Lesker Tech "...vacuum science is our business."

Volume 3, Issue 1 March, 2004

# Pumping Up Your Applications

## Part 1

### Introduction

The most frequently asked vacuum technology question has to be, "What pump should I use?" When asked this, I sigh a lot. The subject has enough tributaries, secret passages, cliffs of insanity, and fire-spurting forests to test the Dread Pirate Roberts.

Without a detailed understanding of your application, no one can answer. Vague, hand-waving descriptions like "Oh, I have this chamber and need to pump some gas" (Honest! That was the opening line in one conversation) just don't even come close to giving it the old college try.

When discussing pumping applications, it's much easier to classify pumps than applications. Most vacuum technology books recognize this and explain pumping mechanisms in exquisite detail. But, no matter how tantalizing to the vacuistic cognoscenti, most real vacuum users find these details a yawn-a-minute. And they're not wrong. The trick to avoiding: *instant pump seizure*; *spectacular pyrotechnics*; complete *process failure*; or their own *early demise* from inhaling toxic gases **isn't** an encyclopedic understanding of pump mechanisms. It's:

(a) knowing all about the application
(b) selecting an appropriate pump
(c) protecting the pump as much as possible

<u>but above all</u>. . .

(d) protecting yourself

So, I'm trying something new—***applications classifications.***

Unfortunately, I can't just jump in before I add water to this pool! And my editors (yes, they now come in plural form—talk about millstones!) insisted the first draft was both too long and incomprehensible. Looks like another trilogy. However, all the writing's just about done and any publishing delay is squarely on editorial shoulders.

This first issue deals with different ways of classifying pumps that, with luck, gives some insight into broad applications vistas. Obviously, I can't completely ignore mechanisms and one classification method (see Table 1) is a list of mechanism names.

In part 2 of the trilogy, I'll repeat Table 1 and examine each entry's applications claims-to-fame. Finally, in part 3, we'll get to real *applications classifications*. But be warned, that issue invokes scads of chemistry. Oh, come on, stop whingeing! It might have been physics.

## Classifying Pumps

While this list of 'ways to classify' pumps may not be comprehensive, it's reasonably broad:

- **A.** Pumping mechanism details
- **B.** Pumping speed and ultimate vacuum
- **C.** Names of mechanisms
- **D.** Operating pressure range
- **E.** Capture vs Transfer
- **F.** Wet vs Dry
- **G.** Normal vs Corrosive

Since **A** (pumping mechanism details) won't help, I'll ignore it and start by haranguing you about **B** (pumping speed and ultimate pressure). I'll follow that with Table 1 that combines **C** (mechanism names) and **D** (operating pressure range).

Then I'll discuss three different classifications, methods **E**, **F**, and **G**, that are all mechanism-related but have good applications implications. It's a little strong to use *vs* as the separator in the titles since I'm not suggesting use 'this' type and never 'that'. It's more about *choosing horses for courses*. . . getting the right pump for 'this' job, whatever 'this' happens to be.

### B — Pumping Speed and Ultimate Pressure

Clearly, these are primary criteria for classifying pumps. If you don't know the pump's pumping speed and ultimate pressure, there's little hope you can match it to any application.

But we dealt with them in *Lesker Tech Vol 1 issues 1, 2 & 3* where I emphasized the true significance was not the manufacturers' quoted values but how those values translate into **Effective Pumping Speed** and **Base Pressure** for your chamber. And you do know how to make those translations, right?

### C & D — Name That Mechanism

With a little shoe-horning, pump mechanisms can be split into four pressure regimes (Table 1). Mechanisms with names that appear in two pressure regimes usually have design changes or, in patent legalese, different physical embodiments.

(While describing the **E**, **F**, and **G** classifications, I refer to these mechanism names and note the characteristics that limit or extend applications for each mechanism. Also, in Table 1, you'll see cryptic notations such as (oil), (rdp), etc. The reasons for these identification will become clearer as you read classifications **E** and **F**.)

