The Environmental, Health, and Safety Aspects of Solid-State UV Sources

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Abstract

UV curing technology continues to dramatically transform industrial applications improving both quality and safety. UV curing allows the replacement of solvent-based polymers which give off significant air borne toxins, which must be managed to prevent fires, excessive fumes, excessive heat, or toxin releases into the environment. New uses for UV curing technology that improve our environment continue to emerge. The fiberglass industry, for example, is converting to UV cured composite resins because UV curing virtually eliminates the emission of dangerous styrene from the curing process.

Reducing dangerous emissions and fumes, improving processing speeds, and reducing floor space has led to double digit growth rates of UV curing technology in several industries and constant expansion into new applications. UV curing technology is undoubtedly safer, but there are health, safety, and environmental issues which must be considered in the implementation.

Recently, new technology using solid state emitters has entered the UV curing market, such as those shown in Figure 1. These systems, which include Semiconductor Light Matrix (SLM) devices, UV LED devices, and other diode based emitter technology have much lower environmental, health, and safety concerns, but still these need to be properly understood and managed. This paper will highlight some of the common environmental and safety issues associated with medium pressure arc lamps and more recent solid state light sources built on UV LED technology.

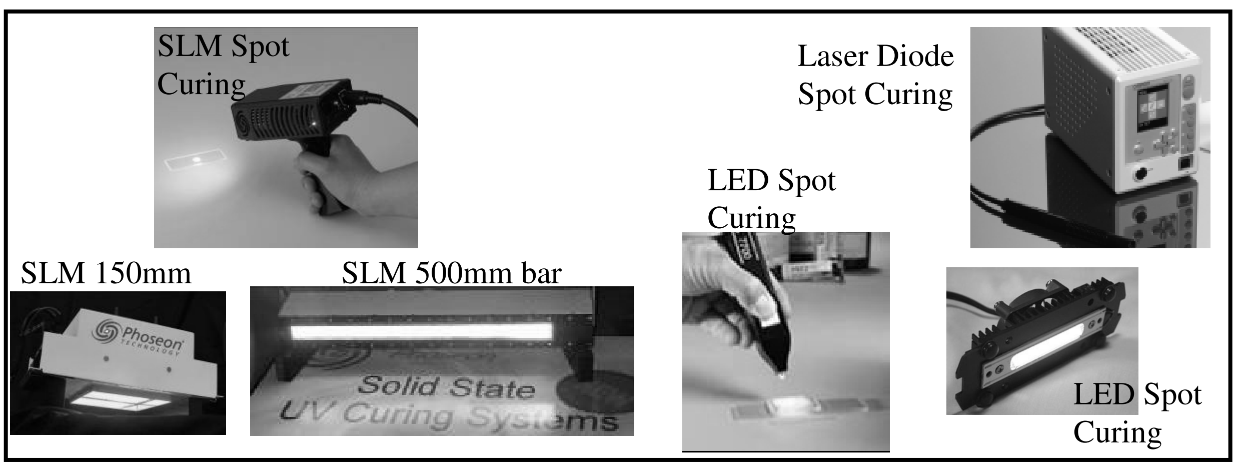

Figure 1. A variety of solid state light sources, including laser diode, UV LED and SLM technology have entered the UV curing market.

Environmental, Health, and Safety Issues with Medium Pressure Arc Lamps

The most common light source used for industrial curing historically is the medium pressure arc lamp so it will be discussed to frame the environmental, health, and safety issues involved and to contrast with solid state UV light sources. Other bulb based sources have similar issues so they are not detailed separately.

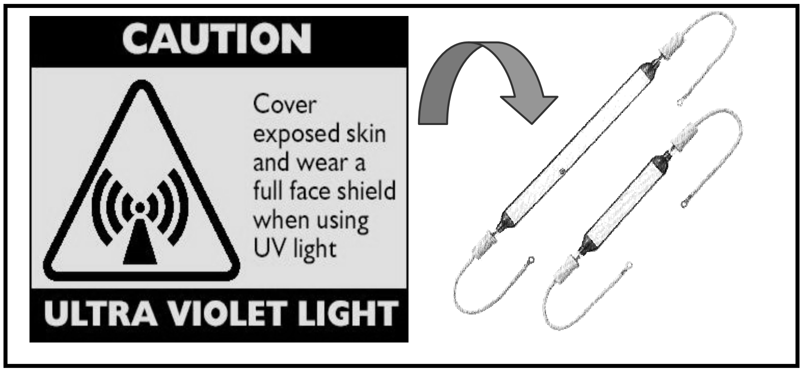

Figure 2. Medium pressure arc lamps are the most common source of UV light for industrial curing and require different environmental, health, and safety considerations than newer solid state light sources.

