

## **Industrial Heating: Do-It-Right ADVISOR Topics**

*How to select the right vacuum pump for the application*

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Selecting the right vacuum pumping system for your heat treat application is a complex and challenging task with the realization that no single type of vacuum pump is likely to provide all the characteristics necessary to meet all your process requirements. Vacuum pump selection not only demands a thorough understanding of what you need your vacuum system to do, as important is knowing the impact the selected vacuum system will have on the overall cost to produce your product, pertaining to cost of ownership and how the selected vacuum system will impact product quality and / or yield. It should be recognized early on during the design and equipment selection stage that pumping system configuration can be just as important as the pump technology selected and even small changes in configuration can make significant improvements to vacuum system reliability reducing overall user intervention.

To focus the discussion we will concentrate mainly on vacuum systems capable of low or “rough” vacuum from atmospheric pressure to 10 torr and medium vacuum from a 10 torr to  $10^{-3}$  torr. Low and medium vacuum will typically utilize a stand alone mechanical vacuum pump with a capacity of 200-600 cubic feet per minute (CFM) or a roots blower in series with a suitable mechanical vacuum pump with a system capacity of 500 to 20,000 CFM. The configurations vary with roots blowers in series or in parallel backed by one or more mechanical vacuum pumps. Some heat treating applications call for secondary vacuum pumps such as diffusion pumps and vapor boosters with a capacity range of 7000 CFM for a 10 inch diffusion pump up to 25,000 CFM from a single 30B5M vapor booster. Imagine all that pumping speed from a pump with no moving parts! Mostly we will focus on choosing a mechanical vacuum pump looking at oil sealed rotary pumps, primarily piston pumps, and dry running claw or screw type vacuum pumps. A brief discussion on secondary pumps i.e. diffusion pumps and vapor boosters will round out the discussion giving coverage to the specific types of vacuum pumps widely used in the heat treating industry.

Applications which evolve large gas loads and require medium, tending towards high vacuum ( $10^{-1}$  torr to  $10^{-5}$  torr) may call for secondary vacuum pumps known as diffusion pumps or vapor boosters. A well designed diffusion pump for heat treat applications will offer high throughput (mass flow) and have a high tolerance to gas surges. Vapor boosters operate in a similar way to vapor diffusion pumps yet are distinctly different in that they generate high boiler pressures approximately 10 times higher than is typical for a vapor diffusion pump. The high boiler pressure feeds motive fluid to powerful ejector nozzles specifically designed to enhance the mass flow capability of the pump. They are well suited to applications in the 0.1torr range to 0.0005torr range where mechanical pumps are often at their limit. Classical diffusion pumps become unstable as pressure tends towards 0.1torr. Diffusion pumps and vapor boosters are incapable of exhausting to atmosphere and require a mechanical rough pump to be operated continuously in series with it so mechanical pump selection remains important. Turbomolecular pumps are another type of medium to high vacuum secondary vacuum pump which, when backed by

a dry pump, may have uses in the heat treat industry when extremely clean, hydrocarbon free vacuum atmospheres are required.

An integral part of the selection process is detailing what you need your vacuum system to do. The application must be clearly defined in order to determine a vacuum system solution to meet your specific needs. An important question to ask up front: Do you need to protect the process from the pump, as it pertains to hydrocarbon contamination, or do you need to protect the pump from the process as it pertains to reactive gas or dust, particulate, and corrosives? Often times, the furnace operator will need to deal with both problems at once. Other questions for consideration: Will the pump system be required to simply pump down a chamber to a certain vacuum level and then be taken off line or remain at the attainable blank off pressure? Maybe you need the vacuum system to handle a specific mass flow while holding at a specific pressure. Maybe you need rapid pump down to cross-over pressure of a secondary vacuum pump and then the system will be used in series to back a secondary vacuum pump such as a vapor booster or diffusion pump. Often the vacuum system will execute a pump down and then hold at vacuum under specific mass flow conditions or maybe rapid cycling from atmosphere to vacuum is required.