**Table 1 — Pumping Mechanisms**

| **Coarse** (760 – 1 torr) | **Rough** (760 – $10^{-3}$ torr) | **High Vacuum** ($10^{-4}$ – $10^{-8}$ torr) | **UHV** ($10^{-9}$ – $10^{-12}$ torr) |
|---|---|---|---|
| *Rotary vane (oil)* | *Rotary vane (oil)* | *Diffusion (oil)* | *Ion (rdp)* |
| *Liquid ring (water)* | *Rotary vane (dp)* | *Turbo (ceramic bearing–dp)* | *Getter Evap (rdp)* |
| *Screw (dp)* | *Rotary piston (oil)* | *Turbo (mag.lev bearing–rdp)* | *Getter Non-Evap (rdp)* |
| *Hook & claw (dp)* | *Recip. Piston (rdp)* | *Cryogenic (rdp)* | *[Turbo (rdp)]* |
| *Steam ejector (water)* | *Scroll (rdp)* | *Molecular drag (dp)* | *[Cryogenic (rpd)]* |
| *Venturi (air)* | *Screw (dp)* | *Hybrid-Turbo/Drag (dp)* | |
| *Diaphragm (rdp)* | *Cryosorption (rdp)* | *Hybrid-Turbo/Drag (rdp)* | |
| | *Roots (dp)* | *Getter-Evap (rdp)* | |
| | *Vapor booster (oil)* | *Getter-Non-Evap (rdp)* | |

Remember, I'm just introducing the mechanism names in this table. We'll return to this table in part 2 of this trilogy to tease out further applications details.

## E — Capture vs Transfer Pumps

As the name indicates, a *capture* pump actually holds on to the gas it's pumping. And the immediate question is: what happens when it fills up? Well, different gas capturing mechanisms have different answers: re-generation; re-building; re-placing exhausted components; and, occasionally, tossing in the trash.

But what if I'm capturing something particularly nasty. . . something that's either a significant health hazard or explosive? It's a very good point and my personal 'do not capture' gases include ozone and carbon monoxide.

By contrast, a *transfer* pump takes in gas at one pressure and exhausts it, using some compression mechanism, at a higher pressure. One hopes no gas is retained in the mechanism and, if you are pumping nasty gases, that you have excellent connections between the pump's exhaust and the outside world or, better yet, a 'burn box' (otherwise known as an *exhaust gas abatement system*).

For reasons discussed in the next division (*Wet* vs *Dry*), most capture pumps are 'cleaner' than many transfer pumps. So, folks wanting particularly 'clean' environments might opt for capture pumps. But it's not a slam-dunk, universal choice. The selection between capture or transfer is, or should be, applications-driven.

### Examples of *Capture* vs *Transfer* Choices:

(a) With the exception of the diffusion pump, there's something solidly mechanical happening in all *transfer pumps*. That implies they vibrate a little or a lot. Most *capture* pump mechanisms (but not the major group, cryogenic pumps!) have no moving parts. So, for anything involving *optics*, you'd probably look first at *capture* mechanisms that won't jiggle the system. Interestingly, electron microscope manufacturers opt for diffusion pumps despite their 'old technology' and well-documented drawbacks.

(b) Car headlight reflectors are made by flash evaporating aluminum onto formed plastic parts in a batch coater. For cost-effective production, the production cycle (atmosphere - $10^{-5}$ torr - atmosphere) can only be a few minutes. The high gas load conditions make a *capture* pump an unlikely first choice.

(c) In contrast, the surface science community has gas loads close to zilch. They operate in UHV and are distinctly upset when asked to deviate from it. A capture mechanism like the ion pump, which is not noted for its staggering gas throughput, is right up their alley.

But I can't leave this subject without re-telling my dirty capture pump story. (*Sensitive and non-adult readers should close their eyes while reading this*.) If you don't know what an RGA is, no worries. Just accept it has an ionizer with insulators separating high voltage and grounded electrodes. Many years ago, a NASA customer complained the RGA we'd sold him didn't work because the ionizer was shorting to ground. On the bench and when first mounted in the chamber, the RGA checked out fine. But by the time the chamber had pulled to a low pressure with its *capture* ion pump, the ionizer was shorted. When he vented the chamber and pulled the RGA to check what went wrong, he was very puzzled. The resistances were OK.

