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

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How Low Can You Go? Part 5

Put on Those UV-defying Blues Brothers Shades.

New Readers - **Don't start here.** Go back to *Lesker Tech* Volume 1 Issue 4 where this stuff started as a trilogy (Ha! A 5-part trilogy!). Also, my editor says this one's so far out in left field, it will only interest the academic few. But. . . it's about outgassing. Isn't *everyone* interested?

Introduction

Wow! Did *Lesker Tech* Vol. 2 Iss. 2 cause a brouhaha!

To paraphrase - and distort to suit my purposes - two readers scolded me for claiming UV light was useless for outgassing chamber walls. I didn't say that! I would never say that! It isn't true! Short wavelength UV has enough energy to break chemical bonds.

But the furor made me reflect and . . . what I wrote wasn't crystal clear. Let me re-phrase that . . . I didn't define the type of lamps I was talking about and what's written is, therefore, subject to misinterpretation. Aw heck, let's face it–I screwed up!

In consequence, I'll take one final stab at describing light as an outgassing agent with emphasis on the ***lighters*** and what makes them tick.

I'll start with words about wavelength so we're all nodding our heads at the same frequency when UV is mentioned. But, since it's easier to understand the concepts, this section is mostly about visible and IR wavelengths.

Then I'll do a mini-tutorial on lamps–the obvious *lighters*–emphasizing UV light output or lack thereof.

Finally, and this is a first, I'll show results illustrating UV degassing. Let me hasten to add, these results are from **Tom von Alten**, one of the two readers. Tom sent data taken during routine daily operations of his system. The data are, therefore, unadorned, untweaked, and unoptimized. . . the best kind!

Wavelength

To talk sensibly about light or, more generally, electromagnetic radiation, we have to talk wavelengths. Wavelength is, of course, the parameter that distinguishes: yellow light from green light; blue light from x-rays; or, putting it in more gut-wrenching terms, your microwave oven from your toaster. And to talk wavelength we have to talk units. I'll use nanometers (nm). If you like angstroms, multiply every number I give by 10. If microns are your bag, then divide by 1000.

Visible radiation is from ~400nm (blue) to ~700nm (red) so anything a bit less than 400nm is UV radiation and anything slightly greater than 700nm is IR radiation. However, don't cut the limits too fine. Radiation at, say, 390nm is in the UV range all right, but each photon just doesn't carry enough oomph to break interesting chemical bonds. You probably need to get down to 320nm or so to start cutting the chemical mustard and breaking C–C bonds.

Similarly, but differently, just over the red line, photons carry the maximum IR energy. Trouble is, assembling lots of 710nm photons in one place is a challenge. For example, a filament at 2200°C, puts out ~96% of its energy between 700nm and 10,000nm. However, it only puts out 0.5% between 700nm and 720nm. Its peak energy output (the wavelength at which most of the photons are released) is around 1172nm.

For the theorists out there, yes, I'm assuming a blackbody filament and I'm using a wonderful little applet:

http://thermal.sdsu.edu/testcenter/javaapplets/planckRadiation/

[For the practiquists out there, first: how do you like your new collective name? and second: don't worry about this blackbody stuff. It's explained in the next issue when I discuss sample heating.]

The applet lets me make other pronouncements about 2200°C filaments. Roughly 3% of the energy released is between 400nm and 700nm. So, lamps with 2200°C filaments are much better heaters than *lighters*. And UV content? Between 100nm and 400nm the fraction of total energy emitted is 2.8×10^{-4} . . . that is, their UV emission characteristics are pathetic.

Shining a Light on Lamps

This is a seriously limited discussion of lamp variations. If I went into every niche lamp manufacturers claim make their lamps different from the other guy's, this would be a 10-part trilogy. I'm not saying the lamps aren't different but I'm only giving you an introduction to UV-assisted outgassing. Selecting appropriate lamp types require much more investigation than given here.

Lamps divide into two groups:

1. Filament lamps (also called *incandescent*)
2. Discharge lamps (also called *arc*)

I won't define 'discharge' but you should know it involves making positive and negative species that make the gas electrically conducting.

The two groups are further sub-divided:

1. Filament lamps

A) Vacuum

B) Gas Filled

C) Halogen

2. Discharge lamps

A) Fluorescent

B) Neon

C) Xenon

D) Sodium

E) Mercury

F) High Intensity Discharge

Why do so many different types exist? Well, it's all about getting more photons in the visible range and getting more photons per watt. A report prepared for the Energy Efficiency and Conservation Authority of New Zealand shows an interesting comparison.

