INTRODUCTION

The science of creating vacuum is often misunderstood and when the desired vacuum condition is not being achieved in a manufacturing setting this usually means production comes to a halt and all eyes become focused on the vacuum pump as the root cause. However, the vacuum pump is usually not the root cause of the problem. In almost all cases either: 1) the pump is being operated in a condition for which it was never intended, or 2) one or more of the user’s interface points with the pump (suction/discharge lines, water supply, process contaminant, etc.) are being operated outside of design parameters, or 3) the vacuum chamber and/or vacuum lines were improperly specified. Each vacuum pumping technology will react differently to various conditions so it is not possible to offer a “one-size-fits-all” answer to the problem. The following is a guide to systematically identifying the root cause of the most common problems and correcting based on general vacuum system recommendations as well as technology-specific issues.

VACUUM TECHNOLOGIES

In the world of process industrial vacuum the most commonly employed vacuum technologies fall into two categories: 1) Wet technologies and 2) Dry technologies. The terms “wet” and “dry” refer to whether or not the user’s process gas comes into contact with a liquid as the gas passes through the vacuum pump. Wet technologies utilize a liquid to create a seal between the discharge and the suction of the pump in order to minimize the “slip” of gas backwards from the discharge to the suction and increase volumetric pumping efficiency. Dry technologies have no liquid contact with the process gas.

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GENERAL RECOMMENDATIONS FOR VACUUM SYSTEMS

The following are recommendations that can be applied to all vacuum systems regardless of pump type:

1. Vacuum leaks – ALL vacuum systems have some amount of air-in leakage which may or may not be known at the time the vacuum pump is sized. Excessive system leaks result in reduced process gas pumping capacity because the pump is required to move not only the process gas from the vacuum chamber, but also the air-in leakage. Leaks occur at the joints of the vacuum lines and at the vacuum chamber. To avoid excessive air-in leakage the following is a general recommendation of operating pressure ranges for various joining methods in vacuum systems:

<table>
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<th>Piping/Joining Method</th>
<th>Operating Pressure Range (mmHg/torr)*</th>
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<td>PVC or thermoplastic/glued fittings or solvent cement</td>
<td>100-760</td>
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<tr>
<td>Copper/Soldered or brazed</td>
<td>10-100</td>
</tr>
<tr>
<td>Steel/threaded (NPT/BSPP/other tapered thread) or Flanged (ANSI, ASA, DIN) with gasket</td>
<td>0.01-10</td>
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<tr>
<td>Steel/Welded or Flanged with o-ring, KF, NW, or ISO joints</td>
<td>10⁻⁷-0.01</td>
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*These recommendations are generic and may vary depending on skill level of assembly personnel

2. Determining vacuum pump vs system problems – When evaluating a loss of vacuum issue it is difficult to know if the pump is the issue or if there is a problem with the other equipment in the vacuum system. In order to make this determination an isolation valve and an accurate vacuum gage should be mounted in-line as near to the suction connection of the vacuum pump as possible. Close the isolation valve and then measure the ultimate vacuum (also called blank-off) performance of the vacuum pump. Then compare the measured vacuum to the manufacturer’s published ultimate vacuum value. If this value is reasonably close to the published value this is an indication that there is an issue with the vacuum system in the form of leaks or outgassing.

3. Excessive pump discharge or back pressure – Vacuum pumps are designed to discharge to atmospheric pressure or just slightly above, unless they are specifically designated by the manufacturer as a compressor. As the discharge pressure of the pump increases above atmospheric pressure this increases the differential pressure across the pump resulting in:
   a. Increased pump temperature and possible overheating leading to pump seizure
   b. Increased current draw and subsequent overheating of the electric motor or overload/fuse/breaker fault

4. Improperly sized suction and discharge lines – Sizing of system piping is crucial to pump performance and should be performed by qualified vacuum engineers. However, to avoid problems the following guidelines may be applied:
   a. Suction and discharge lines should NEVER be smaller than the suction or discharge connection size on the vacuum pump.
   b. For every 50 feet of suction or discharge piping, increase the pipe size by one nominal pipe diameter. Example: A vacuum pump has an inlet connection of 2”. The suction line between the pump and the vacuum chamber is to be 70 feet in length. To avoid restrictions to gas flow and pumping performance issues the vacuum line should be increased to 3”.

