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*                  VARIOUS NOTES ON THE SULFUR LAMP                  *
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**************** INTRODUCTION ****************

Sulfur lamp technology:

There has been quite a bit of publicity lately about a new technology in lighting - the sulfur lamp. While lighting is not normally thought of as high tech, you may change your mind after reading these articles.

This document contains a collection of articles and discussions on various aspects of sulfur lamp technology.

Microwave energy similar in power and wavelength to what your microwave oven uses (microwave oven parts may actually be used in some implementations) excite sulfur in an argon filled bulb (other gasses may also be used and affect the spectral distribution). The small bulb must spin as well as being forced air cooled to prevent an instant melt-down. The spectra is not quite like daylight but is broad-spectrum - more polychromatic than most other non-incandescent technologies. In the current implementation, the bulbs are very small (golf ball size or less) but are used to illuminate the inside of a long light pipe which is actually used to distribute and diffuse the light.

The Smithsonian Air and Space Museum apparently has installed 3 of these to replace over 100 high pressure discharge lamps with a resulting brighter more natural illumination and reduced energy. They kind of look like overgrown fluorescent bulbs - a substantial fraction of the length of the exhibit hall. The sulfur lamps and microwave exciters are at each end.

Unfortunately, it is not clear how well this technology will scale down to residential use. The excitation requires a microwave generator - magnetron like in your microwave oven. At the present time, the bulbs need to be rotated continuously to distribute the sulfur/Ar mixture so there is also a motor involved. Hopefully, these problems can be overcome economically.

An interesting technology. Stay tuned.

**************** ROB'S DETAILED NOTES ON THE SULFUR LAMP ****************

(From: robpen@wseo.wa.gov (Rob Penney))

Introduction:

These notes are somewhat out of date at this time (1996), but cover the fundamentals and include contacts for updated information. I hope this helps. Anyone west of the Mississippi would like us to research this further (the latest articles, papers, proceedings, info from manufacturer and researchers), contact me at the address below and I can do this as part of a contract with BPA and WAPA to support energy conservation for utilities and their customers.

Nutshell:

Exciting sulfur and quartz with microwaves creates great amounts of light with similar properties to sunlight but without the ultraviolet component.

The light is distributed though light pipe for hundreds of feet, replacing hundreds of conventional fixtures. A smaller version may be installed in a torch-type indirect lighting system. The lamp itself may last indefinitely, and the microwave generator may need occasional replacement parts. Lumen depreciation is negligible, and CRI will remain fairly constant.

Construction:

Sulfur lamps consist of a golf-ball-sized sphere filled with sulfur, quartz, and argon. It is energized by a 5900-watt magnetron similar to that on a kitchen microwave oven. The spherical lamp is constantly rotated at about 600 rpm on a glass spindle surrounded by a jet of compressed air. If the lamp were ever to stop rotating, it would melt within two seconds. The technology is quite similar to a UV light source that Fusion Systems has been selling to chip manufacturers and printers for 15 years. Fusion is planning to release more efficient, smaller models by early 1996, roughly 1000 watts and 140,000 lumens. Lawrence Berkeley Labs is working on a 75-watt version of this for interior lighting. They are also working on making the magnetron smaller by using more solid state electronics. The smaller models will not use cooling air and would spin about 1000 rpm. The technology has the environmental advantage of using no mercury.

The light emitted is reflected by a parabolic reflector into a 10" light pipe made of acrylic, prismatic film. This pipe is almost opaque on top.

The bottom is made of many parallel, curved, reflective grates which catch some of the light and reflect in down and out to the sides. The ration of how much light goes down and how much out to the sides can be varied to meet design needs. How much light goes out altogether varies along the length, with more allowed to pass through farther from the light source and less near the light source, to create more uniform luminance along the length.

The light pipe would therefore need to be purchased in sections, each with specific characteristics. A mirror at the far end of the pipe reflects back any light traveling that far. Smaller models may not use light pipe, either using a more standard fixture or possibly fiber optics. One such application being considered is to install the light on a 7' tall pedestal in an office cubicle area creating a powerful indirect lighting system.