We played telephone diagnostics, testing possibilities. Our best speculation was, the RGA's mounting flange warped (very slightly) under vacuum and the RGA's long 'moment arm' allowed the ionizer to touch the nearby chamber wall. Yeah, we thought it was crazy too.

In straw-clutching desperation, I had him describe the chamber's mechanical layout in detail and learned the ionizer was right over the pumping port—and it hit me. Titanium, sputtered during ion pump operation, was exiting the pump port and coating an ionizer insulator with a conducting film. Venting converted the Ti to oxide and the short circuit disappeared. The customer installed a thin metal plate in the line-of-sight between ionizer and pumping port and, as my Brit mates claim, "Bob's your uncle."

## F — Wet vs Dry

For vacuum technology newbies I'll explain: *wet* vs *dry* in this context is not related to 'wet ´n dry' ports in your Shop-Vac. A wet pump uses a low vapor pressure oil in the pumping mechanism. A diffusion pump, for example, uses oil vapor flow as the pumping mechanism while a rotary vane pump uses oil to lubricate and seal sliding joints between vanes and casing. So, in any wet pump, oil liquid and vapor co-exist in the pump's vacuum volume.

And what's wrong with that? Well, nothing. . . except you usually can't keep them in the pump. Like Mary's little lamb, they wander—the liquid by *surface* creep and the vapor by *backstreaming*. Is this bad? Depends on the application!

While *dry* pumps have no oil in the vacuum volume, there are *dry* pumps (**dp**s) and really dry pumps (**rdp**s). The **dp** doesn't use oil/grease to seal but does use it to lubricate gears or bearings outside the vacuum volume (as in roots pumps, screw pumps, claw pumps) or at the pump's high pressure end (as in ceramic ball-bearing turbo pumps). In the first case, shaft-seals prevent vapors re-entering the vacuum volume. In the second, the pumping mechanism prevents the vapors traveling backwards.

By contrast, **rdp**s don't have lubricants anywhere close to the vacuum volume. Capture pumps fall into this category, as do transfer pumps using PTFE (Teflon®) as a sliding lubricant (as in scroll pumps, reciprocating piston pumps) or as the gas seal (as in diaphragm pumps). But solid lubricants lack the lubricity of fluid lubricants and life-times are not as long.

Some turbo pumps, take a different approach to **rdp**-ness. For these models, the main bearings are *not* only not lubricated, they're *not installed*. Huh? Yeah, the high-speed rotor is magnetically levitated. And before you ask, reputable pump manufacturers build in dry-lube ($MoS_2$) back-up ball bearings. Since these 'real' bearings are only in-play when the pressure suddenly goes kitty-wonkers, their relatively short life (maybe 500 'touch downs') shouldn't limit the turbo pump's operational longevity.

As you might expect, it's tough to distinguish **dp**s from **rdp**s since manufacturers of both types shout, "Ours' are *dry* pumps!" And, to a large degree, they're right. But when discussing *dry* pumps, dyed-in-the-wool skeptics and **rdp** salesmen would agree with Robbie Burns (if they understood him), "The best laid plans of mice and men oft gang agley."

### Examples of *Wet* vs *Dry* Choices

(a) We sell bits and pieces to a company making thermostats. They evacuate a whole bunch of 1m long, narrow bore tubes sealed at one end. Still under vacuum, the open tube ends are dipped under oil and the chamber is vented. Atmospheric pressure forces oil to fill each tube after which the open end is permanently sealed. The thermostat is really a variable set-position pressure switch powered by the differential thermal expansion between oil and metal. As is obvious, this is a pretty oily application. Choosing *dry* pumps would be daft.

(b) A research group near us deposits precise 'spin valve' films, some less than 10Å thick. Phrases like 'spin valves' and 'giant magneto-resistance' are bandied about by these smart guys who helped turn computer hard-drives from megabytes to terabytes in ~20 years. Surface oil would be a major spanner in the works. This is an obvious *dry* pump application.

