

## **HOW TO MATCH PUMPING SPEED TO GAS LOAD**

Pumping speed is one of the triumvirate of quantities that make up the fundamental relationship that governs the behavior of all vacuum systems. This relationship, written as  $Q$  (gas load) =  $S$  (pumping speed)  $\times$   $P$  (pressure), should be constantly in the forefront of the mind of every vacuum technologist. Achieving and maintaining the pressure required by the process will be dependent upon the matching of the gas loads and the pumping speed. Once a system's gas loads have been assessed, the pumping speed requirements need to be considered if the process specifications are to be met. Additionally, in terms of existing systems, the same process will help in understanding the system's performance and aid in trouble-shooting when possible performance problems are encountered.

Although the  $Q=SP$  relationship is pretty handy, a certain amount of confusion can ensue if you don't stop to realize that  $Q$  (gas load) and  $S$  (pumping speed) are two different ways of defining gas flow. Gas load is referred to as mass flow while pumping speed is referred to as volume flow. This clears up a little if you think of mass flow as the total number of molecules that a pump has to deal with and volume flow as the volume of gas a pump can inhale at a given pressure where you think of pressure as the population of molecules per unit volume. If you look at a manufacturer's data sheet for a given pump, you'll see that the pumping speed specification is given in volume per time such as cubic feet/minute or liters/second. It's really as simple as that, but if you don't keep the difference between the two types of flow in mind when numbers are being thrown around, you can end up with a lot of confusion.

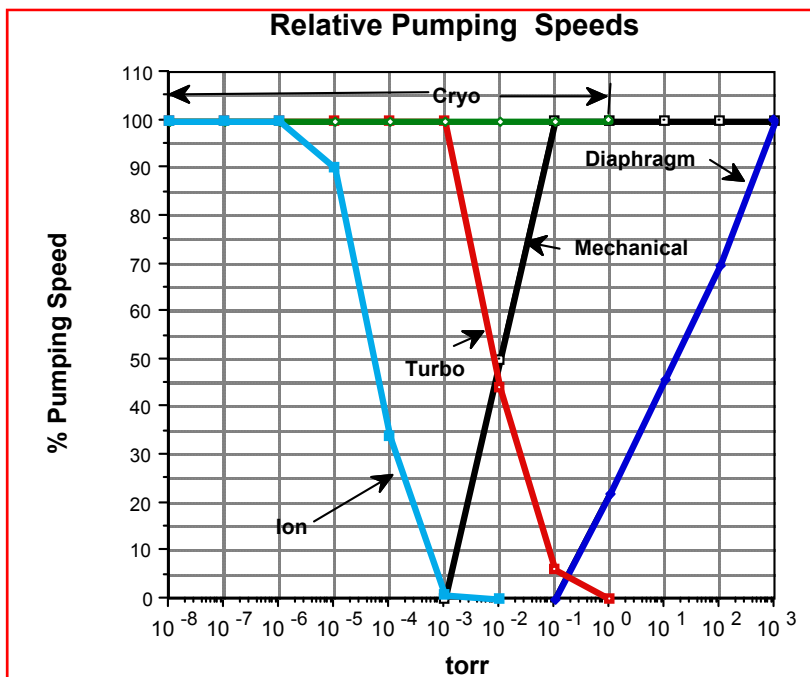
Any pump manufacturer is faced with the need to differentiate one pump, of the same type, from another. This is both logically and traditionally done by pumping speed so that a potential customer can zero in on the particular model pump that best suits the application at hand. Although this is probably the most reasonable system of differentiation, a potential danger lurks quietly here for the user. That is, the very differentiation system can generate a misunderstanding which can easily lead, in turn, to a misapplication. Once a number is stated, it tends to get mentally locked in. If, say, a pump is listed as having a nominal pumping speed of 1,000 liters/sec., there's a tendency to continue using that number for subsequent thinking and calculation.

Three separate considerations then come into play and wave a caution flag:

1. Most pumps have pumping speeds that vary with pressure,
2. Most pumps will pump different gases at different speeds, and
3. The speed of the pump itself is seldom the realized pumping speed at the system's chamber.

If all three of these considerations aren't taken into account, you can easily end up with the wrong pump in the wrong installation and a very wrong system performance. Attempting to make a  $Q=SP$  calculation with the wrong numbers for a particular application can be an application disaster. For fuller understanding, these three considerations need to be discussed separately.

The nominal pumping speed listed by most manufacturers' literature is a pump's maximum speed. This might, at first glance, seem to be mere sales hype, but it makes sense. You'd want to choose a pump that would have its maximum speed at the pressure where you needed the speed for your application. Since it's the usual practice, maximum speed specifications make as much sense as any other. In most literature, you'll also find a pumping speed vs pressure curve. This curve is immensely useful because it describes the pump's performance throughout its probable application range. If, for example, you look at the curves for most positive displacement roughing pumps, you'll see that the highest speed is shown at atmospheric pressure, but that the speed declines precipitously as the pump begins to



The relative pumping speed changes with pressure for common vacuum pumps.

declines precipitously as the pump begins to achieve its lowest attainable pressure. If the pump is intended to serve as a roughing/backing pump for a turbo-pumped system, the pumping speed curve would provide the crucial information that would tell you if it had enough pumping speed to adequately support the turbo pump and handle the amount of gas flowing out of the turbo's exhaust. Other important information to be gleaned from the pumping speed vs pressure curve(s)

would be to ascertain whether a given pump could meet and maintain a specified pressure at a specified process gas flow adequately. The importance of these curves becomes plainer when it's necessary to compare one manufacturer's pumps to another. The shape of the curve can easily help make the decision when specific speeds at specific pressures are important to the process. Pumping speed vs pressure curves can be even more important when high vacuum pumps are considered. While roughing pump speeds tend to drop off as the pressure drops, most high vacuum pumps, with the notable exception of cryopumps, have speeds that increase as the pressure is lowered until they level off at some maximum speed.

