The Importance of Developing a Standardized Procedure for the Operation and Characterization of UV-LEDs

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Introduction

Light emitting diodes (LEDs) are semiconductor devices that can emit radiation of different wavelengths. They can be designed to produce ultraviolet (UV) radiation at the optimal germicidal wavelength. This and many other advantages of UV-LEDs make them an attractive alternative to mercury-based UV lamps in water treatment systems.

Despite rapid improvements in the performance of UV-LEDs and their enormous potential role in water treatment systems, there is no standardized assessment of the operation and application of UV-LEDs for studying the inactivation of microorganisms. In addition, there is no standard protocol for efficiently measuring the characteristics of UV-LEDs. The lack of such a protocol can result in inconsistent, inaccurate and irreproducible output and results. A recent review paper on the application of UV-LEDs for water disinfection (Song et al. 2016) demonstrates many inconsistent and incomparable data from published studies, which highlights the importance of developing a standard method. In this article, we present parameters that can affect the output of UV-LEDs, and discuss the necessary considerations for developing a protocol to reliably measure UV-LED output.

The necessity of determining UV-LED output

In order to utilize each new UV source for inactivating microorganisms or degrading micropollutants, a standard method is required to measure their output. In the case of UV-LEDs, parameters such as radiation profile, radiant power and peak wavelength are critical for designing a UV photoreactor. The position of UV-LEDs in a reactor, and their radiation profile and power output, determine the radiation distribution inside the reactor. Working with these parameters, an appropriate radiation field – based on the hydrodynamics of the reactor – can be achieved to provide optimum inactivation efficiency of a UV reactor. The total power output and even the spectrum of a UV-LED is a function of operational conditions, which need to be appropriately and consistently controlled.

For monochromatic, low-pressure UV mercury lamps, for example, a standard measurement method has been proposed (Lawal et al. 2008). The existing protocol for conventional UV lamps, however, is not applicable to UV-LEDs. Since the power output and peak wavelength of UV-LEDs are a function of operational conditions, such as temperature and current, the absence of a standard and universally accepted protocol for measuring UV output will result in inaccurate calculation of UV dose delivered to a solution. This could lead to inconsistent, and sometimes incorrect, data among different studies for calculating the UV dose-response of microorganisms.

UV-LEDs are typically distinguished by their radiation profile, radiant power and peak wavelength. In comparison, the radiation profile of low-pressure mercury lamps is axisymmetric, and the emitted radiation spectrum is constant, such that lamp output can be calculated by measuring single-point irradiance at a specific distance from the lamp at steady state using an appropriate formula. This procedure is not directly applicable for determining UV-LED output, since their characteristics cannot be represented by a single-point measurement.

The differing radiation patterns of typical UV-LEDs are depicted in Figure 1. It is evident that irradiance at the centerline and a specific distance from a UV-LED will differ, depending on its radiation profile. As a result, single-point measurement cannot provide accurate calculation of the power output. For instance, 5 μW/cm^2 irradiance at a distance of 30 cm from each of the UV-LEDs can be related to very different radiant powers, ranging from 0.16 to 16.9 mW, as presented in Table 1. It should be mentioned that the small footprint of UV-LEDs makes it possible to measure radiant power using a calibrated

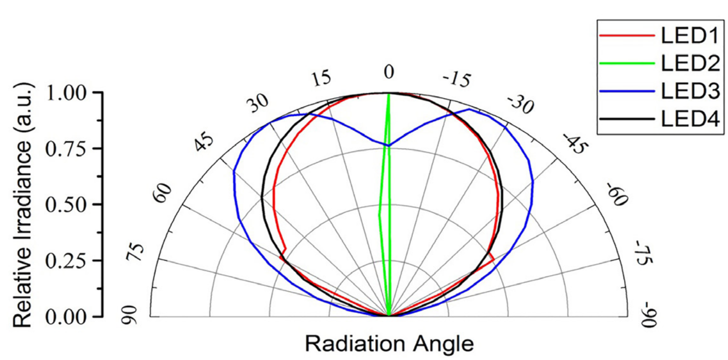

Figure 1. Radiation profile of four different UV-LEDs

Table 1. Potential radiant power based on 5 μW/cm² irradiance at 30 cm distance from UV-LED centerline

UV-LED	Calculated Radiant Power (mW)
LED – 1	11.9
LED – 2	0.16
LED – 3	16.9
LED – 4	13.5

integrated sphere. However, the radiation profile and the total radiant power delivered to a solution for inactivation studies could differ from the total UV output. Therefore, measurement of the radiation pattern (rather than the total output) is usually required for kinetic inactivation studies and for the application of UV-LEDs in water disinfection reactors.

