Disinfection of *Tetraselmis* sp. with UV LED Application

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Abstract – Ship ballast water affects various marine species in the port or near the coast. When ships come in and/or out of the port, the discharged ballast water contaminates the seawater and destroys the marine ecology system. Therefore, the International Maritime Organization (IMO) adopted the Convention on Ballast Water Management in February 2004 and insists that all ships be equipped with a ballast water treatment system beginning in 2010. In this paper, the disinfection characteristics of *Tetraselmis* sp. were analyzed using a deep ultraviolet light emitting diode (UV LED) as a basic study for the development of a ballast water treatment system. UV LED modules with peak wavelengths at 255, 265, and 280 [nm] were fabricated, and each module was exposed to the same UV dose of 100~400 [mJ/cm^2]. The experiment results showed that the highest disinfection wavelength on the *Tetraselmis* sp. appeared at 265 [nm] with a constant UV dose.

Keywords: UV LED, Phytoplankton, Disinfection, Wavelength, Ballast water

1. Introduction

Ballast water is seawater that fills a ship to maintain its balance. Annually, about 10 billion tons of ballast water with organisms such as planktons, germs, and bacteria is being transported around the world, and they cause diseases and contamination of marine ecology[1]. Due to this, the IMO, in February 2004, adopted regulations for the treatment of ship's ballast water and suggested that all ships gradually be equipped with ballast water treatment systems (BWTSs) beginning in 2010[2]. Currently, methods of treating ballast water using filtration, ultraviolet light, ozone and electrolysis are being developed. UV treatment has the advantage, however, of having no remaining toxic and DBPs (disinfection by products)[3]. Low-pressure and medium-pressure UV lamps are mainly used in the latest UV treatment method, but they should be explosion-proof and safe, since they consume much power at a high voltage. On the other hand, UV LED has a low power consumption rate and only a 10~100 [mA] applied current, apart from which its disinfection efficiency can be raised because it can selectively irradiate monochromatic wavelengths in UV-C [4].

Therefore, UV LED modules were designed and fabricated to analyze the disinfection characteristics of UV LED with wavelengths of 255, 265, and 280 [nm] on phytoplankton such as *Tetraselmis* sp.

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2. UV LED System

2.1 UV LED

A device that is based on the AlN, ZnO, and GaN of the direct band gap structure is being designed for the development of UV LED, with a wavelength range of 200-400 [nm].

Within this range, 200~300 [nm] is well known as the disinfection wavelength, which transforms the structures of the DNAs and RNAs of microorganisms.

In this paper, UV LED with peak wavelengths of 255, 265, and 280 [nm] was used to analyze the disinfection characteristics of phytoplankton, in accordance with the UV wavelength. Table 1 shows 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 The caption must be followed by the table

Wavelength [nm]	255	265	280
Forward voltage [V_{DC}]	7.3	6.5	5.7
Current [mA]	20	20	20

2.2 UV LED Module

Fig. 1 shows the fabricated UV LED module. The 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 paralleled to the UV LEDs, to protect the device.

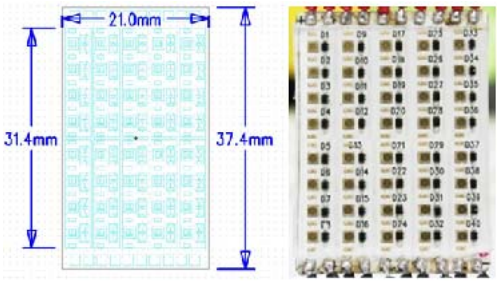
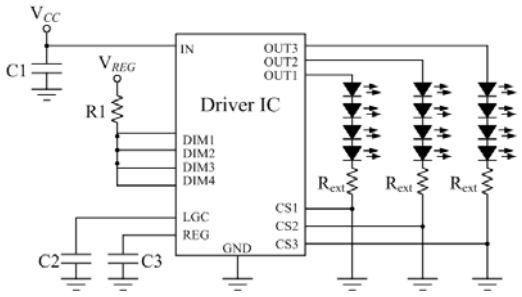


Fig. 1 Configuration of the prototype UV LED module

2.3 UV LED Driving Circuit

Driving by controlling a constant current was required, because the device can be destroyed or slow down the performance during the current is over than the rated current.