Lamp Type	Efficacies (lumens/W)
Incandescent	<20
Mercury Vapor (High Pressure)	50
Mercury Vapor (Low Pressure Fluorescent)	80
Metal Halide (Mercury Vapor)	90
Sodium (High Pressure)	120
Sodium (Low Pressure)	150

Filament Lamps

1A. Vacuum


Ordinary Lamp.

Ordinary domestic lamps have tungsten filaments raised to moderately high temperatures in a transparent (at visible wavelengths) vacuum envelope. The temperature is a compromise. Tungsten's vapor pressure increases with temperature which means the filament evaporates faster, coats the envelope walls (reducing light output), and eventually 'blows'. Clearly, the consumer doesn't want this, so the filament temperature must be low. But low filament temperature gives a very yellow light and consumers want white light.

Vacuum incandescent lamps, as suggested by the 2200°C filament data above, are reasonably efficient thermal sources. But they are not used for vacuum bakeout because even a 100W lamp takes up so much volume. These lamps are only installed in a vacuum chamber to illuminate something that moves . . . are you into watching dinner rotate in the microwave oven too?

1B. Gas Filled

A high pressure inert gas, argon or xenon, added to a regular filament lamp allows the wire's temperature to be raised. The light gets noticeably whiter but, again, this type attracts no attention from vacuum designers.

1C. Halogen.

It's obvious–to improve the light's whiteness, we must raise the filament's temperature. But how do we avoid the envelope's coating getting thicker quicker and the lamp starting to flicker quicker before rapidly going permanent bye-byes?


Halogen

Let's digress. I'll bet everyone has an opinion about *fluorides* added to drinking water and toothpaste. Those who do laundry might know Clorox 1 uses *chlorine* as a bleach and we all know common salt is a *chloride*. The more medically inclined will recognize *iodine* as a 'tincture' or a component in 'Betadine' skin disinfectant. And the medicinal uses of a *bromide* are legion (and probably apocryphal). Fluorine, chlorine, bromine, and iodine are all *halogens* and, in their elemental state, are a highly reactive, nasty bunch - the chemical Kray twins.

But, hold the phone! Add iodine to a tungsten filament lamp and all sorts of wonders happen. First; iodine (I) and tungsten (W) react at high temperature; second; the product is volatile; and third (and quite fortuitously); the reaction is reversible. That is,

$$W + 2I_2 \leftrightarrow WI_4$$

goes to the left at very high temperatures and to the right at just high temperatures.

So, iodine reacts with the tungsten film on the envelope to form WI_4 vapor. These molecules bounce around until they contact a super-hot point where they promptly break into component atoms and deposit tungsten. And where's that super-hot spot? Yep, you've got it, right where the filament is thinnest.

In other words, WI_4 vapor breaks down and deposits tungsten in just the right place to restore the filament's thinning diameter to its original value. These devices, known as *tungsten-halogen* or *quartz-iodine* lamps, are small, high powered, efficient generators of thermal energy and are used extensively in vacuum as bakeout **heaters**.

And just why have I taken all this space on a *heater* when describing *lighters*? Well, in *Lesker Tech* Vol. 2 Iss. 2, I was trying to make the point that tungsten halogen lamps, while brilliant white, are still filament lamps. If I assume they operate at 2700°C (where tungsten's vapor pressure is mid 10^{-5} torr) the handy-dandy applet shows the fraction of total energy between 100nm and 400nm is ~0.2%. I regard that as decidedly unspectacular UV performance. For UV degassing applications, halogen lamps are not *lighters* at all.

Discharge Lamps

2A. Fluorescent


Fluorescent

If you take a mixture of mercury vapor plus low pressure argon and put a reasonable high voltage across it, a discharge forms and electrons are generated. Under the voltage's influence, the electrons accelerate until they slam into mercury atoms. This promotes the mercury into an unstable, electronically excited state which, on returning to ground state, releases excess energy as UV photons. Phosphors coating the fluorescent tube absorb the UV and re-radiate (fluoresce) in the visible at a color determined by their chemistry. The manufacturer tailors the fluorescent's 'warmth' or 'coolness' by choosing the right phosphor mix.

