

Pumping 'Effectively'

Last time (in *Lesker Tech* Vol. 1, Iss. 2) I was deliberately evasive on two subjects: *effective pumping speed (EPS)*; and the *gas flow* a system can handle. Since these subjects are related, let's 'belly up to the bar' and deal with them squarely.

EFFECTIVE PUMPING SPEED

Remember the EPS is only vaguely related to the pump's quoted *pumping speed*. Last time I mentioned a chamber connected to 1000 L/sec pump in a way that made the EPS 20 L/sec. I'm sure no-one believes this ever happened (and my lips are sealed) but calculating a few EPSs will reinforce the notion that frittering away pumping speed is all too easy.

And the chief fritterer is . . . conductance.

Conductance (see *Lesker Tech* Vol. 1 Iss. 1) has the same relationship to a tube, elbow, valve, etc. that pumping speed has to a pump. That is, conductance measures the tube's ability to transfer gas molecules from one end to the other. So a pipe with a conductance of 20 L/sec limits the volumetric flow to 20 L/sec in either direction.

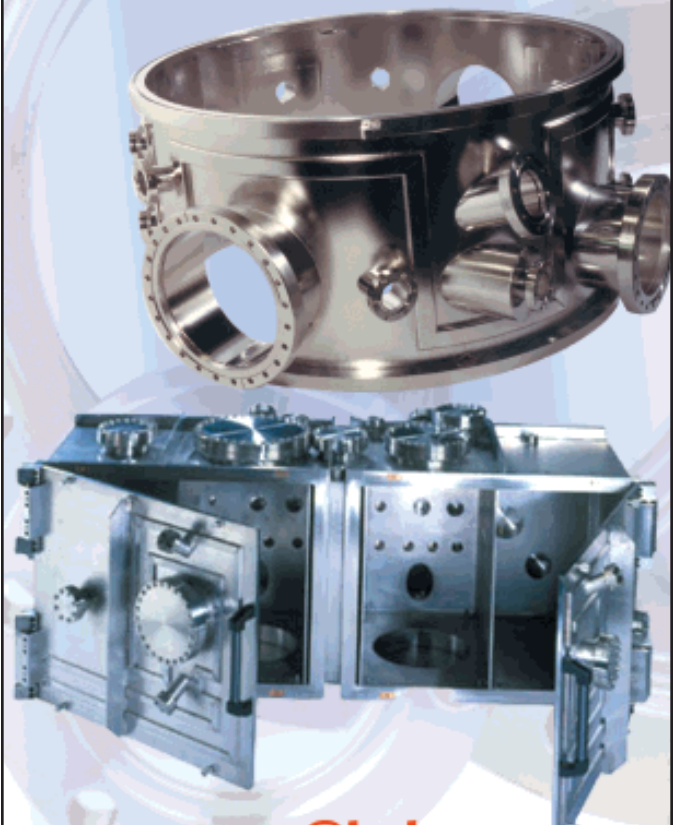
Since conductance and pumping speed are in the same units, we can combine them with some nifty arithmetic. If a tube has 20 L/sec conductance and a pump has 20 L/sec pumping speed, the EPS at the tube's open end is (fig 1):

1	$1/\text{EPS} = 1/\text{conductance} + 1/\text{pumping speed}$
2	$1/\text{EPS} = 1/20 + 1/20$
3	$1/\text{EPS} = 2/20$
4	$1/\text{EPS} = 1/10$
5	EPS = 10 L/sec

Figure 1

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Now think about the same tube connected to pumps with a 80 L/sec, 160 L/sec, 320 L/sec, and 1000 L/sec pumping speed (see fig 2):

Conductance	Pumping Speed	EPS
20 L/sec	20L/sec	10 L/sec
20 L/sec	80L/sec	16 L/sec
20 L/sec	160 L/sec	17.8 L/sec
20 L/sec	320 L/sec	18.8 L/sec
20 L/sec	1000 L/sec	19.6 L/sec

Figure 2

And, surprise! even with a 1,000,000 L/sec pump, that (expletive deleted) tube will limit the effective pumping speed to slightly less than 20 L/sec, leading us to the third great principle of vacuum technology:

The Smallest Conductance Rules.

Let us calculate the EPS for an 8" ID 1500 L/sec pump attached to a chamber by a 8" ID gate valve and an 8" ID pumping port. For simplicity we'll say the port's length and the valve's thickness are the same, 4". Since both components are the same ID and length, they will have the same conductance value.

So, how do we find a conductance?

- (1) From 'book' formulas
- (2) Using Monte Carlo methods
- (3) Looking at Sam Dushman's conductance table, or (if you're really lazy like me)
- (4) With the Vactran program.