Before moving on to weighing the attributes of various pumps against a particular application, a somewhat subjective and frustrating task, let us consider system sizing criteria. The basic information needed to size a vacuum pump for a specific pump down requirement is chamber volume, chamber surface area, chamber materials of construction, vacuum system leakage, target vacuum level and desired time to achieve the required vacuum level. Sizing a vacuum pump for a specific pump down requirement commonly assumes a clean, dry and empty chamber having a leakage rate of zero. The fluid being pumped is air at 68 degrees F. Although the chamber is assumed to be dry there is chamber out-gassing associated with microscopic layers of water vapor which adhere to the chamber walls hence there is a direct correlation between surface area and the overall amount of chamber out-gassing. The more surface area exposed to vacuum the more out-gassing so considering the surface area of chamber fixtures is important. Most times the engineer executing pump down calculations use published out-gassing rates for specific materials of construction. The rates used are widely accepted in the vacuum engineering community. Zero chamber leakage is usually a reasonable assumption given the quality of modern vacuum furnaces in relation to the size of the vacuum pumping systems employed. With that said if atmospheric leakage is known it is easily incorporated into vacuum pump down calculations.

Often furnace applications require the vacuum system be able evacuate the chamber of atmospheric air in a reasonable period of time while at the same time the material being processed contributes significantly to the overall gas load. Sizing a vacuum pump for a new application such as this can be challenging. It is useful to employ past experience on similar furnace applications to make a reasonable determination of the vacuum pumping speed required. As challenging is determining the vacuum pumping speed required to hold a chamber at a specific vacuum level for a given chamber load. Again, past experience is useful to make a reasonable determination of the vacuum system capacity

required. Generally speaking, furnace capacities and associated vacuum systems must be reasonably sized to meet overall size, foot print, utilities and budget considerations.

Sizing a vacuum system to back a secondary pump such as diffusion pump or vapor booster is a fairly straightforward. A secondary pump will have a published known maximum mass flow and a published critical backing pressure, sometimes referred to as critical fore-pressure. The mechanical system required to back a secondary pump must be capable of handling the published mass flow of a single secondary pump or the combined mass flow of multiple secondary pumps while maintaining a backing pressure well below the published critical fore-pressure of the secondary pump(s). The manufacturer of secondary pumps often specifies the required backing speed to further simplify sizing.

Now let's consider what is arguably the more challenging aspects of selecting the right vacuum pump for your application as it relates to specific selection criteria and the challenges you face in your specific application and installation. Below is a summary list of some selection criteria.

- Environmental Health and Safety (e.g. emissions and waste generation, noise, general equipment safety)
- Operating cost
- Maintenance cost
- Capital cost
- Effect on process / product
- Reliability
- Servicability

This list has the potential to be much longer but these are some of the primary considerations. Examining each of the criteria as it relates to your particular application and installation allows one to draw conclusions on what criteria matter most to your particular situation. Although this discussion is not intended to be a discussion about wet vs. dry pumping technology nor is intended to favor one over the other, the case for wet vs. dry is pertinent at this point in the selection process. In some applications, dry pumps do appear to offer advantages over oil sealed pumps.

The mechanical vacuum pump historically the work horse of the industry is the oil sealed rotary piston (OSRP) pump such as the Stokes 412. However, in the last decade dry pump technology is becoming widely accepted in the heat treat industry. In some applications dry pumps are proven to reduce cost of ownership, improve product quality and increase up time but the argument of wet vs. dry is still a subjective one. Generally speaking oil sealed pumps offer industry proven reliability and performance. The trade off is coping with oil contamination issues which in the end can significantly degrade reliability and performance, impacting product quality contributing to total cost of ownership. Some applications may require frequent oil changes with rising disposal costs and then need to address other environmental concerns which further add to the overall cost of ownership. Improvements in dry pump technology allows the user greater

reliability than ever before minimizing contamination, virtually eliminating oil vapor emissions and cumbersome oil handling issues associated with oil sealed pumps. There is no better time than during the pump selection process to detail the issues and concerns with the present technology, to investigate alternatives and collaborate with industry experts. There are a few cases where the choice is clear in that hydrocarbon oil contamination cannot be tolerated so dry vacuum pumps immediately become the technology of choice. Most applications are not so clear cut requiring more investigation to better understand the impact of vacuum pump selection as it relates to your specific application and specific environmental, health and safety compliance.

The following is a sample of heat treating processes where vacuum is employed. A general summary of each application is given and a case for dry and wet pump technology is presented.