Potential features of an appropriate protocol

Operational conditions: UV-LEDs are highly sensitive to operational conditions such as temperature and electrical current, which can easily affect the radiant power and peak wavelength. Consequently, appropriate equipment is needed to control and monitor temperature and current. The UV-LED temperature may be controlled by any combination of a heatsink and thermo-electric cooler. Electrical current can be maintained by means of a constant current driver. UV-LEDs may be operated by direct connection to a power supply, but the resulting output would be inconsistent. Increased UV-LED temperature could result in lower resistance, leading to greater consumption of current. Higher current consumption leads to greater radiant power and heat generation, resulting in higher temperature, and this cycle could continue affecting the radiant power and lifetime of UV-LEDs.

Measurement procedure: Considering the significance of measuring radiation pattern, radiant power and the peak wavelength of UV-LEDs, an appropriate set-up for accurate measurement of these parameters is needed. Figure 2 shows

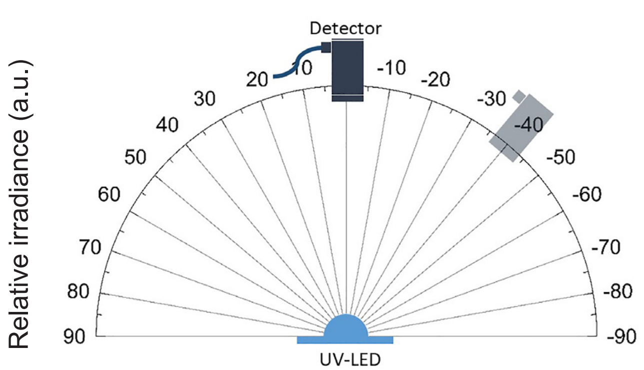

Figure 2. Goniometric method to measure UV-LED radiation profile

an example of a suggested goniometric method to measure the radiation profile of a UV-LED. Since the radiation profile of UV-LEDs may not be symmetrical in the azimuthal direction (Figure 3), three-dimensional (3D) measurement of the radiation profile has to be conducted. The integration of the 3D radiation profile determines the total radiant power of the UV-LED. When performing inactivation studies in a solution, knowing the orientation of the UV-LED and the solution allows the total radiant power delivered to the solution to be estimated.

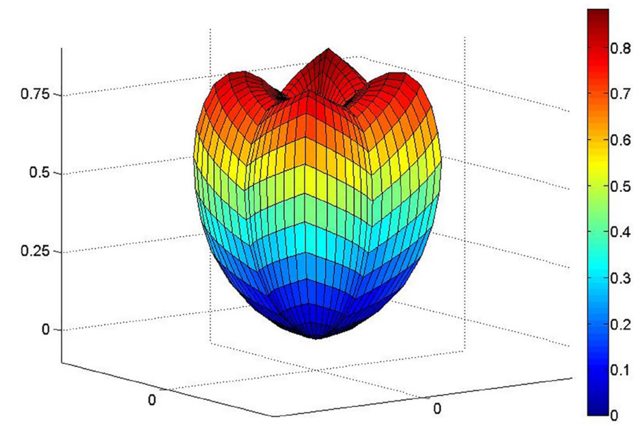

Figure 3. 3D Radiation pattern of a UV-LED

Conclusion

A standard method of measuring the output and maintaining the performance of UV-LEDs is required to obtain reliable inactivation kinetic information. The operational parameters of UV-LEDs, such as current and temperature, must be controlled as they can impact radiation profile, radiant power and spectral power distribution. Furthermore, an appropriate method for measuring total UV-LED output and total radiant power delivered to a solution should be determined, taking into consideration the effects of UV-LED/solution orientation and UV-LED radiation profile. Such protocols could ensure appropriate design and consistency in the execution of experiments and among the results obtained from different studies. ■

References

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