENERAL PRACTICES

Since the purpose of the vacuum diffusion pump is to create a vacuum by removing molecules, the surfaces inside of the chamber have to be very clean during operation.

Technicians are advised to wear gloves when working on a pump, because even a single fingerprint can outgas water vapor and other molecules. When a vacuum diffusion pump is slower than normal in pumping down to the desired vacuum level, the reason is likely to be either outgassing of moisture
on internal surfaces of plastics or other volatile substances, or a leak. All have the same effect, i.e., they add molecules to the atmosphere that the pump is trying to evacuate. When a pump is disassembled for routine maintenance and cleaning, one of the final steps is typically purging with dry nitrogen.

**MAINTENANCE**

It is strongly recommended that the operational manuals for equipment are made available and logbooks are kept to track maintenance history.

Diffusion pump maintenance activities are centered on the diffusion pump fluid, cooling water lines and heater elements. The following describes general practices that should be considered.

**Diffusion Pump Fluid:**

Check the condition and level of fluid when the pump is cold. Withdraw a sample through the drain and visually check the level of fluid through the sight glass. Use new O-ring gaskets when replacing fill and drain plugs. During maintenance intervals, try to log the amount (if any) of diffusion pump fluid loss. This loss of the fluid can be caused by:

- Admittance of excessive air or other gas to a hot pump
- Inadequate water-cooling
- Continuous operation in the overload range (often referred to as the "knee of the curve")
- Failure to reinsert the foreline baffle in the pump assembly

The recommended frequency at which the diffusion pump fluid is changed depends on the specific process. Slight discoloration of the fluid does not affect pump performance, but material build-up in the fluid can lead to inefficiency of heat transfer.

Also, if multiple processes are run on the same equipment, there is the potential for cross contamination of by-products in the fluid. There is no magic formula, and tradeoffs are made between the expense of replacing fluid and the risk of losing performance.
When fluid is changed in the pump, it is very important that appropriate precautions are taken during the initial start-up of a system, as new fluid is subjected to degassing. This can cause periods of foreline pressure fluctuations. These are considered normal and will pass as the fluid becomes fully degassed.

After maintenance, the pump down characteristics of the system should be monitored. Ideally a log is kept that compares the pump down curves after maintenance over time. This is the most likely time that system leakage can occur. 
If leakage is the suspected cause of poor system performance, first check the following items:
- inlet and foreline connections are tight
- drain and fill plugs are tight
- other compression fittings, such as high-vacuum gauges in the system
- threaded connections, such as a foreline gauge.

Before proceeding with a program of step-by-step troubleshooting, check the performance and accuracy of the vacuum gauges used on the system.

Cooling Water Lines.
The function of the cooling water is to convert gas phase fluid into liquid so that it is retained in the pump and re-circulated. It is important that the cooling lines remain capable of providing adequate water throughput to remove heat. If the heat removal is insufficient, the vapor molecules will be pumped out with the process gas, rather than condensing to a fluid and returning to the boiler. This may overload the jets and lead to excessive backstreaming.

Typically, flow meters are used to measure the flow rates of cooling water. Diffusion pump manufacturers have operational specifications for cooling water temperature range, and these should be followed. Depending on water quality, the cooling coils can become restricted due to solid deposit built-up. Ensure that cooling water flow is unobstructed and that the flow rate does not fall not below manufacturer’s specification.
Heater Elements:
Heater elements may burn out from time to time and need to be replaced. It is recommended that factory replacement elements be used. As a preventive pre-caution, when the pump is cold, check that the heaters are bolted snugly to the boilerplate and that all heater terminal connections are fastened tightly inside the junction box. Also, check the total heater power input and balance of the load.

TROUBLESHOOTING
First things first, on rare occasions, system problems can be caused by fairly obvious causes. These should not be overlooked and can be quickly checked. The following checks are suggested as initial steps:
- the position of system valves (check before repositioning)
- the level of diffusion pump fluid.
- Confirm that the cooling water lines are open and water is flowing.

