Deep UV Light Emitting Diode Technology for compact Point-of-Use Water Disinfection Systems.

I. Gaska[1], O. Bilenko[1], I. Shturm[1], S. Smetona[1], Y. Bilenko[1], M. Shatalov[1], T. Bettles[1], R. Gaska[1], M. Shur[1], Z.Gleason[2], M. Sim[2], T. Oriard[2]

[1]Sensor Electronic Technology, Inc., Columbia, SC, USA. Phone: (803) 647-9757, Fax: (803) 647-9770,

[2]Cascade Designs Inc., 4000 1st Avenue, South Seattle, Washington 98134.
Phone: (206) 505-9500, Fax: (206) 682-4184

ABSTRACT

Deep Ultraviolet Light Emitting Diodes (DUV LEDS) have shown their effectiveness in microbial sterilization of drinking water. These semiconductor-based DUV light sources offer narrow spectral power distribution (<12 nm FWHM) with peak emission wavelengths from 227 nm to 340 nm. The efficiency up to 8% and CW optical output power of up to 100 mW (at 275-280 nm wavelengths) has been achieved by SET, Inc. using a single, hermetically sealed lamp with a footprint of about 1 square inch.

This technology has been incorporated into a SETi next generation compact aluminum chamber with an internal volume of approximately 52 mL. A $\geq$5 LOG *E.coli* bacterial reduction at 100mL/minute was achieved with an output power of 18mW and $\geq$6 LOG at 28mW while an average of 5 LOG *E.coli* reduction was achieved at 200mL/minute with an output power of 28mW.

The DUV LED chamber was also tested in its efficacy towards viral disinfection. MS2 bacteriophage was chosen to represent viral microbes. Average influent concentrations ranged in between 10^3-10^4 plaque forming units (pfu)/mL of deionized water.]. Preliminary testing was carried out at a constant flow of 100mL/minute and an average 1.56 LOG reductions were achieved using an optical output power of approximately 28mW.

Keywords: UV disinfection, E.coli, MS2 bacteriophage, Light Emitting Diodes, point-of-use water disinfection.

Introduction

Clean drinking water is essential for any healthy and functioning society, however according to UNICEF 783 million people lack access to any form of clean drinking water [1]. Many modern water disinfection systems use highly reactive chemicals, such as chlorine, in order to eliminate microbes. These chemicals can create hazardous chemical by-products when exposed to organic matter in the water. UV light has been well established as a feasible alternative means of water sterilization using low and medium pressure mercury lamps. Drawbacks to these systems include long warm up times, sensitivity to temperature changes, production of ozone, possibility of mercury contamination, and limited lifetime. DUV LEDs provide an effective hazard free alternative to mercury lamps. Small DUV LEDs can fit into compact disinfection systems, require low voltage, RF noise free, and can be precisely controlled for energy saving and optimal germicidal disinfection operation. We previously reported [2] on successful DUV LED application in POU (Point Of Use) disinfection systems. In this presentation, we report on a compact water disinfection system (WDS) that is suitable for use in various mobile water purifications systems and discuss further development and optimization options.

Deep UV LED Water Disinfection Chamber

Figure 1 Compact DUV LED Disinfection System Exterior and Interior Views.

SETi next generation compact DUV LED water disinfection chamber is 4 inches long with a 1 inch diameter. The chamber contains a single UVCLEAN® TO-3 lamp on one end and was rated to deliver up to 80mW output optical power at peak wavelength of 272-273 nm. Disinfection chamber was designed to use the flowing water as the primary system to dissipate the heat produced by the TO-3 lamp. The disinfection system was equipped with a custom designed power supply for the TO-3 lamp.

Microbial characterization and testing

The microbial disinfection efficacy of the chamber was measured using *E.coli* bacterium, which is an excellent indicator of water contamination with human fecal matter. The bacteria were purchased from American Type Culture collection (ATCC) vial number 11303. *E.coli* was independently grown in Tryptic soy broth to mid-log phase. Sterilized cotton swabs were used to methodically inoculate Tryptic soy agar plates to propagate the E.coli and to check for any possible contamination. Inoculated plates were then placed in an incubator at 37^{o}C for 24 hours. New sterile cotton swabs were used to take an *E.coli* sample from the agar plates and inoculate a fresh test tube of Tryptic soy broth to be placed into the incubator at 37^{o}C for 24 hours. The overnight solution was then used for the preparation of bacterial concentrations for testing. The approximate influent bacterial concentration was around 10^6 coliform forming units (cfu)/100mL of Deionized water (DI). A final 2 Liter suspension was created for each experiment and mixed vigorously. Multiple dilutions from each 2 Liter suspension were made in order to effectively determine the influent bacterial concentrations.

Testing solution would them be placed onto a magnetic stir plate and pumped at 100mL/minute using a Cole Palmer Masterflex L/S pump in combination with a Masterflex L/S Easyload II pump head. Pump system was chosen due to its accuracy and consistency in order to minimize and possible deviations during testing. Multiple tests were conducted using various optical output powers. During testing output current was measured along with voltage and lamp temperature in order to ensure optimal DUV LED lamp performance. Upon experiment completion, aliquots were collected and further dilutions were made in order to determine the *E.coli* survival concentrations post-irradiation, which was done immediately in order to minimize the possibility of light-reactivation.