Tuthill Vacuum & Blower Systems 4840 West Kearney Street, Springfield, MO  65803-8702       800.825.6937      tuthillvacuumblower.com
5. **Proper isolation for pumps operated in parallel** – Many vacuum pump installations are comprised of multiple pumps operating in parallel and utilizing a common suction and discharge header. For these type of installations pumps that are not in operation should be isolated at the suction and discharge from pumps that are in operation. Failure to isolate the idle pumps may result in 1) discharge gas from the operating pumps entering the idle pump and contaminating the pump, and 2) creation of vacuum in the idle pump and resulting liquid back stream into the vacuum lines and chamber.

### LIQUID RING PUMPS

Liquid Ring (LR) pumps are subject to several possible operating conditions that can cause insufficient vacuum the most common of which are:

1. Sealant vapor pressure is too high
2. Incorrect sealant flow rate being supplied
3. Process contamination of the sealant

#### 1. Sealant Vapor Pressure is Too High

Liquid Ring (LR) pumps utilize a sealant which is most commonly water however, other liquids may be used based on the specific application of the pump. Generally, the lower the temperature of the sealant, the lower its vapor pressure, resulting in increased pumping capacity and deep vacuum performance. In addition, as the process vacuum level approaches the sealant’s vapor pressure the sealant will begin to flash from the liquid to the vapor phase (cavitation), subsequently displacing the pump’s capacity. Sealant temperature/Capacity correction factors should be utilized from the specified liquid ring pump manufacturer in order to properly size the pump.

As a rule of thumb, to avoid pump cavitation when selecting a sealant, the vapor pressure ($P_v$) of the sealant at operating temperature should be less than half of the required vacuum level ($P_1$) as measured at the pump inlet. For instance, the vapor pressure of water at 60F (15C) is $P_v = 13.3$ mmHg absolute. Therefore, the lowest vacuum operating pressure for the pump would be:

$$P_1 = 2(13.3) = 26.6 \text{ mmHg}$$

Operating the vacuum pump’s suction pressure below this level will result in cavitation of the water within the pump and can ultimately damage the pump’s impeller.

**Water temperature too high** – High water temperature supplied to the pump directly as sealant or indirectly as coolant to the heat exchanger of a full sealant recovery system will increase the vapor pressure of the sealant. As the vapor pressure increases this value may approach the vacuum level of the pump and cause the sealant to flash and reduce the pumping capacity. In many cases the use of cooling tower water in high ambient temperature climates (>95F or 35C) resulting in significant capacity reduction. Above are examples of capacity reduction for water as the sealant when operating the pump at 75 torr.
2. Incorrect Sealant Flow Rate Being Supplied

Each model of a particular manufacturer’s liquid ring pump has a specific sealant flow rate requirement in order to achieve the published vacuum performance. The sealant flow should be regulated to within approximately +/- 5% of the published sealant flow requirement. Simple and inexpensive flow control devices are available to regulate this flow. So what happens if this flow is not accurately controlled?

**Too much sealant is supplied** – If too much sealant is fed to the vacuum pump, the volume of the liquid ring within the pump will increase. Subsequently the volume of the rotor available for the pump to move process gas will be displaced and the pump will lose pumping capacity, resulting in a loss of vacuum.

**Too little sealant is supplied** – If too little sealant is fed to the vacuum pump, the liquid ring volume will be reduced and the liquid ring will no longer be able to create the necessary seal between the rotor and the housing allowing internal “slip” of the discharge gas back to suction, resulting in reduced pumping capacity and loss of vacuum.

3. Process Contamination of the Sealant (in full sealant recovery systems)

**Condensable carry-over** - During the process of moving gases from the vacuum chamber through the liquid ring pump, the process gas will contact the sealant and may subsequently collect in the sealant. If the substance collects in the sealant liquid and has a vapor pressure higher than the sealant, the substance will enter the liquid ring pump and flash from the liquid to the vapor phase and reduce the pump’s capacity. As an example, when using oil as the liquid ring sealant, if water vapor is a carry-over product from the process gas, the vapor will condense to liquid in the discharge separator tank and effectively increase the pump sealant vapor pressure and reduce capacity.

**Particulate carry-over** – Particulate carry-over or other matter may clog sealant piping, strainer, heat exchangers, valves, etc. and restrict sealant flow to the vacuum pump resulting in reduced pumping capacity and possible overheating of the liquid ring pump.

**OIL SEALED ROTARY PISTON PUMPS/VANE PUMPS**

Over the years the following are the some of the most common field issues experienced by oil sealed rotary piston and vane pumps:

1. Belt squeal/high amp draw at start-up
2. Pump will not blank-off (high ultimate pressure)/milky oil
3. Back-streaming of oil into suction lines/vacuum chamber
4. Excessive oil mist discharge

**1. Belt Squeal/High Amp Draw at Start-Up**

Belt squeal of a pump at start-up can be caused by 1) improper belt tensioning, 2) cold oil temperature due to low ambient temperature, or 3) improper shutdown procedure.