The simplest is Dushman's table which we have reprinted (with permission) on our website. [Go to: www.lesker.com and click in the Technical Information circle. When the menu appears, click on Technical Notes, then Calc. Conductance, and when you scroll down, you'll see it.] http://www.lesker.com/cfdocs/newweb/Technical_Info/Conductance_Calc.cfm

Following the instructions given there, I find the conductance of a 4" long 8" ID port or a 4" thick 8" ID gate valve is ~2464 L/sec. When I add these components to the 1500 L/sec pump I get (see fig 3):

1	1/EPS = 1/Valve cond. + 1/Port cond. + 1/PS
2	1/EPS = 1/2464 + 1/2464 + 1/1500
3	1/EPS = 4.058 x 10 ⁻⁴ + 4.058 x 10 ⁻⁴ + 6.667 x 10 ⁻⁴
4	1/EPS = 1.478 x 10 ⁻³
5	EPS = 676 L/sec

Figure 3

Now, before anyone complains that I should have treated the valve and port as one tube with an 8" ID and 8" long, I'll say this: yes I could, and found the EPS of 835 L/sec. But I choose to put the worst face on a system's EPS rather than the most optimistic. That way, some of my surprises are pleasant.

EPS Conclusions

Well, how nasty do you want me to be? Unless every tube and component is as short and wide as possible, with minimum bends, you are throwing away a vacuum system's most vital resource—effective pumping speed.

And before you tell me you don't care, check out the chamber's base pressure or the maximum gas flow you can inject into the chamber while staying below some upper pressure limit. Both are coming right up!

GAS FLOW

Earlier (in *Lesker Tech* Vol 1, Iss. 1) I described *outgassing rate* without giving an example. Here, to calculate a chamber's base pressure, I'm going to ignore all other additions to the gas loads (from leaks, backstreaming, permeation, etc.) and concentrate only on the outgassing from the chamber's internal surface area, which I will say is 8500 sq in. (25190 cm²).

It is prudent to use the outgassing rate for a poorly cleaned stainless steel. O'Hanlon's book *A User's Guide to Vacuum Technology* quotes a number of rates. I will select 2×10^{-8} torr.L/sec/cm² (2.67×10^{-5} W/m² after 10 hours pumping) since this is one for a stainless steel poorly cleaned. The total gas load is found as rate x area:

$$\text{Gas Load} = 5 \times 10^{-4} \text{ torr.L/sec}$$

So, if the EPS is 676 L/sec, the chamber's base pressure is found as 5×10^{-4} torr.L/sec \div 676 L/sec.

$$\text{Base Pressure} = 1.9 \times 10^{-3} \text{ torr}$$

Now that division (gas load \div EPS) will also calculate the maximum gas flow permitted if the chamber must stay below a given pressure. The only difference is, with gas flow there are usually unit conversions that must be made.

Gas flowing **into** a chamber is often measured in "skims" (sccm or 'standard cubic centimeters per minute' to the uninitiated). Gas flow **from** the chamber is often in torr.L/sec. So, we must relate sccm to torr.L/sec. (see fig 4)

atm to torr	- x 760
cc to L	- x 1000
min to sec	- x 60
<i>(but remember it's "per" so you divide)</i>	
Example:	
100 sccm	= 100 x 760/1000 x 1/60 T.L/sec
	= 1.27 T.L/sec

Figure 4

Working Pressure

Suppose we have a chamber with an EPS of 676 L/sec. And let's suppose further, we are told the required gas flow is 100 sccm and the pressure must not exceed 1×10^{-3} torr with the gas flowing. Can this be done? From figure 4 we know that 100 sccm \equiv 1.27 T.L/sec. The working pressure is, therefore gas flow divided by EPS ($1.27 \text{ T.L/sec} \div 676 \text{ L/sec}$)

$$\text{Working Pressure} = 1.9 \times 10^{-3} \text{ torr}$$

Clearly, under the conditions specified, the system cannot maintain the required 1×10^{-3} torr. But I hear that grumbling in the background, "If you had calculated the port and valve conductance as one unit we wouldn't be in this mess." Au contraire! Even if I claim the EPS is 835 L/sec, I still get ($1.27 \text{ T.L/sec} \div 835 \text{ L/sec}$)

$$\text{Working Pressure} = 1.5 \times 10^{-3} \text{ torr}$$

Indeed, here's a way to calculate the EPS of any system that reaches some low base pressure*. Connect a calibrated mass flow controller to the system and measure the base pressure with no gas flowing and at various flow rates up to the maximum chamber pressure for the pump. Each pair of flow rate vs pressure values can be converted into a true effective pumping speed. The results will probably have

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a relatively stable value for a range of pressures but then slowly decline as the maximum chamber pressure is reached.

* The statement "... reaches some low base pressure" is meant to alert you to one critical point missing in all these calculations. We are ignoring the additional gas load from all other sources (outgassing, virtual leaks, real leaks, backstreaming, evaporation). If this part of the gas load is sufficiently high that a low base pressure can't be met, then gas flow and pressure calculations must be modified to allow for two gas sources: the chamber's regular gas load and the inlet gas flow. I'm not going to explain how this modification is made since the only sensible course of action is to fix the chamber's problems.

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