Determination of *E.coli* was conducted by using Colilert-18™ (IDEXX Laboratories Inc.) The methodology was approved by the US EPA [3]. The irradiated solutions were then diluted by deionized water into final volumes of 100mL and mixed with Colilert-18 reagent. Then the solutions are poured into Quanti-Tray/2000, sealed, and placed into the incubator at 37 ºC for 18-24 hours. LOG reduction values were calculated (N_b/N_a), with N_b and N_a representing the before and after concentrations. Fig. 2 shows the LOG reductions as a function of optical out power.

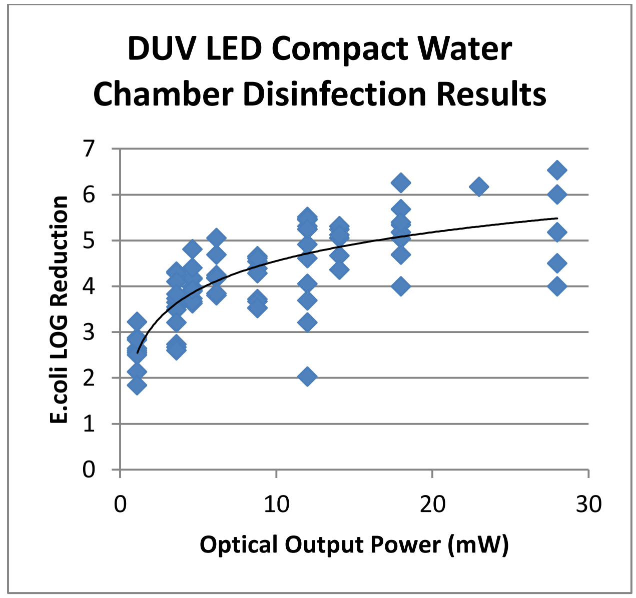

Figure 2 E. coli Water Disinfection at 100mL/minute

A As seen, a ≥5 LOG bacterial reduction at 100mL/minute was achieved with an output power of 18mW and ≥6 LOG at 28mW. Several experimental tests were performed in order to verify these results and the distribution within the graph provides the evidence. Further experiments were conducted by increasing the flow rate from 100 to 200mL/min. Preliminary results revealed an average of 5 LOG reductions were achieved using an optical output power of 28mW.

Deep UV Viral Testing

The DUV LED chamber was also tested in its efficacy towards viral disinfection. MS2 bacteriophage was chosen to represent viral microbes. It was purchased from ATCC and was propagated according to the ATCC method that was provided alongside the MS2 vial. Average influent concentrations ranged in between 10^3-10^4 plaque forming units (pfu)/mL of deionized water. Enumeration and determination were carried out according to a modified US EPA method 1602 [4]. Preliminary testing was carried out at a constant flow of 100mL/minute and an average 1.56 LOG reductions were achieved using an optical output power of approximately 28mW. Further testing and modeling is underway in order to maximize the efficacy of the DUV LED water chamber for viral disinfection. The modeling (SolidWorks FloExpress, COMSOL) and experiment

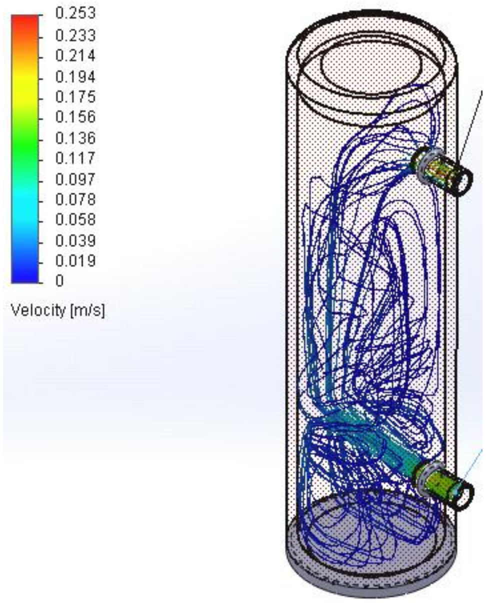

Figure 3 Flow Dynamics Modeling Example

variables include flow rate, DUV power and reactor construction.

Summary

SETi has shown an invested interest in the design and fabrication of compact DUV LED water disinfection systems for the consumer market. Recently SETi has partnered with Cascade Designs Inc., a well-known outdoor equipment designer and manufacturer with brands such as MSR and Platypus, to implement such a system(s) into the market. Cascade Designs Inc. has a long and proven track record for effective microbial testing and water purification system design. With their expertise, SETi is working on designing a new multi-stage water disinfection system for consumer use. The current next generation compact DUV LED chamber has shown LOG reductions in both bacteria and virus at low flow rates and minimal output power. These results will be analyzed and used in order to constantly improve the efficacy of the aforementioned DUV LED water disinfection system. In addition, the data will be used in the design and fabrication of newer and more improved chamber designs that will maximize microbial elimination while minimizing power requirements and space.

References

[1] United States Children’s Fund. Clean Water Campaign, UNICEF 2012.

[2] I. Gaska, O. Bilenko, I. Shturm, Y. Bilenko, M. Shatalov, and R. Gaska, “Efficiency of Point-of-Use Water Disinfection Using Deep UV Light Emitting Diode Technology”, CleanTech 2012.

[3] U.S. Environmental Protection Agency Office of Water. Method 1103: Colilert coliform and E. coli water analysis. EPA 2007.

[4] US Environmental Protection Agency.2001.Method 1602: Male Specific (F+) and somatic coliphage in water by single agar layer (SAL) procedure. EPA 821-R-01-029. US Environmental Protection Agency, Washington DC.