Belt squeal is typically caused by a loose belt. This can be checked by starting the pump and observing the deflection of the belt during rotation. Do not apply belt dressing to V-belt such as those used on Tuthill vacuum pumps. If the belt appears to have excessive deflection, refer to the manufacturer’s product manual for proper tensioning instructions.

The next likely cause of belt squeal/high amps is attempting to start the pump in low ambient temperature conditions, typically <60F (15C). In this case, oil preheaters must be installed in order to bring the oil’s temperature up and reduce its viscosity such that the internal components do not create high torque on the shaft. In many cases, pumps heaters and a temperature switch can be installed such that the pump will not start until the heaters have raised the oil temperature to a value that allows the oil temperature switch to start the pump through communication with the motor control center.
Lastly, oil sealed rotary piston pumps are particularly prone to improper shutdown. If the pump is shut down under vacuum, there will be an excessive amount of oil in the cylinder. After the oil cools and the operator attempts to start the pump, the cold viscous oil will create high torque on the pump shaft resulting in high amp draw. Oil sealed pumps require that the inlet pressure of the pump be increased sufficiently (typically >100 torr for no less than 15 seconds) to allow more gas flow through the cylinder of the pump resulting in displacement of the oil in the cylinder back into the main oil reservoir.

2. Pump Will Not Blank-Off/"Milky" Oil

Oil sealed vacuum pumps commonly fail to meet the published blank-off performance due to: 1) substitution of the manufacturer's vacuum pump oil with an improper oil, or 2) condensable process vapors collecting in the oil.

For various reasons vacuum pump operators may choose to substitute an oil for the manufacturer's recommended oil. This can often result in failure to produce the deep vacuum results as published. This is due to the fact that vacuum pump oils are formulated to have a vapor pressure significantly lower than the pump's ultimate vacuum capability. If a higher vapor pressure oil is substituted, the pump will begin to create vacuum and reach the vapor pressure of the oil in the cylinder. When this occurs the oil will flash to the vapor phase and displace the pump's capacity and result in higher blank-off values. The only remedy is to use an oil that has a vapor pressure equal to or less than the manufacturer's vacuum pump oil. Matching the recommended oil's viscosity will also be required.

Many processes such as vacuum drying contain moisture that will condense when it reaches the pump's oil reservoir at atmospheric pressure. The visual result is “milky” oil. Typically the liquid has a vapor pressure significantly higher than the pump’s ultimate pressure. As the condensed liquid is recirculated with the oil into the cylinder (under vacuum) it begins to flash to a vapor phase. This again results in a higher than published blank-off value. The solution is to either: 1) run the pump’s gas ballast valve open (off process) for 15-30 minutes allowing the incoming air to strip the moisture from the oil, or 2) change the oil more frequently. Note that failure to perform one of these procedures will result in excessive wear of the internals due to increased friction and heat and reduced pump life.


Back streaming of oil into the vacuum lines and/or vacuum chamber is commonly caused by failure to vent the pump’s inlet prior to shut-down (see illustration to right). As noted in Section A, oil sealed pumps require that the inlet pressure of the pump be increased sufficiently (typically >100 torr for no less than 15 seconds) to allow more gas flow through the cylinder of the pump resulting in displacement of the oil in the cylinder back into the main oil reservoir.

4. Excessive Oil Mist Discharge

This phenomenon typically occurs because: 1) the pump has been operated continuously at an inlet pressure greater than the manufacturer’s recommendation, or 2) the pump’s oil mist element has failed.

Oil sealed pumps are commonly used to operate continuously at inlet pressures <10 Torr or for short pump down cycles that don’t allow oil to saturate the pump’s oil coalescing element. If the pump is operated above the manufacturer’s recommended maximum for prolonged periods, the relatively high gas density will carry the oil into the mist element at rates beyond its maximum filtering capability. The result is oil discharge from the exhaust of the pump. The best way to avoid this situation is appropriate sizing of the pump for the system design to avoid high operating inlet pressures for prolonged periods.

The other possibility is the pump’s oil mist element fibers have been separated due to continuous saturation and high pressure differential resulting in the escape of oil mist from the pump’s exhaust. Replacing the element will commonly solve
the problem.

**DRY SCREW PUMPS**

Some of the common issues related to the improper application or operation of dry screw vacuum pumps are:

1. Overheating and seizure
2. High motor amp draw

It should be noted that dry screw vacuum pumps all have some common features, however, the symptoms of each pump will be manufacturer and model specific.