- Hardening: Nitriding
- Hardening: Ion Nitriding
- Hardening: Low Pressure Carburizing (LPC)
- Hardening: Quenching
- Vacuum Brazing

#### **Hardening: Nitriding**

Process gases are typically ammonia and nitrogen with residual water vapor present from the chamber load. Roots pumps with OSRP pumps or dry pumps are used to remove ammonia and flammable hydrogen by-products. Not a particularly dusty application although adequate filtration is recommended to protect the vacuum pumps. Moisture, which may condense in pump oil, is present from large surface area of the chamber load. Moisture combines with ammonia to cause corrosion of pump components, degradation of elastomers and shaft seals resulting in leakage and may attack pump lubricant / seal fluid. Dry pumps offer greater reliability and a more cost effective solution as they do not contain lubricants in the swept volume or retain moisture so long as condensation of vapors in the pump is avoided.

#### **Hardening: Ion Nitriding / Plasma Nitriding**

Process Gases are typically nitrogen and hydrogen. The absence of ammonia avoids many of the problems associated with conventional nitriding. Both dry pumps and oil sealed pumps are equally robust on this application. Dry pumps offer stable performance giving a predictable and repeatable roughing cycle. Oil sealed pumps pumping cycles may take significantly longer if the pump oil becomes contaminated with water and other condensable vapors. Other selection criteria pertinent to your installation may help you to decide which pump technology is best.

#### **Hardening: Low Pressure Carburizing (LPC)**

Process Gases are typically pure hydrocarbons like propane, ethylene or acetylene. With the exception of acetylene, these gases form soot and sticky tar deposits in the furnace and vacuum system resulting in damage lock up when the pump is shut down and a restart is attempted. A flow of pump oil, having detergent and dispersant properties acts

as a solvent to aid in the solubility of the tars. Oil sealed pumps require an oil purifier circuit to continuously remove insoluble particles. Regular and frequent oil changes are necessary. Dry pumps require a solvent flush to through the mechanism to minimize tar build up. As the solvent does not need to provide lubrication there is a wider range of lower cost solvent that can be used and less volume of solvent is required. Both dry and wet technologies can be robust on this application if configured properly.

### **Hardening: Quenching**

Process gases used are hydrogen (flammable), argon, helium or nitrogen. Gases are removed from the chamber by vacuum pumps. Hydrogen and helium are low viscosity gases therefore dry pumps do not perform as well on these gases compared to air. The loss of performance is due to leak back of the low viscosity gases through the pump clearances. Oil sealed pumps do not have this problem due to oil sealing of the pump mechanical clearances. Hydrogen poses a flammability risk which must be carefully managed. Argon has a high heat of compression and low thermal conductivity so it will cause a vacuum pump to get hot (compared to pumping air). For dry pumps this can be a problem unless certain precautions are taken. Oil sealed pumps will run hotter but do not typically have problems. Dry pumps offer stable performance giving a predictable and repeatable roughing cycle. Oil sealed pumps pumping cycles may take significantly longer if the pump oil becomes contaminated with water and other condensable vapors.

### **Vacuum Brazing**

Roots pumps with OSRP pumps or dry pumps are used with vapor boosters or diffusion pumps to provide a desired vacuum environment in the range of  $7.5 \times 10^{-4}$  torr. Vacuum pumps must handle small amounts of particulate along with solvents and residues from braze past, binder and 'stop-off' used. Environmentally friendly acrylic based binders have replaced traditional solvent based binders resulting in problems with the vacuum pumps. These materials can polymerize and build hard deposits in oil sealed pumps. The problem is minimized by applying a gas ballast purge at the vacuum pump but absorption and subsequent polymerization is inevitable. Oil mist from the oil sealed backing pump may contribute to hydrocarbon contamination in the chamber even when used in series with a diffusion pump. The theory is the mechanical pump oil slowly diffuses into the diffusion pump over long period of time. The mechanical pump oil has a higher vapor pressure than diffusion pump fluid and contributes largely to backstreaming in the chamber. Dry pumps eliminate the potential for this problem. Polymerization in the dry pump can be reduced or avoided by proper purge strategies.

Keeping a vacuum system running in a safe and efficient manner is a top priority and proper selection of a vacuum pump will make this task easier. It is hoped that the material presented will help one better understand selection process in order to determine which solution is best for the given application and situation. Borrowing a few words from my distinguished colleagues: good design, good procedures, good maintenance and good housekeeping equals good vacuum!

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