The environmental, health, and safety issues associated with medium pressure arc lamps include:

- Ozone generation
- High intensity light emissions
- Deep UV emissions
- Mercury exposure
- Glass breakage
- Heat
- Electrical shock

The Dangers of Ozone:

Ozone is generated when light wavelengths below 220nm cause O2 to split and recombine as O3, which is a highly reactive molecule. Ozone blocks harmful rays from the sun in the upper atmosphere, but it is a highly reactive and dangerous gas that can cause lung problems in very low dosages or be lethal at higher dosages. The NY State Dept of Environmental Conservation reports:

> "High ozone concentrations irritate nasal, throat and bronchial tissues. Ozone attacks certain components of the body's defense system, raising concerns about the effects of ozone exposure on the human immune system." [1]

Ozone levels are limited by several governmental organizations. The OSHA Permissible Exposure Limit (PEL) of 0.1 ppm for O_3 exposure[2]. The Food and Drug Administration limit of 0.05 ppm O_3 in enclosed spaces (21 CFR 801.415). The U.S. Environmental Protection Agency (EPA) has established a National Ambient Air Quality Standard (NAAQS) for O_3 at 0.12 ppm for a 1-hour average. Smell is detected at levels of 0.01-0.02 ppm, so if you can smell it, you are getting close to an exposure limit. It is easy to exceed these safety numbers unless special filters, inerting, and exhaust systems are used, which also implies equipment to monitor the status is required.

Arc Lamps: Ozone is generated from the UV wavelengths of light emitted deeper in the spectrum, particularly 180-220nm in arc lamp systems. All UV emitting lamps, whether from pulsed Xenon, Excimer, microwave excited, or Mercury arc lamps emit these deeper UV wavelengths. Filtering, governmental monitoring, and proper exhaust is required.

Solid State UV Sources: Semiconductor Light Matrix (SLM), UV LED, and other solid state light sources use wavelengths typically above 300nm, which do not generate ozone. No safety procedures or monitoring equipment is required.

High Intensity Light Emissions

All visible light emissions between 400nm and 700nm have the potential to damage the eye at intensity levels or durations above the thresholds established by the CRDH and IEC. At some intensities and wavelengths, light can also have other bio-effects including skin damage or cancer.

Arc lamps are covered under Sec. 1040.30 High-intensity mercury vapor discharge lamps[3]. For focused arc lamps, even the reflections far exceed safety thresholds for each lamp peak shown in Figure 3, so “welder’s” style goggles, with high attenuation at all wavelengths are required. Light baffle shields should always be in place in use.

Light Emitting Diodes are not covered under US guidelines but are included in European guidelines IEC 60825 which defines most solid state UV curing lights as a class 3b device requiring some safety precautions. ACGIH guidelines suggest limiting exposure to 100 J/cm2 over an 8 hour period. Low cost plastic safety goggles attenuate only the intense peak, allowing visible viewing during use.

The Dangers of Short Wavelength UV Emissions:

Exposure to shorter wavelength radiation below 320nm is far more damaging and can cause a wide range of side effects[4]. Industrial lights have many safety precautions and shields to prevent exposure. Special face shields and goggles are required whenever arc lamps are serviced. One arc lamp manufacturer details the dangers inherent in these bulbs:

> “Even brief exposure to the short arc lamp’s radiation, especially the mercury/xenon lamps, can cause severe burning of the skin and eyes. Even a minor ultraviolet radiation burn affecting the cornea can cause permanent eye damage. The burn which feels like sand in the eyes that cannot be washed out, will take days to heal. Extended exposure to the high power ultraviolet radiation may cause blindness.” [5]