For the safe driving of the UV LED, a circuit-controlling constant current was fabricated, as shown in Fig. 2.



(a) Circuit

(b) Photograph

Fig. 2 The prototype UV LED driving circuit

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

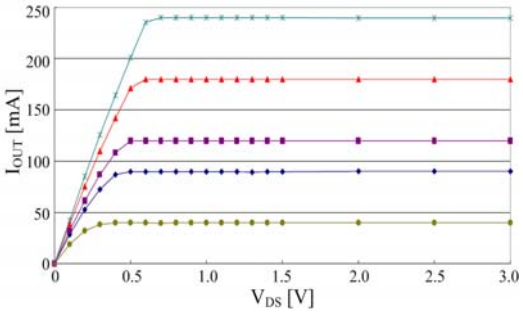


Fig. 3 Current characteristic of the driving circuit

3. Experiments

3.1 Spectrum Analysis

To analyze the optical spectrum characteristics of the fabricated UV LED modules, a spectrometer (Avaspec-3648, Avantes) was used.

The results of the spectrum analysis are presented shown in Fig. 4. The UV LED modules that were used in the experiment showed peak wavelengths at 255, 265, and 280 [nm] and approximately 10 [nm] FWHM (full widths at half maximum). Because the UV LED had the characteristics of a monochromatic wavelength that does not show its spectrum in ranges except for those mentioned above, selective UV irradiation was possible [5].

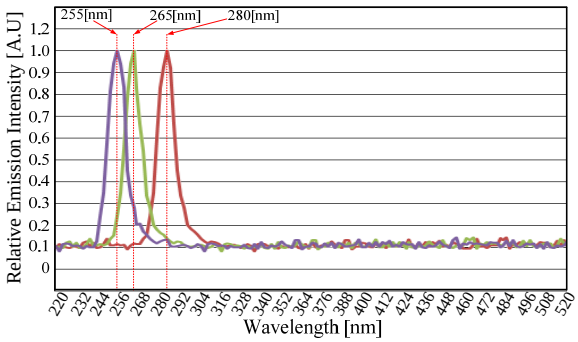


Fig. 4 Spectrum of the UV LED modules

3.2 UV Intensity Analysis

To achieve equal irradiation rates, the UV intensity of each of the fabricated UV LED modules was analyzed using a UV power meter (HD2102, Deltaohm). Fig. 5 shows the UV intensity of the used UV LED modules at 255, 265, and 280 [nm].

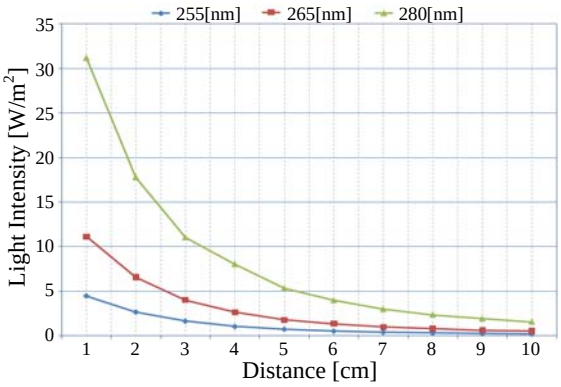


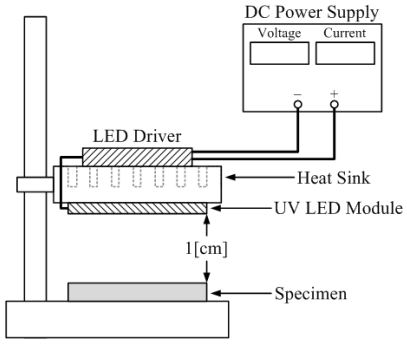
Fig. 5 Intensity of the UV LED modules

Because the module had different UV intensities, the irradiation time was changed to achieve equal amounts of irradiation.

$$UV\ dose = I \times t\ [mJ/cm^2] \quad (1)$$

3.3 Analysis of Disinfection Analysis

To analyze the disinfection characteristics of the UV LED modules, the experiment was set up as shown in Figure 6. The culture fluid of the *Tetraselmis* sp. was placed 1 [cm] below the UV LED module, and an energy volume of 100~400 [mJ/cm^2] was irradiated onto each specimen.



