Disinfection of *Tetraselmis* sp. with UV LED Application

Dae-Won Park*, Yong-Ki Choi**, Gyung-Suk Kil†, Ji-Ho Chang*** and Cheol-Young Choi****

**Abstract** - Ship ballast water affects various marine species in a port or in a coastal area. The International Maritime Organization (IMO) adopted “the Convention on Ballast Water Management” in February 2004 and insisted that all ships be equipped with a ballast water treatment system beginning 2010. As basic study on a low power consumption ballast water treatment system (BWTS), the disinfection characteristics of *Tetraselmis* sp. were analyzed using an ultraviolet (UV) light-emitting diode (LED). UV LED modules with peak wavelengths of 255 nm, 265 nm, and 280 nm were fabricated, and each module was exposed to the same UV dose of 100–400 mJ/cm². The experimental results showed that the highest disinfection wavelength for *Tetraselmis* sp. appeared at 265 nm with a constant UV dose, and its disinfection rate was 91 %.

**Keywords:** Ultraviolet (UV), Light-emitting diode (LED), Wavelength, Disinfection, Phytoplankton, Ballast water

1. Introduction

Ballast water is nothing but seawater that is accumulated in a ship to maintain its balance. Annually, about 10 billion tons of ballast water containing organisms such as plankton, germs, and bacteria is transported around the world, and these organisms cause diseases and contaminate the marine ecology [1]. Owing to these drawbacks, the International Maritime Organization (IMO), in February 2004, adopted regulations for the treatment of ships’ ballast water and suggested that all ships be gradually equipped with ballast water treatment systems (BWTSs) beginning 2010 [2]. Currently, methods for treating ballast water, involving filtration, ultraviolet (UV) light treatment, ozone treatment and electrolysis, are being developed. The UV treatment has an advantage, in that it does not yield toxic by-products and disinfection by-products (DBPs) [3]. Low-pressure and medium-pressure UV lamps are mainly used in the latest UV treatment method; however, it is important that these lamps be explosion-proof and safe, owing to the fact that they consume a considerable amount of power at high voltage. On the other hand, UV LEDs have a low power consumption rate and require a current of only 10–100 mA; further their disinfection efficiency can be enhanced owing to the fact that they can selectively irradiate monochromatic light in UV-C [4]. Therefore, UV LED modules with peak wavelengths of 255 nm, 265 nm, and 280 nm were designed and fabricated to analyze the disinfection characteristics of phytoplankton such as *Tetraselmis* sp.

2. UV LED module

A device comprising materials with a direct band gap structure, such as AlN, ZnO, and GaN, is being designed for the development of a UV LED, with a wavelength range of 200–400 nm. The range between 200 nm and 300 nm is well known as the disinfection wavelength range, which transforms the structures of the DNAs and RNAs of microorganisms.

In this study, a UV LED with peak wavelengths of 255 nm, 265 nm, and 280 nm was used to analyze the disinfection characteristics of phytoplankton. Table 1 lists the specifications of the UV LED that was used in the experiment. The forward voltage differed depending on the wavelength range of the UV LED when the applied voltage was fixed at 20 mA.

**Table 1. Electrical characteristics of the UV LED**

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>255</th>
<th>265</th>
<th>280</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward voltage [V&lt;sub&gt;DC&lt;/sub&gt;]</td>
<td>7.3</td>
<td>6.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Current [mA]</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

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Fig. 1 shows the fabricated UV LED module. This module consisted of a metal PCB that emitted heat from the LED, 40 UV LEDs that were arranged in a row, and a zener-diode that was placed parallel to the UV LEDs, to protect the device.

The LED module can be destroyed or its functions can be degraded when it is driven by large varying currents; therefore, to avoid the module from breaking down, it should be driven by a constant current. Therefore, as shown in Fig. 2, a driver was designed for driving the LED module in a safe mode.

The current characteristics of the UV LED driver are shown in Fig. 3, and they could have determined the $V_{DS}$ of the LED. The output of the constant current, $R_{ext}$ had been controlled.

