

THE DIFFERENCE BETWEEN VOLUME FLOW AND MASS FLOW

One bit of confusion that continues to bedevil and confound practitioners of vacuum technology is that there are two kinds of flow rates that inhabit and inhabit the common parlance: mass flow and volume flow. The problem is this, they both have different definitions, but there is an understandable tendency to either mix them up or assume that they are the same thing. So what's the difference?

Looking at the fundamental vacuum relationship $Q=SP$, we have

$$\begin{aligned} \text{Gas Load} &= \text{Pumping Speed} \times \text{Pressure,} \\ \text{or Mass Flow} &= \text{Volume Flow} \times \text{Pressure.} \end{aligned}$$

Volume Flow

Volume flow is most commonly used to describe and quantify pumping speeds. Most commercial sales literature for pumps will provide a pumping speed vs. pressure curve. The figure shows some examples. Although these curves are essential for understanding a pump's performance, they can be misleading if not interpreted properly. Since volume flow can be defined as the volume of gas flowing at a given pressure, it's obvious that a pumping speed comparison has to take pressure into account.

If the curve is flat over a pressure range, the pumping speed is constant in terms of volume of gas pumped, but the concentration of gas molecules in that volume varies with pressure. Looking at the pumpdown of a chamber, there are fewer and fewer molecules per volume as the pumpdown progresses, even though the rated pumping speed is constant. The point, then, is that the pump is not removing the same number of molecules per unit time as the pumpdown proceeds through the pressure range where the pumping speed is constant.

If the pumping speed curve increases or decreases in pumping speed as the pressure drops, even the same volume of gas is not being removed per time. These curves are essential in understanding a given pump's actual pumpdown performance, but they don't directly reveal a pump's ability to remove a given number of molecules, which is what the whole subject of vacuum technology is about. For that additional piece of information, it's necessary to look at mass flow.

Mass Flow

Mass flow ignores the concept of volume and deals entirely with the total number of molecules flowing per unit time. It is commonly referred to in several different ways that all describe the amount of gas per time, and the amount of gas is always either total number of molecules of gas, moles of gas, or pressure times volume. All three are essentially the same thing, but they are considered depending upon the problem being dealt with.

1. **LEAK RATE:** the amount of gas entering through a leak. The units are usually scc/sec. (standard cubic centimeters of gas at atmospheric pressure), torr liters/sec., or millibar liters/sec.
2. **THROUGHPUT:** the amount of gas a pump is expected to deal with on a constant flow basis as differentiated from a sudden aliquot or slug of gas that is injected into a system. The units are most often torr liters/sec. or torr/CFM.
3. **GAS LOAD:** the total amount of gas entering a vacuum chamber from any source such as leaks, degassing, volume gas, or any process gas deliberately introduced.

Leak Rate

Leak rate is a common concern in all vacuum practice since the whole idea is to remove gas molecules from the chamber, and gas molecules leaking into the chamber will have an obvious effect on a system's ability to reach a pressure spec. In a practical systems sense, it is not always necessary to quantify a leak rate. If the system pumps down to a specified pressure and the pumping speed is known, it can be assumed that the leak rate is at or below some rate calculated by a simple $Q=SP$ calculation.

If components or static (sealed off) systems are being considered, however, it is necessary to know exactly what the actual rate is in order to know its performance on a system or how long a static system will stay under vacuum. This is why helium leak detectors are carefully calibrated so leaks can be measured, even though they are most often used merely to find leaks so that they can be repaired.

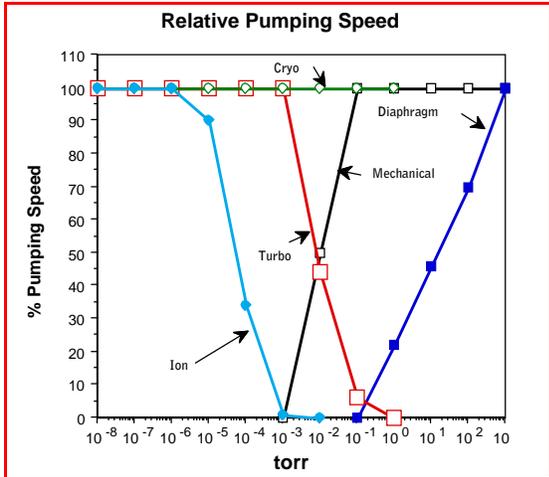
In dynamically pumped systems, the leak will be a steady gas load that flows through the system into the pump, but in a static system, the leak will allow a steady and inexorable pressure rise.

Throughput

Mass flow, when looked at as throughput, becomes an essential consideration when attempting to assess a system's performance either in the design stage or during process. This is especially true when matching type of pump and pumping speed to actual process requirements.

Figure 1, which shows volume flow vs. pressure, can be used to understand the effects of throughput on a practical system's performance.

If, for example, initial pumpdown time is of importance, the pumping system of choice would probably be a combination of roughing and high vacuum pump where both pumps would have fairly flat pumping speeds across the pressure range, since this combination would maximize their effective throughputs and result in the shortest pumpdown time. In this



case, an oil-sealed mechanical pump and a cryopump would fulfill this requirement, assuming such considerations as possible backstreaming of mechanical pump oil were not a leavening concern. Conversely, a combination diaphragm roughing/backing pump and a turbomolecular pump would suffer in initial pumpdown time due to the low pumping speed and throughput between their performance maximums. The concept of mass flow in terms of throughput is even more important when gas loads during process are considered. These gas loads can be either

deliberately introduced process gases, such as are used in sputtering processes, or internally generated gas loads such as water vapor desorbed from the chamber's internal surfaces during process. Thermally induced desorption from a radiating evaporation source would be a good example.

If any pump type shown in Figure 1 has produced a pressure that lies along a flat pumping speed pressure area, the effects of a known mass flow can be easily calculated by $Q=SP$. If the new pressure does not rise to an area where the pumping speed is lower, the pump will be able to handle the gas load and maintain a fixed and expected new pressure. If, however, the new pressure will be too high to stay within a flat area, the system pressure will be too high for the pump's throughput capability and the pressure will continue to rise. In some cases, the pump will not be able to handle the increase at all. An ion pump with a gas load that raises the pressure above 10^{-5} torr would be a good example, since the steadily lowering pumping speed and throughput would cause the pump to overheat and shut down.

Gas Load

Overall gas load is often a combination of the above and will need to be considered carefully when system performance is evaluated in terms of $Q=SP$ calculations.