(a) Experimental set-up

(b) Photograph

Fig. 6 Configuration of the experimental apparatus

A fluorescent microscope such as that shown in Fig. 7 was used to determine and calculate the number of disinfected phytoplankton. The disinfection characteristics were analyzed by comparing the number of planktons immediately before/after and five days after the experiment.

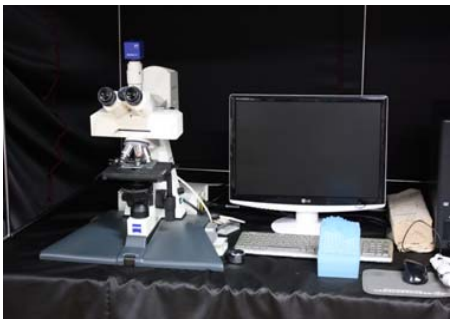
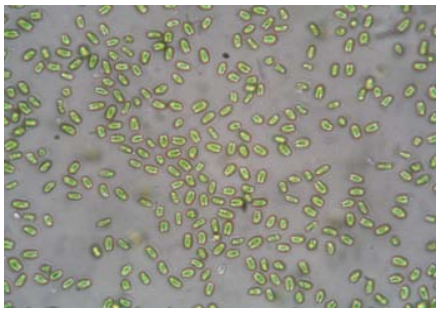


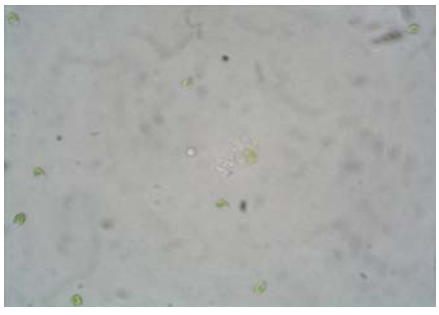
Fig. 7 Photograph of the fluorescence microscope

4. Experimental Results

Fig. 8 shows the shape of the *Tetraselmis* sp. before and after the UV treatment. While the *Tetraselmis* sp. clearly showed a round cell membrane before the UV treatment, the shape of the cell membrane was transformed after the UV treatment [6].



(a) Before



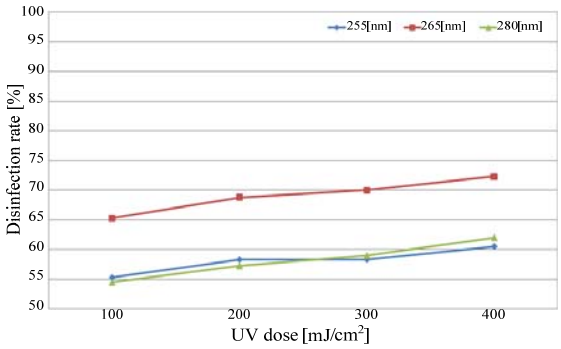
(b) After

Fig. 8 Shape of *Tetraselmis* sp. before and after UV treatment

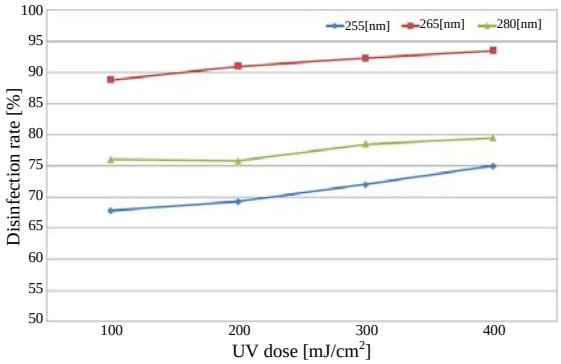
Fig. 9 shows the disinfection rates of the *Tetraselmis* sp. in accordance with the energy that was irradiated onto each UV LED module. The results show that the more the energy

that was irradiated was, the higher the disinfection rate was. The modules showed different disinfection rates: 89~93 [%] for the 265 [nm] module, 68~75 [%] for the 280 [nm] module, and 76~80 [%] for the 255[nm] module.