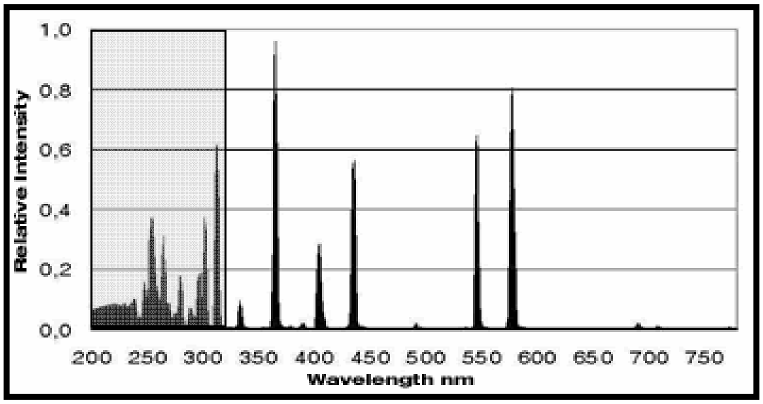

Figure 3. The output spectra of a medium pressure mercury lamp contains a great deal of energy in the potentially dangerous actinic regions of UV <325nm, and all emission peaks in the visible region exceed safety thresholds as well.

RadTech International has issued a UV safety publication[6], which lists the biological effects of UV radiation result mostly from exposure to wavelengths below 325 nm or the "actinic" region where the American Council of Government Industrial Hygenists (ACGIH) and the National Institute for Occupational safety and Health (NIOSH) have established exposure limits for UV lamps sources. The actinic region is overlaid on the spectral output of a typical arc lamp and solid state UV light source is shown in figures 3 and 4.

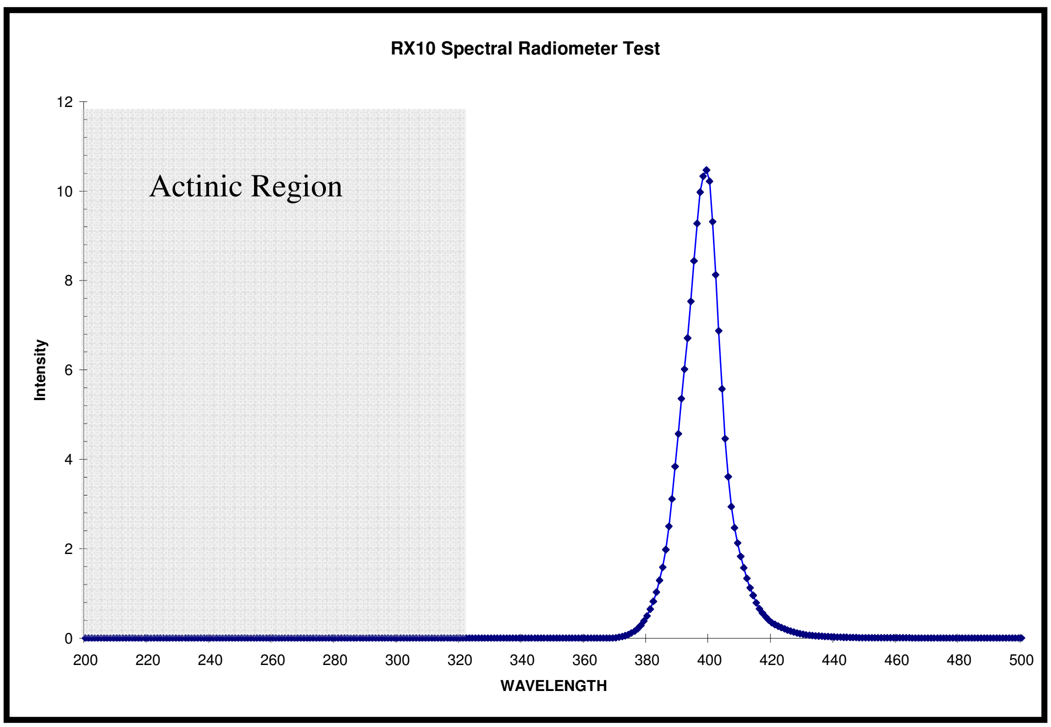

Figure 4. The spectral output of a solid-state UV light sources are typically above 365nm with no light output in the actinic region. Shown here is an SLM light source with all emissions in the relatively safe 380-420nm emission band.

Arc Lamps: All visible and UV emissions exceed government safety thresholds and can cause immediate blindness or permanent eye damage if viewed directly. Goggles rated for the appropriate wavelength should be used at all times. Deep UV exposure, even of the skin, should be prevented. Protective covers should always be in place when the light is on.

Solid State UV Sources: Semiconductor Light Matrix (SLM), UV LED, and other solid state light sources emit light in the UVA and UVV above safety thresholds, so goggles are required when viewed directly, but reflections and longer distances are below thresholds. No skin exposure risk for durations < 1 hour.