3. Experiments

3.1 Spectrum analysis

A spectrometer (Avaspec-3648, Avantes) was used to analyze the optical spectrum characteristics of the fabricated UV LED module. The spectrum of the module showed peak wavelengths at 255 nm, 265 nm, and 280 nm and approximately 10 nm full widths at half maximum (FWHMs) as shown in Fig. 4.

There are many UV LEDs having monochromatic wavelength, we could select the best wavelength for a purpose [5]. To obtain equal irradiation rates, the UV intensity of each of the UV LED modules was analyzed using a UV power
meter (HD 2102, Deltaohm). Fig. 5 shows the UV intensity of the modules with peak wavelengths of 255 nm, 265 nm, and 280 nm. Because the fabricated module had different UV intensities, the irradiation time was changed to obtain the same degree of irradiation.

\[
UV_{dose} = \frac{I \times t}{[\text{mJ/cm}^2]} \quad (1)
\]

**Fig. 5.** Intensity as a function of distance from the UV source.

Fig. 6 shows the experimental setup used to analyze the disinfection characteristics of *Tetraselmis* sp. using the fabricated UV LED module. The culture fluid of *Tetraselmis* sp. was placed 1 cm below the UV LED module, and an energy volume of 100–400 mJ/cm² was irradiated onto each specimen.

The phytoplankton used in the experiment is 10–50 μm *Tetraselmis* sp., which is a type of a marine diatom and is widely used as a feedstock for the production of rotifers, which are in turn used to feed other organisms [6]. The density of the *Tetraselmis* sp. is 2–3×10³ cell/ml according to “the regulation for the control and management of ship’s ballast water”. A fluorescent microscope was used to determine and calculate the number of disinfected phytoplankton. Disinfection of *Tetraselmis* sp. can be decided by the fluorescent color of the chlorophyll, red represents a living cell and yellow represents a dead one. For 5 days after the UV treatment, *Tetraselmis* sp. was stored in a darkroom. A comparison was drawn between the number of living cells just before and after the treatment in order to determine the disinfection rate.

**4. Results**

Fig. 7 shows the shape of *Tetraselmis* sp. before and after the UV treatment. While *Tetraselmis* sp. clearly showed a round cell membrane before the UV treatment, the shape of the cell membrane was transformed after the UV treatment [7].

**Fig. 6.** Configuration of the experimental apparatus.

**Fig. 7.** Shape of *Tetraselmis* sp. before and after treatment.
Fig. 8 shows the disinfection rates of *Tetraselmis* sp. in accordance with the energy that was irradiated onto each UV LED module. The results show that the greater the energy, the higher was the disinfection rate. The modules showed different disinfection rates, i.e., 89–93 % for the 265 nm module, 68–75 % for the 280 nm module, and 76–80 % for the 255 nm module.

In the case of *Tetraselmis* sp., the valid disinfection area was formed within the wavelength of the UV-C, and in particular, the highest disinfection rate obtained between 260 nm and 270 nm.

![Fig. 8](image1.png)

![Fig. 9](image2.png)

**Fig. 8.** Comparison of the disinfection rates for *Tetraselmis* sp. by UV dose.

**Fig. 9.** Disinfection rates of *Tetraselmis* sp. by UV dose.

5. Conclusion

From the analysis of the disinfection performance of UV LED for *Tetraselmis* sp., it was found that the 265 nm UV LED module exhibited the highest disinfection rate. Five days after the experiment, the disinfection rate was found to be higher than that on the day of experiment. This is deemed
to have been attributed to the destruction of the DNA and the suppression of cell multiplication by the UV rays.

The experimental results showed that *Tetraselmis* sp. had the highest absorption rate within 260–270 nm, which is in accordance with the report that the DNA of cells absorbs wavelengths close to 260 nm well, such as that of the UV-C. It appeared most efficient to use the 265 nm UV LED for disinfecting *Tetraselmis* sp., with equal amounts of UV irradiation. The highest disinfection wavelength for *Tetraselmis* sp. appeared at 265 nm, and its disinfection rate was greater than 91%.

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