(c) A South African company contacted us about 'cooling' lettuce to keep it crisp. This involves moistening the lettuce and using water's huge *enthalpy of vaporization* to locally cool each leaf as the water evaporates under vacuum. Clearly, massive quantities of water vapor must be pumped. High capacity *dry* pumps, if they exist, are probably stupefyingly expensive. Oil-sealed pumps will corrode and trap water in a vapor/liquid cycle, ruining the pump's ultimate pressure. This application is best approached with a special kind of *wet* transfer pump—either a water-sealed liquid ring pump or a steam ejector.

## G — Normal vs Corrosive Pumps

You don't have to be a chemical whiz to recognize—pump an aggressive gas and the pump's lifetime depends on how quickly its critical bits are destroyed. Pump manufacturers, wishing to sell pumps that cause them least future hassle, offer versions with some degree of protection. However, no matter what level of protection is built-in, expecting a pump to resist everything you care to throw at it is what we behavioral psychologists call, thinking 'outside the solar system'—as in 'space cadet'.

### Corrosion Resistant Capture Pumps

Before writing this, it hadn't occurred to me—capture pumps aren't rated for chemical resistance. Why? Well, possible reasons are:

a) Cryo pumping mechanisms operate at low temperatures. As Svante Arrhenius announced in an Uppsala bar—for each 10ºC drop, reaction rates are roughly halved.

Can't say if that postulate piqued other patrons' interest but it helps here. At -193ºC (80K), the reaction rate is ~$2^{20}$ or $10^6$ less than at room temp 20ºC (293K). Perhaps corrosion of a cryo pump's critical parts is just too slow to matter.

b) Titanium sublimation pumps and getter pumps use highly reactive metals or alloys to chemically react with the gas. Since corrosive gases are necessarily reactive, as far as this pumping mechanism is concerned (to borrow a politically charged phrase)—bring 'em on!

c) The ion pump mechanism used for UHV conditions operates effectively only at very low pressures and gas loads. Corrosive conditions imply lots of gas so this mechanism isn't likely to see corrosive conditions.

d) I skipped that part of the brochure.

## Corrosion Resistant Transfer Pumps

### Rotary Vane and Rotary Piston

There are no standards covering chemical resistance—each manufacturer devises its own anti-corrosion strategies. Most major manufacturers have no name for their 'normal' level of protection. What I'm calling the 'chemical' level, is variously named: corrosive; corrosion resistant; corrosion protected; chemically resistant; etc.

Only one manufacturer I can find identifies 'plasma' level protection. But plasma processes are too frequently used for other manufacturers to ignore. I suspect they build corrosion resistant pumps to operate under plasma conditions too but decided to build just two pump types, not three. One iconoclastic manufacturer (a Brit, of course) builds only one type of pump. For corrosive conditions, the recommendation is fill the pump with an inert fluid.

Without openly stating it, vendor literature suggests corrosion resistance includes: special coatings for shaft bearings; Viton® O-rings and gaskets; gas ballasts; gas bubblers; and inert fluids. (The sidebar addresses the last three.) There is murmuring about inert coatings applied to internal construction parts, but it's only gossip.

## Ballasts, Bubblers, & Inerts

**Gas ballast** adds gas, often air but sometimes inert, into a late position in the pump's compression cycle. The idea is to raise the pressure in the 'just-about-to-be-exhausted' segment of gas. With luck, any vapor stays vaporized and is swept out by the larger gas flow. Gas ballast helps remove: (a) solvent vapors that ruin ultimate pressure and cause loss of lubrication by dilution and; (b) water vapor that equally ruins ultimate pressure and rusts the internal parts. But it's not a free ride. With the ballast open the ultimate pressure rises a factor of ~10.

The **gas bubbler's** path doesn't enter the pumping mechanism at all. Inert gas bleeds into the bottom of the oil casing. While the bubbles help purge dissolved gases from the oil, the bubbler's main purpose is diluting the rubbish exiting the pump's exhaust valve. When pumping spontaneously combustible gases like phosphine or arsine, or highly flammable gases like hydrogen or methane, an inert gas bubbler is a very good idea. It both dilutes the nasty and promotes increased mass flow towards the burn box. This is a free ride since the bubbler has no effect on the pump's ultimate pressure.