1. **Overheating and seizure**

Dry screw vacuum pumps are sensitive to several variables that can cause overheating. The more common are:

   a. Reduced cooling water flow/High cooling water temperature
   b. High inlet gas temperature
   c. Improper staging with a vacuum booster

**Low cooling water flow/High cooling water temperature**

Due to the high internal temperatures discussed in the previous section, the dry screw pump is very sensitive to cooling water flow and temperature relative to other technologies. A reduction in cooling water flow rate below the manufacturer’s minimum recommendation and/or supply cooling water temperatures in excess of the manufacturer’s recommendation can result in thermal growth and ultimately seizure of the pump.

**High inlet gas temperature**

Because dry screw pumps have no internal liquids to absorb heat, the internal temperatures of dry screw pumps can range from 250°F to 450°F depending on the screw design. Due to this fact, they are sensitive to inlet gas temperatures and each has a manufacturer’s maximum inlet gas temperature rating. During the selection process this value is sometimes not considered and as a result the pump has gas temperatures entering it that exceed this value, resulting in excessive high internal gas temperatures resulting in thermal growth and subsequent pump seizure.

**Improper staging with a vacuum booster**

The sizing process of a vacuum pump with a vacuum booster has several parameters that must be considered. However, one of the most important considerations when pairing a vacuum booster upstream of a dry screw pump is staging ratio. Staging ratio is defined as the ratio of the volumetric flow rate of the vacuum booster divided by the volumetric flow rate or:

\[ S.R. = \frac{V_1}{V_2} \]

Applying Boyle’s Law:

\[ \frac{V_1}{V_2} = \frac{P_2}{P_1} \]

Since \( V_1 \) is always greater than \( V_2 \), this means that the pressure between the booster and the dry screw pump will always be greater than the inlet pressure, \( P_1 \), to the system. The gas compression across the booster results in a temperature rise of the gas that will enter the dry screw pump. Therefore, this ratio should be considered carefully to avoid exceeding the inlet gas temperature rating of the dry screw pump.
2. High motor amp draw

High electric motor amp draw is a common field symptom for many types of rotating machinery, however, high amp draw is not usually caused by an issue with the motor but rather the piece of equipment it is driving. In the case of dry screw pumps, high amp draw is typically the result of:

A. Excessive discharge pressure (as noted in the general section)
B. Process build-up in the machine
C. Internal contact due to the cooling water and inlet gas temperature noted above

Items A and C have already been addressed so we will focus on the process build-up in the machine. Many vacuum processes contain chemicals that combine at high temperatures and become sticky or “tacky”. Subsequently there can be process build-up that can be “baked” onto the screws which ultimately creates a “zero clearance” condition inside the pump. This contact within the pump creates additional torque on the pump shaft resulting in increased amp draw.

The solution to this problem must be a recommendation of the manufacturer, however, generally speaking the choice is to 1) knock out or filter the process gases upstream, or 2) supply a cleaning flush. Option 1 is preferable in extending pump life, however, filtration units can be costly and will require continual maintenance and as the filter elements clog, there will be resulting loss of vacuum in the process chamber.

The cleaning flush option avoids the cost of the filtration system, however, may have its own operational issues that could result in damage to the pump and there is no guarantee of success with the flushing process. Choosing a proper flushing media is most important and should be approved by the pump manufacturer. The media may be chosen to be a chemical solvent or simply a mechanical cleaning fluid such as a water. In addition, when injecting a direct liquid flush into a dry screw pump, care must be taken to not flood the pump’s screw chamber as this can result in the pump attempting to compress liquid and subsequent mechanical failure requiring a major rebuild of the machine. Lastly, when injecting a flushing liquid into the pump’s process chamber, the pump’s inlet pressure must be elevated sufficiently above the vapor pressure of the liquid to avoid flashing. If the liquid flashes to vapor this will minimize the cleaning affect as well as potentially create a freezing problem within the machine due to the Joule-Thompson effect.

**SUMMARY**

The process of creating a successful vacuum installation is comprised of several steps:

1. Determine the parameters of entire cycle of the vacuum operation from start-up to shutdown
2. Select the appropriate vacuum technology and material of construction to match the process vacuum and flow requirement and gases to be handled
3. Properly size the vacuum pumping equipment, vacuum chamber and suction and discharge lines
4. Commission and leak check the vacuum system and validate on process

The vacuum pumping technologies addressed in this article are time-proven and will give years of reliable service when properly applied and operated. However, when troubleshooting is required, the process of systematically diagnosing the problem and applying a corrective solution can be equally as valuable. Tuthill Vacuum and Blower Systems application engineers are available to assist with the most challenging vacuum applications.