DIFFUSION PUMP Troubleshooting Guide – The following table lists general faults, probable causes and suggests corrective actions to take if a problem with a diffusion pump is suspected.

<table>
<thead>
<tr>
<th>Fault</th>
<th>Probable Cause</th>
<th>Corrective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor system pressure</td>
<td>Leaks in system, virtual or real</td>
<td>Locate and repair</td>
</tr>
<tr>
<td></td>
<td>High process gas load</td>
<td>Measure gas load, eliminate cause</td>
</tr>
<tr>
<td></td>
<td>System dirty</td>
<td>Clean system to reduce outgassing</td>
</tr>
<tr>
<td>Poor ultimate pressure</td>
<td>Contaminated pump fluid</td>
<td>Examine and clean pump; replace fluid</td>
</tr>
<tr>
<td></td>
<td>Low heat input</td>
<td>Check voltage. Check for continuity, burned-out element, poor thermal contact</td>
</tr>
<tr>
<td></td>
<td>Inadequate cooling water flow</td>
<td>Check water pressure. Check tubing for obstructions and backpressure</td>
</tr>
<tr>
<td></td>
<td>Cooling water is too cold</td>
<td>Check temperature</td>
</tr>
<tr>
<td></td>
<td>Cooling water flow is too high</td>
<td>Adjust water flow</td>
</tr>
<tr>
<td></td>
<td>High forepressure</td>
<td>Check for leak in foreline, poor mechanical pump performance, breakdown of mechanical pump fluid</td>
</tr>
<tr>
<td></td>
<td>Water in Quick Cool coil</td>
<td>Check and remove cause</td>
</tr>
<tr>
<td>Slow pumpdown</td>
<td>Low heat input</td>
<td>Check heaters</td>
</tr>
<tr>
<td></td>
<td>Low fluid level</td>
<td>Add fluid</td>
</tr>
<tr>
<td>Problem</td>
<td>Solution</td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Malfunctioning pump assembly</td>
<td>Check and repair or replace</td>
<td></td>
</tr>
<tr>
<td>Improperly located jets</td>
<td>Check and repair or replace</td>
<td></td>
</tr>
<tr>
<td>Damaged jet system</td>
<td>Check and repair or replace</td>
<td></td>
</tr>
<tr>
<td>Inlet pressure surges</td>
<td>Incorrect heater input</td>
<td>Check and correct</td>
</tr>
<tr>
<td>Fluid outgassing</td>
<td>Condition fluid by operating the pump for a few hours</td>
<td></td>
</tr>
<tr>
<td>Leak in system ahead of pump inlet</td>
<td>Check and correct</td>
<td></td>
</tr>
<tr>
<td>High chamber contamination of the pump fluid</td>
<td>Forepressure too high</td>
<td>Check for leak in foreline, poor mechanical pump performance, breakdown of pump fluid, and incorrect valve operation</td>
</tr>
<tr>
<td></td>
<td>Prolonged operation in overload range</td>
<td>Adhere to operating procedures</td>
</tr>
<tr>
<td></td>
<td>Cutting over from the backing pump too early in the pump down cycle</td>
<td>Cut over at a lower chamber pressure</td>
</tr>
<tr>
<td></td>
<td>Improper system operation and air release procedures</td>
<td>Adhere to operating procedures</td>
</tr>
<tr>
<td>Pump will not start</td>
<td>Safety circuits or protective devices prevent contactor from staying closed</td>
<td>Check utilities, flow devices switches, interlock. Check thermostat operation</td>
</tr>
</tbody>
</table>

Source: Varian Incorporated, Varian Vacuum

**Conclusion**

Diffusion pumped vacuum systems often provide the most efficient and cost-effective environments for production processes. To secure these benefits, it is extremely important to follow the simple maintenance practices described here or as recommended by the pump manufacturer. A small investment in planned maintenance can yield a high return in the ongoing high-level performance of your production system.

**References**


Varian Incorporated – Diffusion Pump Operational manual (699901140)
CLICK TO RETURN TO LIST OF PAPERS AND PRESENTATIONS