The old idea of a T-12 standard 4 ft long, 1½″ diam. 40W fluorescent tube has been blown out of the water. Nowadays, there's a huge variety of shapes, wattages, and sizes fitting the 'Edison Screw' socket. (Do UK's bayonet fittings have the same variety?) My house has three such devices. I just hope they're energy efficient because they surely have no other desirable properties: the regularly shaped bulb in a table lamp has a horrible yellow hue; and two 'floods' in the kitchen take two minutes to reach full illumination.

From messing with photo-sensitive chemicals eons ago, I noted that normal fluorescent tubes emit tiny amounts of UV. In Sadie's Sans-Clothes Sunning Saloons, the lamp tubes are made of materials that 'up' the UV ante. But, as you know from your last visit to Sadie's, these lamps generate little in the way of heat. So, they are not heaters and the relatively low UV output (and huge size) of a tanning bed lamp array means they're useless as *lighters* too.

2B. Neon

Neon

You don't have to visit Las Vegas to know exactly what neon lights are. To many, neon spells their favorite German words: Busch, Schlitz, Pabts, and Open. If you do visit Vegas, ignore the neon siren's lure and book seats at *Cirque du Soleil*. What about neon and vacuum degassing? Forget it! Go book those seats.

2C. Xenon


Xenon

This designation covers a heap of different constructions, gas pressures, continuous or flashing modes, and applications. Basically, a high voltage between two electrodes strikes a discharge in high purity xenon at pressures from a few hundred torr to a few atmospheres. The pressure affects the lamp's spectral output, or 'color,' but just about any pressure gives high intensity emissions at 235nm and lower. This is real UV output. Or at least it might be, except these lamps often have UV opaque containers to reduce the risk of fried retinas or skin melanomas.

Applications are as varied as: camera flash guns and flood lights; warning flashers on some school buses; aircraft hazard indicators on power transmission towers; germicidal 'cold' sterilization; and forcing plant growth. Obviously, for the last two, some UV emission is needed.

So, xenon discharge lamps can be used in vacuum technology for surface degassing. The trick is selecting a type that fits these constraints:

1. When operating, it must be vacuum compatible, which means (a) it doesn't outgas; (b) it doesn't explode; and (c) it doesn't overheat.
2. A high percentage of the power must be emitted at useful UV wavelengths and not absorbed by the envelope.
3. Its wattage must be sufficient to "do the job."

2D. Sodium


Sodium

Most European, New Zealand, and South African readers have seen the ghostly (ghastly?) effects of sodium vapor lamps used for street and parking lot illumination. Low pressure sodium vapor discharge lamps are the most efficient at converting watts into lumens. But the light is an intense yellow with no UV and little IR.

High pressure sodium lamps appear 'whiter' but are less efficient. For vacuum technology, however, both versions are spectacularly uninteresting. But here's a tip. LP sodium lamps make the red/pink/brown/black/yellow of our skin tones, look sickly at best. Stand under a portable sodium lamp when your boss walks by. He'll immediate suspect hepatitis, an excess of 'bili-bob rubin' in your blood (I'm from the south), and tell you to go home for a week. And it's off to the *Cirque du Soleil*.

2E. Mercury


Mercury

In one of its many guises, mercury lamps are like fluorescent tubes without phosphors. A little argon, a little mercury, a little electricity, all in a silica envelope and, bingo, lots of UV. But manufacturers have played games with pressure, additional gases, discharge geometries, etc, and have produced lamps with phenomenal light (and UV) outputs. Go to a night-time game at your local Australian-rules football stadium and you'll see it perhaps better than in daylight, courtesy of high pressure mercury discharge lamps.

If these lamps are so great, why mess with xenon or sodium? Well, mercury lamps contain, ahem, mercury – a well-known toxic element. Cleaning up after a lamp explosion or even regular disposal when the lamp quits becomes, at best, an ecological pain in the derrière. Using a mercury lamp as a flash is also a tad tedious – the time to reach full output from a cold start may be 10-15 minutes. Worse yet, hot re-starts may never happen!

The technological cutting edge combines mercury and xenon at operating pressures of several atmospheres with short arc geometries. With a UV transparent envelop these goodies put out high intensity UV. The numbers for one particular mercury-xenon lamp are (percentages of total energy):

360-370nm	8.4%
310-320nm	5.7%
290-300nm	4.2%
260-290nm	~6%

Ignoring anything above 320nm, that's almost 16% appearing in the degassing photon range.

Again, the vacuum compatibility selection criteria given for xenon lamps must be observed. But for this lamp type, the power issue is pretty much duck soup. Versions range from 700W to 5000W.