**Chemically inert fluids** replace hydrocarbon oils (HC) in applications where the latter's flip-side characteristics leave 'room for improvement' (why does that remind me of school reports?) when pumping:

- Reactive process gas—will attack HC fluids
- Oxygen—forms explosive mixtures with hot HC vapors
- Spontaneously flammable gas—with hot HC oil does one of those table-side flambé numbers so beloved in pseudo-posh ristoranti.

Only perfluoropolyethers (PFPE) pump fluids are totally inert, completely unreactive, won't explode, and can't catch fire. So, when faced with an application like those above—find some Fomblin® PFPE fluid fast.

*As an illustration: a Pump Repair technician once asked me to share a moment over a customer's seized rotary vane pump. When the drain plug was opened, no oil ran out. Great! Our message about draining pumps before shipping had worked. But when the tech slipped off the oil casing, the internal pump parts were surrounded by a green, smelly, massive quivering glob. "It must be jelly 'cos jam don't shake like that."*

### Turbo Pumps

Manufacturers building turbo pumps for corrosive applications are equally reticent, so I'm stretching here. Are rotors or stators coated with something? It seems unlikely. Are different materials used in chemical and regular series? Hmmm. . . maybe once, long ago, there were aluminum and stainless steel pumps of identical design, but now? I don't think so.

One common turbo pump anti-corrosion feature is a gas bleed directed at the motor and bearings. Fresh inert gas, entering through the bleed port, prevents the diffusion of corrosive gas to these critical surfaces. Chemically resistant versions of both greased-bearing and mag-lev-bearing turbo pumps use this strategy. Obviously you don't want the grease to react, but why do this for the mag-lev? Again, no-one's saying. I've not heard that using the bleed inflicts an ultimate pressure penalty but obviously the foreline pressure increases.

### Examples of *Normal vs Chemical*

Classifying applications is, to some degree, a tabulation of new and exciting ways to destroy expensive pumps with arcane, hazardous chemicals or particles. Examples of *normal* vs *chemical* application are really the heart of part 3 of this trilogy, so that's where they'll appear.

That's it! No dramatic ending, no flashing lights, nor sirens. But you are now primed for *Lesker Tech Vol 3 Issue 2*—a detailed look at the applications implicit in Table 1. And "Lang may your lum reek" (attribution unknown, but certainly not Robbie).

### Future Lesker Tech Subjects

Many readers responded with good LT topics that I've consolidated and added to the list. One, however, was a twist on all those LTs about removing contamination. The writer asked—what are common sources and the chemical nature of contamination and what can one do to avoid them?

Also, the 'academic' responded. He picked up self-recognition clues from what I'd written and claimed I had totally mis-represented his position. Moi? Misrepresent? Oh, say it ain't so! (*Now, let's see, he's stated he can't stand to read my shtick, yet he recognized my word-portrait. For ½ your final grade discuss: Self- and non-self-referential paradox*).

But he too had a question that fits this contamination topic—is there a 'cheap' test of surface cleanliness? (Ah, so he's one of *those* academics.) He'd been told, "If the surface wets with water, it isn't contaminated." But with tests he showed the premise fitted a status my mother used to call, "Neither use nor bloody ornament!"

My question is, while there is merit to this pro-active approach to contamination issues, is it of sufficient general interest to write about again? Give it your gladiatorial thumbs down (by **not** writing me at techinfo@lesker.com and saying, yeah! yeah!) and it's gonzo! Again, many thanks.

## Lesker On The Road

| Date | Event | Location | Booth |
|---|---|---|---|
| Mar 17-19 | Semicon China | Shanghai, China | 7637 |
| Mar 22-24 | APS (Amer Physical Soc) | Montreal, Canada | 705 |
| Apr 13-15 | Spring MRS | San Francisco, CA | 603 |
| Apr 19-24 | Hannover Messe CEMAT | Hannover, Germany | Hall 05/E28/2 |
| Apr 20-21 | ICMCTF | San Diego, CA | 20 |
| Apr 26-27 | SVC | Dallas, TX | 803 |
| May 3-5 | ANL-APS Users Meetings | Argonne, IL | |
| May 25-27 | SID (Soc for Info Display) | Seattle, WA | 247 |

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As always, your comments and suggestions are valued and welcomed.

Kurt J. Lesker Company