

Matching Vacuum Pump to Process

“What’s the best vacuum pump?” is one of those maddening questions that can only be answered with another question such as, “What are you trying to do?” That’s because the real answer is that there is no best pump, and there is no worst pump. At least not in an overall and non-specific sense. The best pump is, and always will be, the pump that does the best job at what you need it to do. Although that answer might seem to be obvious, the question continues to arise. It seems to arise due to the common human need of finding “the” answer to a problem. The hard thing to face up to, then, is the fact that there’s no single problem and no single answer, but that reality is composed of a number of complex problems with complex answers. This is especially true when considering vacuum processes and vacuum pumps. There is no single type of pump that will provide all the attributes necessary to meet any and all process requirements. Although the available varieties of pumps seem to present a bewildering collection of choices, the best choice becomes more and more apparent as you go down the list and remove the pumps that won’t meet your process requirements. This requires a careful analysis of your process and its pumping needs before you begin the elimination sequence. It also helps to break down the types of pumps into overall groups to simplify the process.

Questions to Ask While Choosing a Pump

- What ultimate pressure is required?
- What gas loads will be present?
- Are there process gas problems?
- What cleanliness levels will be required?
- Will the system be opened frequently?
- Will the pump require valving and a backing pump?
- Do the pumping speed vs pressure curves match the process requirements?
- Can the pump be installed easily on the system?
- What maintenance requirements or problems are there?
- What will the cost of ownership be?

There are a number of important considerations to keep in mind when beginning the process of winnowing down to the final, and best, choice for your process. Obviously, you need to consider the pump’s ability to produce and maintain the ultimate pressure your process requires. The pumping speed vs pressure curves usually supplied in the various manufacturer’s literature need to be carefully considered and compared. The pump must have enough pumping speed to easily achieve and maintain the ultimate pressure required, but it must also have the ability to handle any process gas loads that will be introduced deliberately during the process or internally liberated during the course of

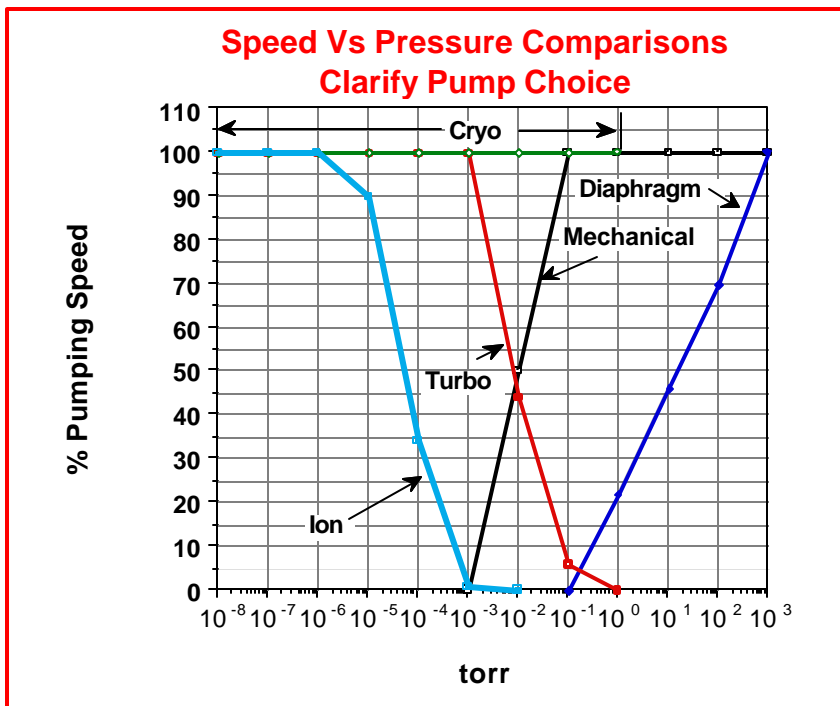
the process. The speed vs pressure curves, then, will allow you to assess the pump's capability to produce both the required pumping speed (volume flow) and throughput (mass flow) to match the process's needs. This can be checked by a simple Q (gas load) = S (pumping speed) \times P (pressure) calculation. At this point, it is also convenient to compare the candidate pump's ability to handle particular gases involved with the process. This should be done in terms of pumping speed, throughput, corrosion, cleanliness, and safety. Additionally, the particular aspects of the type of pump and its attendant operational requirements should be taken into account. All of these points can be garnered by a careful reading of the manufacturer's data sheets. The reading of data sheets is usually a painfully acquired skill, or, as is often the case, an art. One of the most important concepts in the reading of data sheets is to look for what isn't said. If several manufacturers carefully make a certain point and one doesn't make the same point, there's likely to be a reason. It might be an oversight, but there's usually a more important reason. This is where you should focus your inquiries. As the field narrows, the time arises to begin to look at the economic aspects. Although the purchase price is important, you should think carefully about "cost of ownership." These include operating costs, maintenance cycles and costs, consumables, and the cost of ancillary equipment such as backing pumps and valves. With all these points in mind beforehand, the next move is to start to break the pumps down into groups broad enough to allow a rational sorting process to succeed. The first divisional cut is to break the list into two main groups: roughing and high-vacuum pumps.