2F. HID

It's possible to call just about any modern discharge lamp a *high intensity discharge* (HID) device. However, the term is reserved for mercury/inert gas lamps to which *metal halides* (indium, scandium, or thallium iodides) have been added. Why add halides? Well, to improve efficiency (see the table) but also to "fill out" the spectral emission in the visible. These lamps give a whiter shade of pale. (Any Procol Harum fans out there? No? Me neither!)

HID (on the right)

These lamps combine high intensity, high efficiency, small size and have started popping up as – yes, even car headlights. Have you read reports condemning 'blue headlights that blind'? Personally, I don't get it. When I drive at night, my focal point is my curb, near and far. I never look at on-coming headlights, especially if they're 'flashing' - the result of HID's sharp lateral beam cut-off and a bumpy road. Oh, yeah. . . I also drive a car equipped with HID headlights but I insist that *macht nichts*.

HID lamps have generated enough light, and political heat, that European law permits them only on cars equipped with self-leveling headlights. *Consumers Reports* is recommending the NHTSA adopt this measure in the USA.

Do HID lights have any use in vacuum technology? I'd have to say. . . hmmm, I dunno. Yes, they're small. Yes, they last a long time. Yes, they can have high UV content. But mostly the metal halides are added to improve the visible emission characteristics, not to jazz up the UV. Anyway, most HID lamps have UV opaque envelopes. Literally blinding someone with your car headlights comes under the heading of poor social skills.

Outgassing with UV

I am indebted to Tom von Alten for these results and his permission to publish them. To avoid 'seeming endorsement' issues, I'm not saying where Tom works but it's big, multi-national, and operates many vacuum processes.

Tom bought the lamp and power supply as a kit for vacuum outgassing. The vendor has undergone recent organizational changes and Tom's not sure the kit is still offered. Both Tom and I have tried tracing the lamp, but its model number no longer appears on the lamp manufacturer's website. Given the rest of the product range, however, it's probably a low or medium pressure mercury vapor discharge lamp.

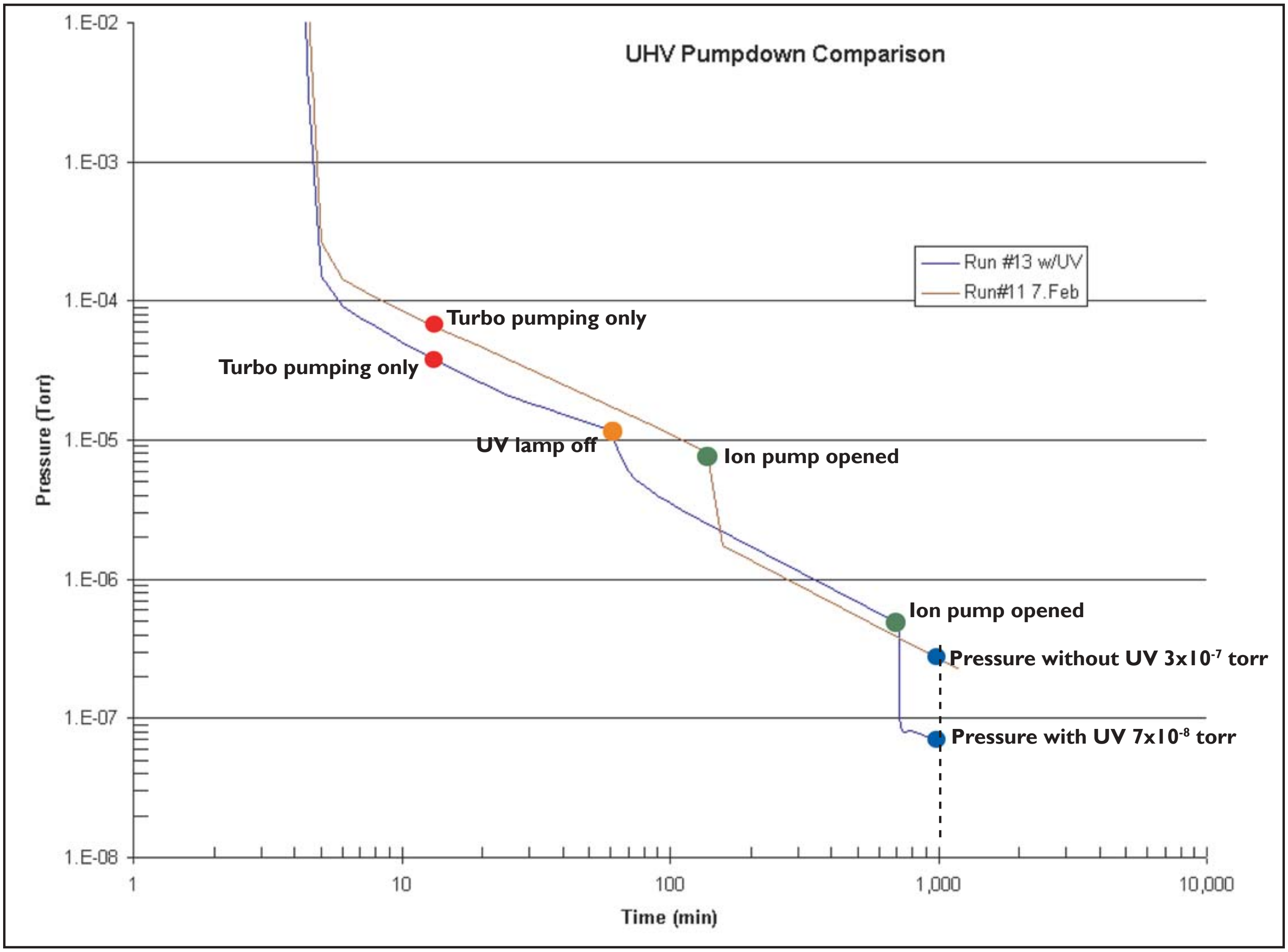
The graph shows the chamber pressure vs time for a system requiring frequent pumping from atmosphere to 'high' UHV. To introduce the results Tom wrote:

