The Increase in Energy Efficiency and Useful Working Life of Induction-Based UV-C Emitters Versus Traditional UV-C Technologies

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1 Overview

Ultraviolet (UV) radiation is a type of electromagnetic radiation (EMR) with a wavelength roughly between $10nm$ and $400nm$. Specifically, UV-C radiation, the shortest wavelength of the three forms of UV, has been shown to be an effective germicide used in the disinfection of air and water (Reed, 2010). The basis of the mechanism of action of UV disinfection relates to its effects on the molecular structure of DNA. High energy UV-C photons result in the covalent linkage of nitrogenous bases, forming pyrimidine dimers within DNA (Douki et al., 2017). This induces mutations, double-stranded breaks, and other disruptions during replication of the genetic material, which results in the inactivation of viruses and bacteria (Douki et al., 2017). In most germicidal applications, UV-C light is produced from the excitation of a fluorescent bulb with electricity. While this remains a viable option, induction-based UV-C lamps have the potential to be more cost and energy efficient without sacrificing fidelity. The source of UV-C radiation is an important factor when considering the overall costs versus benefits in designing a germicidal lamp. Here, we review the potential benefits of selecting an induction-based UV-C lamp and contrast it to more traditional UV-C emitters, such as fluorescent lamps. We discuss the differences in cost, efficiency, and output between these various UV-C emission technologies in the context of usage in a germicidal lamp.

2 Fluorescent and LED Lamps

A fluorescent bulb consists of a gas tube, filled with mercury vapour and an inert gas, along with a set of electrodes at either end. When an electric current is run across these electrodes, electrical energy excites the mercury gas, which produces UV radiation, typically at 254 nm (Roberts, 2014). Standard fluorescent lights are equipped with phosphors to convert the ultraviolet light generated into visible light that is safe for human exposure. In a germicidal lamp, the emitter is housed in glass that permits the emission of UV-C light. Mercury-based UV lamps have been around since the early 1900s, and were widely implemented in the 1950's (Bolton and Cotton, 2008). The main cause of fluorescent bulb failure is the breakdown of the electrodes bounding the tube of gas over time as current is repeatedly run across them. In a theoretical fluorescent light that does not use electrodes, the bulb's lifespan would be greatly extended, and the limiting factor would only be the gradual depletion of the mercury particles (Roberts, 2014).

Light emitting diodes (LED) lights will emit radiation at a single wavelength when current is applied to them. While the use of LED technology in the generation of visible light is well established, their usage in generating radiation in the ultraviolet spectrum (200-400nm) is rapidly growing (Gora et al., 2018). LED lights use less power, are smaller in size, and have a reduced environmental impact versus their fluorescent counterparts. In addition, they have the added flexibility of being able to modulate the exact wavelength of UV light being emitted. In a 2018 study, UV-C LEDs emitting a wavelength of $265nm$ were found to be effective at inactivating P. aeruginosa bacterial biofilms (Gora et al., 2018). In a 2009 study, LED UVC lamps at the same wavelength were shown to be effective at disinfecting P. aeruginosa biofilms on catheters (Bak et al., 2009).

3 Energy Efficiency of Induction Lamps

Induction lamps share many commonalities with fluorescent lamps. Both utilize a gas-filled tube in which a solid metal is contained. Upon electrical excitation, mercury molecules become energized, which results in the emission of UV-C radiation as they fall back to their ground state. While fluorescent lamps use electrodes to maintain the flow of current, induction lamps instead use a high-frequency generator with a power couple that produces a magnetic field. The gas is excited by this magnetic field and emits ultraviolet light. Because of this, induction lamps are not as prone to degradation over time from repeated oxidation. In fluorescent lights, electrode degradation is an eventual certainty, and the light will flicker as the bulb nears the end of its operational lifespan. Because induction lamps do not use internal electrodes, they are not prone to this flickering. Induction lamps have the added benefit of instantly turning on, as opposed to fluorescent lights, which require some time to reach full potential. There are two main types of induction bulbs: external and internal inductor lamps. In external inductor lamps, the magnetic coil is housed externally to the glass tube, while internal inductor lamps have the coil in the centre of the lamp (Roberts, 2014).