Light output:

It emits 450,000 lumens, 310,000 of which are reflected into the light pipe.

The spectrum is closer to visible light than most conventional lighting sources. The chemistry of the lamp can be varied somewhat to adjust the exact light spectrum. Light output of lower wattage versions would be less.

Health effects:

There is a greatly reduced component of damaging ultraviolet light.

Efficacy:

The efficacy of the lamp itself is 450,000/5900 = 76 l/w. If you consider the lamp reflector as part of the lamp, the efficacy drops to 310,000/ 5900 watts, so 53 lumens per watt. The light pipe is roughly 60 percent efficient, so the efficacy of the whole fixture is 31 lumens per watt. That would be reduced further if the system gets dirty or is not properly maintained. This does not compare well with other light sources which have efficacies up to 180 lumens per watt, although the CRI of the sulfur lamp is greatly superior to such other lamps. Looking at fixture efficiency, this would be 0.7 (reflector) times 0.6 (light pipe), producing a fixture efficiency of 0.42. This matches very closely that measured by LBL.

Fusion hopes in increase lamp efficiency considerably.

Life expectancy:

The sulfur lighting system is currently rated to last 10-20,000 hours, but this is a rough estimate. Because the components in the lamp do not chemically react and it has no electrodes, the life of the lamp itself should be quite long. What would probably fail is an electrical component of the magnetron.

Electrical/mechanical maintenance:

Because one sulfur lighting system can replace several hundred conventional light fixtures, maintenance can be greatly reduced. In an area with an inaccessibly ceiling, this can be an attractive feature. The light pipe itself needs to be cleaned periodically, probably with something on the end of a long stick. The electronic components in the magnetron will eventually need replacing, but that can all be located in a easily accessible spot.

Lumen maintenance:

Again, because the components in the lamp do not chemically react, light output and quality should remain unchanged. However, if the light pipe is not kept clean, the effective light output will suffer.

Other performance issues:

Many of those who witnessed the first installation of a light pipe system were distracted and surprised by the noise of it. This was primarily due to the cooling system, probably an air compressor which are notoriously noisy. Using a single source, a large area could lose lighting if the light source failed. Systems should therefore be designed with redundant light sources with automatic backup.

Availability:

Products were expected to be available at the end of 1995. Cost estimates are unknown, but the system installed at DOE headquarters was reported to cost one-third that of the mercury vapor system it replaced.

Expert resources:

The folks most on top of this new technology are with the manufacturer (Kirk Winkler at Fusion Lighting 301/251-0300) and with Lawrence Berkeley Labs (start with Francis Rubinstein 510/486-4096, FMRubinstein@lbl.gov). LBL is doing a lot of research for DOE on applications for this new technology.

Manufacturers:

Fusion Lighting, Inc., of Rockville, MD, a privately-help spin-off of Fusion Systems Corp., makes the fusion lamp. 301/251-0300. Kirk Winkler, x5553. A.L. Whitehead of Vancouver, BC, makes the light pipe.

**************** ITEMS OF INTEREST ****************

This is the only slightly edited transcript of an email discussion between Sam (>) and Don. (From: Don Klipstein (don@misty.com)).

> When will we see household sulfur lamps?:

My answer is, not any time soon. Consider the electricity cost of operating compact fluorescent lamps a few hours a day, and maybe the cost of the bulbs. How much would you invest up front to cut the electricity costs by 50 to 60 percent? The return should exceed that of competing investment opportunities.

There are quite a few minor technical hurdles. The sulfur lamps in use now are 5.6 KW (or is that 5.9 KW?) units of golf ball size. The Fusion Lighting Co. (unsure of exact name) is working on 1 KW units. I am guessing that using a xenon-sulfur mix instead of an argon-sulfur mix might reduce heat conduction enough to reduce the bulb's diameter by (optimistically) a half to two-thirds. This would would reduce the power to around 100-200 watts. If you blow a jet of air at the bulb to cool it further, they might be scalable down to the point that power input is only a few times the heat conduction loss. I am guessing 30 to 50 watts, as a number out of a hat.

