A Journal of Practical and Useful Vacuum Technology

From THE VACUUM LAB

By Phil Danielson

KNOWING YOUR EFFECTIVE PUMPING SPEED

There are two important considerations when designing a new vacuum system or evaluating the performance of one that already exists. These two considerations, total gas load and pumping speed, can be considered separately for evaluation, but they are mutually interdependent when system performance is at issue. First, the total gas load from the system must be known or estimated. This is usually done by adding up all of the specific and separate gas loads such as chamber volume, material outgassing and permeation rates, surface area, process load, etc. Then, and only then, It becomes possible to evaluate the pumping requirements necessary to meet those gas loads with speed and performance to spare. This is determined by the fundamental relationship:

$$Q = SP, \text{ or}$$
$$\text{Gas Load} = \text{Pumping Speed} \times \text{Pressure.}$$

If the gas load is known, and the pressure to be obtained and maintained is chosen, it's a simple matter to calculate the minimum required pumping speed. For example, a small system with a total gas load (Q) of 1×10^{-5} torr liters/sec. that has to operate at 1×10^{-7} torr would calculate out as follows:

$$Q=SP$$
$$1 \times 10^{-5} \text{ torr liters/sec.} = S \times (1 \times 10^{-7} \text{ torr}), \text{ so}$$
$$S = 100 \text{ liters/sec. Pumping Speed.}$$

This calculation shows that 100 liters/sec. of pumping speed would maintain 1×10^{-7} torr, but would provide no performance reservoir for any possible increases in gas load. In any practical system, the gas load can't be known that well since variations will inexorably occur. Changes in humidity will cause changes to the gas load due to an increase or decrease in the amount of desorbing water vapor; a minuscule addition of contamination will increase the desorption rate, or a tiny leak will suddenly appear. The point is that the gas load cannot be known to a great degree of accuracy, nor can it be depended upon to be reproducible exactly from pumpdown to pumpdown. The solution, then, is to provide a fudge-factor of up to roughly 1.5. This would mean the pump's speed should probably be about 150 liters/sec. and that should solve the pumping speed problem. Well, not really.

The pumping speed of the pump and the effective pumping speed at the chamber are seldom the same. Since the pump is operating at molecular flow conditions where all molecular motion is random, the statistical chance of a molecule traversing the length of tubing, valve, etc., between the chamber and the pump is affected by the length and diameter of the connection. Molecular flow is defined as a molecule in motion having a statistically better chance of hitting the wall of the vacuum vessel before it hits another molecule. This means that gas flow through the connection to the pump can be expressed in a volume flow much like pumping speed: liters/sec.

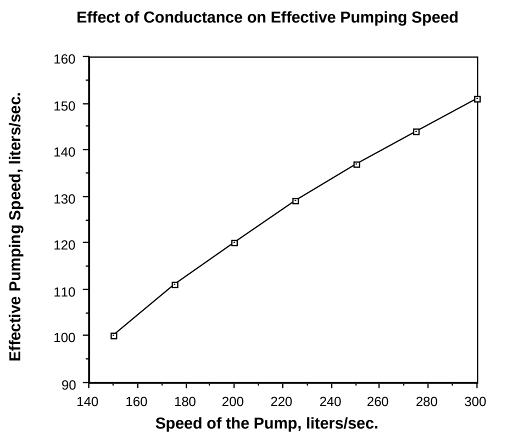
Conductance can be easily calculated for simple comparison purposes by the simplified formula:

$C = 78\ D^3/L$
D= ID of Path in Inches
L= Length of Path in Inches
C= Conductance in liters/sec.

Taking a hypothetical system, then, with a 150 liter/sec. pump, we would probably have a 2.5 inch ID tube that is 4 inches long connecting the pump to the chamber. Plugging into the above equation, we have a conductance of 304 liters/sec. Since this conductance value is much larger than the pumping speed of the pump, the first assumption would be that enough pumping speed would be available to meet the projected gas load. This, though, is not the case. Even though the conductance is larger, in terms of liters/sec., there is still an effect on the gas flow through the tubing. This raises the question of what is the effective pumping speed at the chamber since the connecting tubulation should actually be considered as part of the pump. This new relationship is expressed by the formula:

$1/S = 1/S_p + 1/C$ where,
S = Effective Pumping Speed in liters/second
S_p = Speed of the pump in liters/second
C = Conductance in liters/sec.
On a scientific calculator, $S = 1/\ [(1/S_p) + (1/C)]$

Running this calculation gives an effective pumping speed of only 100 liters/sec. at the chamber. Since we had already decided that 100 liters/sec. was just barely enough pumping speed to meet the "best case" gas flow, and that we really needed about 150 liters/sec. for "worst case," the system, as calculated, will not perform as expected to achieve 10^{-7} torr as an ultimate pressure. The most obvious next move would be to increase the pumping speed.



The figure shows the results of increasing the speed of the pump on the effective pumping speed. This apparently obvious next move, then, is obviously not a solution since it will take a pump with 300 liters/second pumping speed to provide an effective pumping speed of 150 liters/sec. at the chamber which will add both physical size and cost to the system.

If the system is already built or cannot be modified, there is no other solution to the pumping speed dilemma other than going ahead and using the 300 liter/sec. pump. On a system that is just being designed, however, the problem partially solves itself in that a pump with a pumping speed above 150 liters/sec. would have a larger inlet to allow a higher pumping speed. It would probably be a nominal 4 inch diameter. This would be about 3.83 inches ID, and would militate that the connecting tubulation would also be the same diameter and probably the same 4-inch length used for the smaller ID tubing. Recalculating for conductance using the formula given above would give a conductance of 1,096 liters/sec.

If the effective pumping speed formula is reconfigured to:

$$S_p = 1/[(1/S) - (1/C)]$$

On a scientific calculator $S_p = 1/ [(1/S) - (1/ C)]$,

To allow solving easily for the pump's pumping speed, the speed required to provide 150 liters/sec. at the chamber is 175 liters/sec.

This exercise points up the importance of knowing the actual effective pumping speed at the chamber in order to be able to match the expected chamber or process gas loads. It also demonstrates the relationship between effective pumping speed and conductance between the pump and the chamber. A further consideration is often required when increasing conductance in a design. As the diameter of the tubulation is increased, the internal surface area also increases, and this results in an increase in water desorption gas load during pumpdown which has to be met with an attendant increase in pumping speed.

Once these considerations are taken into account, the chances of having a successful design where pumping speed is matched to gas load are almost assured.

From The Vacuum Lab of Phil Danielson, 630-983-2674
pdanielson@vacuumlab.com www.vacuumlab.com