Roughing pumps are required by any vacuum process when it's necessary to reduce the pressure within the chamber from atmospheric pressure. This is, of course, true for both batch systems, which are cycled often and repeatedly, and systems that are pumped down and remain at high vacuum for long periods. Roughing pumps can be broken down, in turn, to oil-sealed and oil-free categories. A go-no go decision, at this point, can be as simple as deciding whether the possibility of oil contamination is of extreme importance or whether there are process gases that will react with the pump oil. If oil, then, is ruled out, the list becomes a little smaller. There is, at present, a large number of types of oil-free pumps that are available. These include blowers, diaphragm, piston, screw, and scroll pumps. Each type of oil-free roughing pump has its own peculiarities that need to be matched to your process. Additionally, oil-free pumps are in a state of evolution, and last year's facts and opinions may no longer be relevant. In general, it's particularly important to look at the shape of the pumping speed vs pressure curves in addition to their quantitative ratings. All roughing pumps tend to have their highest pumping speeds at, or near, atmospheric pressure. As the pressure is reduced by the pump, their speeds decline, but they do so at differing relative rates, and the rate of decline is often important to particular processes. The ultimate pressure is, of course, of importance, but it's necessary to consider that the blanked-off ultimate is seldom realized in a practical system. Additionally, the ultimate listed in the data sheets often needs to be taken with a shovelful of salt. For example, many manufacturers of oil-sealed mechanical pumps list an ultimate of 10^{-6}

⁴ torr. This is true if you measure the pressure with a McLeod gauge which ignores condensable gases, but the predominant gas at the pump's ultimate pressure is water vapor which is a condensable gas. A real ultimate would then be between 1 and 10 millitorr instead.

The high-vacuum pump category breaks down into momentum-transfer and capture pumps. Momentum transfer pumps include diffusion pumps and the turbomolecular/molecular drag family. In general, all momentum transfer pumps remove gas from the process chamber and pass it through an attendant backing pump back into the atmosphere. Diffusion pumps are often eliminated from choice because they require water-cooling, a backing pump, and a complex valving system to allow cycling for batch processes. More importantly, they are often avoided because they contain oil, and a liquid nitrogen inlet trap is required to prevent backstreaming oil from entering the process chamber. On the plus side, diffusion pumps are capable of handling very large gas loads, and this makes them ideal for many processes such as metallurgical melting, brazing, or heat treating along with vacuum distillation or drying. On the other hand, the turbo/drag family allows fairly simple installation without valving since they can be quickly shut down between cycles, and they use a mechanically rotating system to transfer momentum to the

gases being pumped instead of high-speed oil molecules. This means that they have a higher inherent hydrocarbon-free cleanliness. In most cases, they require lubricated bearings, and the lubricants are often viewed with suspicion. Oil vapors detected when using this family of pumps, though, is usually traced to oil backstreaming from oil-sealed mechanical pumps. Although the turbo/drag family requires



The increase or decrease of pumping speed at various pressures can have important effects on your process. Roughing pumps tend to lose speed as the pressure drops and high-vacuum pumps tend to have an increase.

backing pumps, they are often backed with oil-free pumps to ensure clean installations. Magnetically levitated versions that require no bearing lubrication are also available at a higher cost.

The second main category of high-vacuum pumps is capture pumps. All capture pumps have the common attribute of capturing and holding the gas molecules they are required to pump. They might hold them permanently or temporarily, but, in the pumping process, they contain them and do not exhaust them back to the atmosphere as do momentum transfer pumps. The capture pump category breaks down into cryogenic, sputter-ion, and getter pumps. One important point that they all share is that of capacity, and this point only arises when considering this group. Manufacturer's data sheets will usually list the capacity of each pump for different gases. This means that the pump can only hold so much of a given gas species without becoming loaded with that gas and ceasing to pump further amounts of gas.

Cryogenic pumps function by sorption of the pumped gases at low temperature usually by a phase change that "freezes" the gas or by enhanced sorption of light gases into molecular sieve or charcoal beds. All of these pumps have very high pumping speeds for water vapor, but they have, relative to water vapor, limited speeds and capacities for light gases such as helium and hydrogen. In cycled batch systems, they require inlet valves to prevent the pumps from loading up when the chamber is let up-to-air for reloading work. They have the advantage, though, of the ability to perform multiple pumpdown cycles before regeneration by warming up the pump to release the previously sorbed gases is required.

Sputter-ion and getter pumps fall within the permanent capture group in that they both pump by means of chemical reactions that combine an active metal with the gas to form a ceramic material with a low vapor pressure. This means that they have a pumping capacity limited by the amount of active metal that can come into contact with the gas to be pumped. In both cases, the exception to the permanent capacity is hydrogen which is pumped by forming a solid solution within the getter material. The dissolved hydrogen can be then removed by heating under vacuum and pumping it away with another high vacuum pump. Getter pumps are unable to pump inert gases such as helium or argon which are always in the atmosphere, but sputter-ion pumps have that ability. This is due to the fact that they operate with a magnetically confined discharge that provides a cloud of electrons to ionize the gases and accelerate them into the active metal. Inert gases are buried while the active gases react chemically. Both getter and sputter-ion pumps have not only a limited capacity that varies greatly, but they have complex throughput considerations that can have important effects on their ability to deal with process gases. In their case, comparing the pumping speed vs pressure curves is of extreme importance.

Once the possible choices are narrowed down through whatever sorting stages are required, the particular choice of the actual pump becomes more and more important. Comparing vendors can be a complex task. Always keep in mind that the

field of vacuum technology contains more opinions than facts, and it becomes essential to talk to a number of people who are actually using a particular pump to collect their opinions. Then, and only then, should you attempt to reach that final and crucial decision. After all, you'll have to live with that choice. Going carefully through the decision-making process described here will get you closer to the best choice for your process, but remember that there is no best pump. There is only the best pump for your process, installation, and expectations, and that choice will require a number of compromises.

Reprinted by permission by R&D Magazine, all rights reserved. Cahners Business Information. A shorter version appeared in R&D Magazine, November 2001.