Sulfur bulbs also have a quirk having to do with convection. The 5.6 KW bulbs must be kept rotating. Otherwise, a major hot spot will develop at the top of the bulb, destroying it in something like 1 or 2 seconds. Use of xenon instead of argon does not help this much. On a smaller scale, convection MIGHT not be as bad, but I suspect the lamp will still need a motor.

Another hurdle is getting 50 watts of microwaves into a target the size of a pea. I doubt this can easily be done at the 2.4 GHz or so frequency of microwave ovens. One would need a much higher frequency probably well over 10 GHz. And the microwave source must still be economical, efficient, and reliable. And all of this must be done in a manner satisfactory to the FCC. I don't know if there are any bands in the 10-30 GHz range where such microwave use is permitted. Of course, the regulations can be changed if the need is great enough.

Since xenon does not ionize as easily as argon, an auxiliary means of "igniting" the bulb might be necessary. This might be some sort of Tesla coil, flyback transformer, or trigger coil type of device. Not too expensive once someone gets in the swing of making the cheapest thing that works, but it is a minor extra expense and possible aggravation.

Meanwhile, what would be "ignited"? The gas in the bulb, or the air outside it? Might be a problem if the gas in the bulb has to be at a really high pressure, and I have little idea what that might be.

Another consideration is the color of sulfur light. Generally, the color temperature is high. I saw a wide range of 4000-10,000 Kelvin somewhere (see below for where), but they said it works best with color temperatures in the middle and upper portion of this range. A color temp. of 5500 K is an icy pure to slightly bluish white. 6500 K is definitely a bit bluish; this is the color of "Daylight" fluorescent lamps. Maybe good for outdoor use away from astronomers, but not a popular color for illuminating a living room. Furthermore, sulfur lamps are a bit greenish compared to a blackbody source.

As for filtering this light, maybe things aren't too bad: The #85 Wratten filter is about two-thirds transparent to 6500 Kelvin light, and converts it to around 3750 Kelvin. A filter gel to convert 5500 to 3750 would be even better, if a mini sulfur bulb can efficiently produce 5500 K light. If fluorescent materials could be employed to convert some of the shorter wavelength stuff to red light, things get even better.

If something can be made for under 100-200 dollars and be satisfactory, we might have something. Otherwise a mini sulfur lamp would be just a curiosity, conversation piece, or suitable for a few special purposes.

For some bits of info about sulfur lamps, check:

http://www.webcom.com/~lightsrc,
and find the part with the "archive" of older articles. The one about sulfur lamps is available for a month every several months. The "archive" rotates in and out some of the more popular articles every month.

Again, I don't expect to find any sulfur lamps in the nearest home building supply store any time soon.

Discussion on the feasibility of a homemade sulfur lamp:

>So when can we build one?

I thought a bit more on sulfur lamps this morning. Don't see problems at frequencies higher than already used, in terms of microwave penetration (should be fairly constant as freq. increases past what works well) or reflection by the plasma (should be even less as freq. increases). Possible problem with small bulbs is getting microwaves absorbed fairly completely by a tiny plasma, but adjusting the fill gas pressure will probably fix this.

As for convection, it not only heats the top of the bulb but also transports heat from the plasma to the bulb. This may be a significant energy loss at lower power levels. Efficiency of smaller bulbs may be significantly improved by rotating them to prevent convection currents.

How to build one? Hardly looks like a DIY to me. Takes quite a bit of doing to blow a good strong bubble out of quartz. Its trickier than glass, and also needs higher temperatures. I will check into this in the library when summer approaches, if there is demand for info on how to do this in your basement.

MY ADVICE: Don't try this at home. Required materials and equipment will probably cost thousands of dollars. You need lots of patience and AT BEST some tricky glassblowing. Prepare for bulbs to explode if flawed. Stick to Tesla coils, they're easier.

> Would a low power sulfur lamp need to be smaller or could the same
> 1 inch or so bulbs be used?