"We haven't gone out of our way to do A/B comparison, as we're interested in results (getting the pressure down to use the chamber as intended), rather than proving the reasonably obvious to ourselves.

"Attached are pumpdown curves from a run just before we installed the UV bulb, and the first run with it. We ran it for only an hour, and got half a decade better pressure in the equivalent pumping time. (There were other differences as you can see from offset in the first hour, so again, this isn't anything like UV lamp test data.)

"Further experience led us to run the bulb for 8 hours as standard procedure, to get the chamber down to high UHV pressure overnight."

See Chart on Page 6



Final Thoughts on UV Degassing

When it comes to your safety, I'm a nervous Nelly.

WATCH OUT 1.

Attempting UV degassing without proper knowledge, preparation, and protection is crazy! One quick glimpse of a strong UV source may be your last glimpse of anything. Your eyes will be fried quicker than your microwave zaps that frozen TV dinner your spouse left (since you weren't home at dinner time). Don't trifle with UV lamps! Make sure any viewports (yes, even "opaque" glass ones) are screened so the lamp cannot be accidentally observed. And Tom advises "Wear UV protective glasses."

WATCH OUT 2.

UV radiation at <240nm has enough energy to dissociate oxygen and form ozone. For sterilization, that's just dandy and there are *Ozonizer* lamps to do that. But ozone reacts with polymeric materials, such as mucous membrane, flesh, and rubber gaskets, breaking the long molecular chains into short bits – how many sci-fi nuts remember the basic premise of *The Andromeda Strain*? Sound familiar?

So, don't flow oxygen (or air) through the chamber, through the (turbo) pumps and into room air, or through the chamber and into the (cryo) pumps when you're using UV light to degas.

WATCH OUT 3.

UV lamps are intended for operation in air at atmospheric pressure. If you intend exploring UV degassing techniques, let me suggest a few tests:

(a) Buy, or steal, a cheap vacuum oven. With the test lamp mounted and suitable temperature measurement equipment in place, evacuate the oven and power up the lamp. Leave it running for two or three times longer than you expect an outgassing cycle to last in the real system.

(b) Mount an RGA on the oven and carefully compare the gas spectra before and during lamp operation. This will give some feel for the lamp's outgassing properties.

(c) Mount a microscope slide, half covered with aluminum foil, near the lamp's connector. After the test, look at the dividing line between covered and uncovered surface with a high powered light microscope. You're looking for visible differences indicating coating. If you're lucky enough to know a tame SEM operator, bend the aluminum back on itself (so you have 'coated' and 'uncoated' surfaces adjacent) and have an energy dispersive x-rays analysis done to identify the elements that evaporated from the connector.

Good luck and remember, no peeking!

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