The Hazards of Mercury:

Most UV Lamp sources generate UV light by vaporizing about 200mg of Mercury (Hg) by heating with an electrical discharge. UV light is generated from the spectral emission bands from the superheated mercury plasma. Mercury is contained within the arc lamp and is only a significant risk if a bulb breaks, which would allow the vapor to be inhaled.

Mercury has been known to be a poison for thousands of years which can be ingested, inhaled, or absorbed through the skin. Mercury is a potent human toxin, and does not dissipate in the environment. As a persistent bioaccumulative toxin (PBT), mercury builds up in the human body, and research has shown that mercury accumulates in vital organs and tissues, such as the liver, brain, and heart[8]. Major symptoms of mercury toxicity include emotional instability, tremors, gingivitis, kidney failure and weakening of the immune system, and with possible links to multiple sclerosis and epileptic seizures and leukemia have been reported. Some experts believe "there is **No Safe Level** of mercury exposure"[7].

Over the past century, the US EPA estimates that the amount of mercury entering the environment has increased fivefold due in part to the increase in use of mercury containing electronic devices. Recently several governments have begun programs to limit mercury exposure and disposal. Radtech has identified a number of States with laws that could potentially affect mercury arc lamps[9]. For instance, Florida's Statute 403.7186 regulates the management of all mercury containing devices and lamps. Other states, such as New Hampshire and California, are proposing legislation to restrict their use. Oregon's Governor proclaimed an Executive Order in 1999 that requires the government to begin a process to phase mercury out of the state by 2020, and is paying consumers to replace mercury based electronic devices. Connecticut, Illinois, Maine, Minnesota, Rhode Island, and Vermont also have relevant legislation that affect notification, labeling, collection plans, and in some cases may restrict sale or distribution.

Whether driven by responsible industry leaders or government regulations, Mercury use will be increasingly restricted in industrial applications over the next decade. There will be an increased pressure on manufacturers who continue to use mercury to take more care (at presumably higher burden and cost to them) to safely dispose of products.

Arc Lamps: Mercury based arc lamps contain sufficient mercury to propose a health hazard if the bulb is broken. Bulbs should be handled carefully only when cooled and disposed as hazardous waste. Release of mercury vapors should initiate evacuation procedures, and spillage necessitates cleanup with mercury specific precautions.

Solid state UV sources have no mercury in them.

Glass Breakage

All lamps and most solid state UV sources have glass in their construction.

Arc lamps are under pressure, so there is risk of flying glass if the bulb breaks in use or during maintenance. Appropriate safety glasses, gloves, and protective clothing should be worn.

Solid state light sources are not under pressure, no special risk.

Heat and Thermal Risks

Both arc lamps and solid state devices are relatively inefficient UV generators, most of the electrical energy is converted to heat. Thermal burns by contact with high temperature surfaces depend on the temperature of the heat source and duration of contact and thermal conductivity and capacity of the skin in contact. In general most people will not get burned by casual contact with temperatures less than ~60°C due to their reflex responses.

Arc lamps operate at very high temperatures 850-950°C, with the glass around 350°C and the housing at temperatures above 50°C. Additionally, arc lamps radiate much of the heat into surrounding work surfaces which can also be elevated above safe levels.

Solid state UV light sources do not radiate their heat and if properly designed and do not heat any surface or housing to unsafe levels. Housings are typically below 40°C and glass surfaces below 60°C.

Electrical Hazards

Many countries and organizations specify that only qualified electrical workers are permitted to work on energized circuitry of 50 volts/25 amps to ground or greater. Arc lamps and solid state light sources are typically 0.5-5kW devices.

Arc lamps use a 45kV ignition voltage which can "jump" over an inch. High voltage circuits have a nominal voltage of more than 600V, and many bulbs are above voltage and current thresholds. Only qualified electrical workers should do maintenance.

Solid state UV light sources operate below the high voltage limit. They are high power devices and operators should be trained in electrical safety.

Summary

While UV curing has radically transformed and improved the safety of many industrial processes, UV lamps have safety and environmental hazards that must be managed. These include:

- Ozone exposure risk
- DUV radiation exposure risk
- Mercury environmental emissions or toxic exposure risk
- Blinding light intensities
- Flying glass
- Thermal burns
- Electrical shock

Solid state light sources formed with light emitting semiconductor diodes eliminate all of these hazards, only low cost goggles during maintenance and general electrical safety guidelines are required in industrial UV curing applications.

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