As a result, in the case of the *Tetraselmis* sp., the valid disinfection area was formed within the wavelength of the UV-C, and especially the highest disinfection rate occurred between at 260 and 270 [nm] appeared the highest disinfection rate.



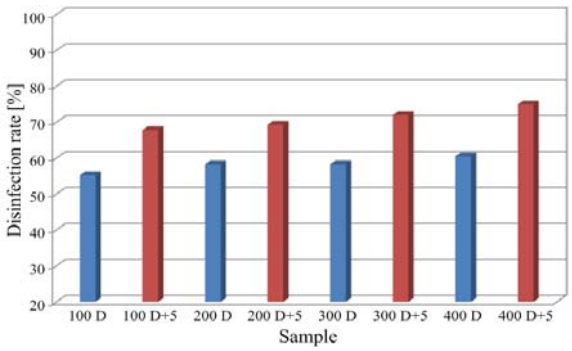
(a) The day



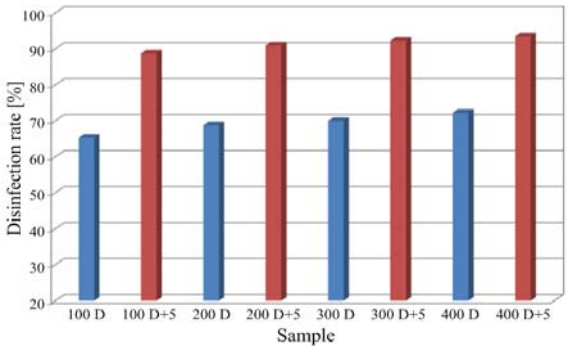
(b) After 5 days

Fig. 9 Comparison of the disinfection rates of the *Tetraselmis* sp. with the UV LED modules

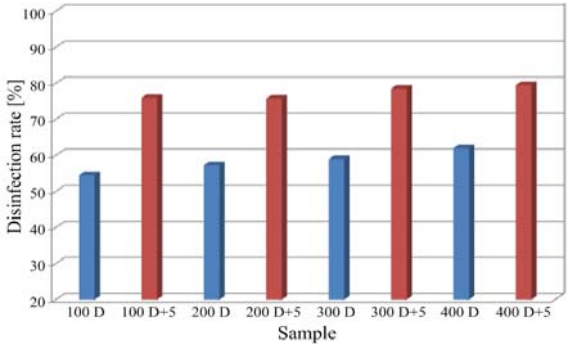
Fig. 10 shows the disinfection rate of each module on the day the experiment was conducted and five days after.



(a) 255 [nm] module



(b) 265 [nm] module



(c) 280 [nm] module

Fig. 10 Disinfection rate of *Tetraselmis* sp. by UV dose

The disinfection rate that was measured five days after the experiment was higher than that on the day of the experiment. This is deemed to have been due to the destruction of the DNA and the suppression of the cell multiplication by the UV light [7]~[9].

5. Conclusion

This paper described the analysis of the disinfection characteristics of UV LED on *Tetraselmis* sp.

In the experiment, the highest disinfection rate occurred with the 265 [nm] UV LED module. The disinfection rate five days after the experiment was higher than that on the experiment day. This is deemed to have been due to the destruction of the DNA and the suppression of the cell multiplication by the UV rays. The experiment results showed that the *Tetraselmis* sp. had the highest absorption rate within 260~270 [nm], which is in accordance with the report that the DNA of cells absorbs well wavelengths close to 260 [nm], such as that of the UV-C. It appeared most efficient to use the 265 [nm] UV LED for disinfecting *Tetraselmis* sp., a phytoplankton, with equal amounts of UV irradiation. Studies on the periodic disinfection efficiency are required, however, since the UV light intensity differs depending on the type of UV LED.

Acknowledgements

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