Underpowering a 1 inch bulb would cause 2 problems:

1. The thermal conduction loss from a plasma at a normal operating temperature is roughly proportional to the diameter of the plasma. I believe this would be a surprisingly constant fraction of the bulb's size.

2. Underpower the bulb enough, and the plasma temperature drops, probably shifting the spectrum to less visible wavelengths and possibly also causing an undesirable color shift (maybe from greenish blue-white to whitish green-yellow). Then again, the color might be like that of a gas mantle, which isn't too bad.

   However, I suspect that efficiency and color may be only mildly impaired by operating a xenon-filled (instead of argon) 1-inch bulb (1-KW size??) at something like 100-200 watts. Nice idea.

> So, maybe they buy the premade bulbs. Just add a microwave oven
> and stir! Sounds like a recipe.

Sounds nice. May only be able to be sold as part of a kit with strong warning statements. Consider the similarities to HTI, HMI, and short-arc/compact source mercury and mercury-xenon bulbs. Of course, the pressure may not be very high and possibly not much UV gets through sulfur vapor, and maybe lack of electrical connections makes the construction a bit simpler and sturdier, and there is nothing toxic or corrosive (at room temperature) inside. This makes them a bit safer, but the Consumer Product Safety Commission might not let anyone sell them where Joe Sixpack would buy them.

However, I like the idea of somebody selling them in kits or through mail-order. I would probably buy one. I would probably put it in my microwave oven and see what happens (Goggles on face, fire extinguisher in hand?). If nothing breaks, I might trash-pick a microwave oven or buy the cheapest junky one, take it apart, and build a working sulfur lamp.

Yes, I like your idea.

Probably has to wait until sulfur bulbs are produced in great enough quantities that some could be diverted to hobbyists, or spare bulbs become available from whoever sells replacement bulbs (I doubt they last absolutely forever).

> So, take the envelope from a burned out HMI bulb (hey, talk about warnings!),
> back fill with sulfur/argon or whatever. I have a couple of vacuum pumps
> that would probably be good enough. The tough part would be the fire
> extinguisher. :-)

Can't do this with anything that has or had electrodes. Hot sulfur and sulfur vapor are corrosive to most metals.

Got me thinking however...

If you take a quartz tube and heat one end, you should be able to squeeze it shut. This will need oxy-something. No torch using any combination of air and propane or MAPP gas seems to be hot enough. Quartz takes at least 1600 Celsius or more to be worked. I tried this with some tubing from a toaster oven. After closing one end, go over the end with the flame and melt it somewhat to be sure it is closed. After that, do the same with the other end.

If the proper fill gas pressure (or one that we can make work) is atmospheric pressure (as measured when the quartz is being worked), then WE ARE IN LUCK. Just blow gas through the tube before closing it off.

Get a bit of sulfur in there first. Try to work the quartz such that its overall temperature distribution makes the gas pressure the same as when you anneal the darn thing afterwards. Annealing requires baking the bulb for something like a day at 1140 Celsius or a bit more, with the gas inside at atmospheric pressure. (Or match bulb and oven pressures.)

Or, push your luck and operate the bulb without annealing. Quartz has very nearly zero thermal expansion, so an unannealed bulb just might not explode.

If the fill gas must be at some odd pressure, then one must seal both ends of the bulb, poke a hole in it, and attach a hollow stem to it. One of us will have to look up how HMI or similar bulbs are made. Then comes the time to anneal it, then dump in some sulfur, then vacuum, gas, and seal and pinch off the stem (easier below atmospheric pressure than above).

Since there is no metal, we don't have to worry about corrosion by contaminants such as oxygen or water vapor. Traces of either of these would be a big problem in bulbs with metal parts inside. However, these DO impair starting, and should be minimized.

> Maybe someday.

Seems interesting. I have always wanted to build my own high intensity discharge bulb, although most of my life I thought in terms of mercury vapor to do this.

*********** LINKS TO OTHER SITES ***********

Another sulfur lamp FAQ at http://www.sulfurlamp.com/index.htm

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(In no particular order.)

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