4 Induction Lamp vs. Traditional UV-C Emitters

Despite their similarities, induction based UV-C emitters hold significant advantages over fluorescent UVC bulbs. They last longer, and can be comparable to choosing LED lamps over fluorescent lamps for the production of visible light. In duration testing, the lifespan of an induction UV-C bulb was quoted at around 30,000 operating hours. This far exceeds the 8,000 working hour lifespan on a fluorescent UV-C bulb (Zaffina et al., 2012). At a strength of 30,000 pw/cm^2, the induction-based UV-C bulb remained effective at eliminating a wide variety of pathogens. Induction lamps boast a highly efficient energy usage rate of 95 - 98% efficiency, which helps in cutting down on operating costs (Roberts, 2014).

In fluorescent lamps, the production of ozone is a byproduct of the excitation of mercury molecules. While this is sometimes purposefully used in the production of ozone gas for commercial or industrial purposes, ozone

UVC against common viruses and bacteria killing efficiency (ultraviolet irradiance 30，000pw/cm²)						
Category	Name	The time kill 100%	Name	The time kill 100%	Name	The time kill 100%
Bacteria	E.coli Diphtheria Tetanus bacteria rod Bacillus anthracis Shigella	0.36s 0.25s 0.33s 0.30s 0.15s 0.80s	Hook end pylori Legionella spp. Micrococcus Mycobacterium tuberculosis Cholera bacillus	10.20s 0.20s 0.40s 0.41s 0.64s 0.37s	Showalter door genus Intestinal fever genus Salmonella typhimurium	0.51s o.41s 0.53s 0.28s 1.23s 0.45s
Virus	Adenovirus prime Tropic virus spores	0.10s 0.20s 0.80s	ECHOvirus flu virus Poliovirus	0.75s 0.23s 0.80s	Rotavirus Tobacco mosaic virus	0.52s 0.16s 0.73s
Mold spores	Aspergillus niger Aspergillus Dung fungus	6.67s 8.80s 8.00s	Mucor Soft spore Penicillium	4.67s 0.33s 2.95s	Toxigenic Penicillium Other fungi	3.33s 10.87s
Water algae	Blue - green algae Chlorella	40.00s 0.93s	Nematode eggs Genus paramecium	3.40s 7.30s	Protozoa genus Chlorella	6.70s 1.22s

Figure 1: Figure adapted from Neu-Tech Energy Solutions

production is an undesirable by-product in the context of germicidal lamps. Prolonged ozone exposure can irreversibly damage respiratory tissue in humans, and lead to the creation of free oxygen radicals, which further damage tissue (Nie et al., 2016). While it is unlikely that fluorescent bulb production of ozone would reach hazardous levels (Boeniger, 1995), it is nonetheless a risk that can be mitigated through the use of an induction-based bulb. Induction-based UV-C lamps do not produce ozone over the course of their operation. This could present as a mitigating safety factor, which is an important consideration when choosing a germicidal lamp product. However, it should also be noted that the inherent risk of UVC exposure remains regardless of the source of emission. Even acute exposure to UV-C radiation can have adverse effects on the eyes and may lead to persistent skin symptoms (Zaffina et al., 2012).

5 Conclusion

Selection of an appropriate UV-C emitting technology is an important consideration in the development of a UV-C germicidal lamp. In this review, we present compelling evidence that suggests induction-based UV-C emitters are more powerful, more efficient, and last longer than traditional UV-C technologies, such as fluorescent-based lamps. Therefore, choosing induction UV-C emitters can help reduce environmental impact, cut down on costs, improve UV generation efficiency, and reduce energy consumption.

6 References

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