Since a vacuum process involves both pumping a chamber down and maintaining a given pressure during a process, it's vital that the pumping speeds of both the roughing and high vacuum pumps are carefully matched to the chamber volume, desorption, and process gas loads.

The pumping speed of a given pump for various specific gases becomes most important when comparing high vacuum pumps. Again, a manufacturer's pumping speed rating can be misleading. The pumping speed rating is usually provided, in an overall differentiation sense, for air or nitrogen. This is both logical and useful, but the potential user needs to interpret this specification in light of the particular application. During a pumpdown cycle from atmospheric pressure, for example, the high vacuum pump will probably never be called upon to pump air to a great extent. Consider that the gas load, during a pumpdown, below 1 millitorr or so will be almost entirely water vapor desorbing from O-rings and from the chamber's surfaces. Although comparing nitrogen pumping speeds from pump to pump is useful, it's even more important, at this point, to begin to compare water vapor pumping speeds. For example, a cryopump will have a much higher water vapor speed than a turbomolecular pump even though both pumps might have exactly the same nitrogen speed.

Obviously, pumping speed is not the only thing to be considered when choosing the type of pump to be used, but it cannot be ignored either. The same thinking must be used when choosing the manufacturer of a given type of pump. A turbo pump for a helium leak detector provides a good example. In this case, the pumping speed for helium is a key requirement since it's necessary to pump away a sudden helium gas load engendered by a leak. Turbo pumps have low helium speeds relative to their nitrogen speeds, and different designs have different helium speeds relative to their nitrogen speeds. In this case, the choice would probably be made to favor the manufacturer with the highest helium pumping speed. The same can be said of any process gas load that needs to be either removed or maintained at a given pressure during the process.

The effective pumping speed provided to the chamber is not completely a function of the pump's actual rated speed. The plumbing connecting the pump to the chamber can be even more important. This is especially true in the molecular flow regime. In molecular flow, the gas molecules are moving randomly with almost no molecule-to-molecule collisions. This means that they will only reach the pump statistically and will not be driven by pressure differential. Calculating the performance of a system, then, has to take into account the type of flow, the speed of the pump, and the connecting plumbing or tubulation. The expected gas flow through the tubulation is a function of both the diameter and length of the tubulation and is referred to as conductance. Conductance is usually given in liters/second so it is volume flow.

Calculating the effective pumping speed can be complicated, but a practical method is available that's fairly straightforward. Roughing pumps, operating mostly in viscous flow conditions are the easiest to deal with by using the conductance(C) formula:

$$C \text{ in liters/sec.} = F \times (\text{avg. pressure in torr} \times \text{diameter}^4 / \text{length})$$
$$F = 2,950 \text{ for inches or } 180 \text{ for centimeters}$$

The effective pumping speed is then calculated by this formula:

$$\text{Effective Speed in liters/sec.} = 1 / ((1/S_p) + (1/C))$$

where  $S_p$  is the rated speed of the pump in liters/sec.

Calculating the effective pumping speed in the molecular flow regime<sup>2</sup> can be a good deal more complicated, but in a well designed system where the connecting tubulation is short, the same diameter as the pump, and the same diameter from chamber to pump a simple method is to use the following system. This method uses the conductance of the pumping line's entry orifice and the transmission probability of molecules down the line to the pump.

**Maximum Orifice Conductance( $C_{\text{Orifice}}$ ) in liters/sec.**

<b>Gas</b>	<b>l/sec/cm<sup>2</sup></b>	<b>l/sec/in.<sup>2</sup></b>
H <sub>2</sub>	44.01	283.9
He	31.23	201.4
H <sub>2</sub> O	14.72	94.9
N <sub>2</sub>	11.81	76.1
Air	11.61	76.1
O <sub>2</sub>	11.05	71.3
A	9.89	63.8
Xe	5.45	35.2

The conductance of the tube is C (liters/sec) =  $C_{\text{Orifice}} \times a$

Where a(transmission probability) is calculated from the formula;  
 $a = 1 / (1 + (L/D) \times ((3L/D + 10)/(4L/D + 10)))$

where length(L) and diameter(D) can be in any units as long as they are consistent since a is based on ratios.

Once the conductance of the pumping line is calculated, the same formula for effective pumping speed as shown above can be used.

A clear knowledge of a system's gas loads and pumping speed can be the basic key to understanding its performance. The simple  $Q = SP$  calculation can then allow predictions of performance to be made during both the design stage of a new system and the ongoing surveillance of an existing system.

*References*

1. "Assessing Gas Loads in Vacuum System Design", R&D, Oct., 2000, pg 39-40
2. "Calculation of Pumping Speeds of High Vacuum Systems in Molecular Flow," G.S. Ash, Soc. Vacuum Coaters, 37th Annual Technical Conference Proceedings, (1994), pg 100-109. Reprints available from [cdemoranville@helixtechnology.com](mailto:cdemoranville@helixtechnology.com) or 508-337-5130.

*Reprinted with permission by R&D Magazine. All rights reserved. Copyright 2000. Cahners Business Information.*

*A shorter version appeared in R&D Magazine, December 2000.*

**From The Vacuum Lab of Phil Danielson, 630-983-2674  
[pdanielson@vacuumlab.com](mailto:pdanielson@vacuumlab.com)      [www.vacuumlab.com](http://www.vacuumlab.com)**