MEDIUM PRESSURE UV TREATMENT OF BALLAST WATER

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ABSTRACT

This study was undertaken to evaluate the ultraviolet (UV) inactivation efficacy for several indigenous species and the formation of other oxidants and by-products by the treatment of ballast water with medium pressure UV (MPUV). The ballast water treatment system used in this study was composed of filtration modules as a pre-treatment process, followed by a UV process equipped with a polychromatic MPUV lamp. The experiments were performed in seawater and brackish water with a flow rate of 250 m^3/h. The disinfection efficacy of this system successfully met the D-2 regulation of the International Marine Organization (IMO). In addition, oxidants [i.e., H_2O_2, total residual oxidants (TRO) and OH radicals] and potential halogenated by-products (i.e., HAAs and THMs), which might be formed after the MPUV treatment, were investigated.

In conclusion, the ballast water treatment system employing the MPUV physical process not only effectively eliminates indigenous species in ballast water, but also does not generate harmful by-products.

Key words: MPUV, Ballast water, Biological efficacy, Oxidants, Potential by-products

INTRODUCTION

Ballast water provides stability to ocean-going vessels, and its uptake and discharge allow ships to compensate for cargo loads. Since it contains a variety of organisms, including indigenous plankton, bacteria and viruses, and large volumes of potentially contaminated ballast water are discharged to marine environment, ballast water is frequently considered as a major cause for the worldwide transfer of non-indigenous species. The International Maritime Organization (IMO) has established international regulations for the control and management of ship's ballast water and sediments, which regulate discharges of ballast water and reduce the risk of introducing non-native species from ship's ballast water (Lloyd's Register, 2010).

Medium pressure ultraviolet (MPUV) has been known as a disinfection process in drinking water and wastewater treatment. The MPUV lamps radiate polychromatically over a broad band of wavelengths (200–300 nm), which makes it possible to inactivate many marine species that have their specific sensitive wavelengths (Giese and Darby, 2000). In a MPUV irradiation system, the photon flux is a key factor for the inactivation of harmful aquatic organisms. In addition to the photon flux, the MPUV irradiation can generate hydroxyl radicals (•OH), other residual oxidants, such as $HOCl/OCl^-$, $HOBr/OBr^-$ and hydrogen peroxide (H_2O_2) (Cooper et al., 1988; de Mora et al., 2000). Once these oxidants are generated, they could react with dissolved organic matter in the water to form several harmful halogenated by-products, such as trihalomethanes (THMs), haloacetic acids (HAAs) and others.

This study aimed to evaluate the biological inactivation efficacy of several marine aquatic organisms and pathogens in ballast water and to investigate the potential formation of any oxidants and harmful by-products using a MPUV ballast water treatment system.

METHODS

Experimental set-up

The ballast water treatment system (GloEn-Patrol™ system, PANASIA Co. Ltd) (see **Fig. 1**) tested in this study was composed of filtration modules configured in parallel as a pre-treatment, followed by the MPUV process to inactivate the microorganisms present in ballast water. The flow rate was controlled to 250 m^3/h for the land-based test (see **Fig. 2**). The test water was prepared using high salinity sea water at the coast of Busan (> 32 PSU) and brackish water at downstream point of the Nakdong River (20–22 PSU) depending on the required salinity.

Biological efficacy test

For the biological efficacy test, marine organisms (> 50 μm and 10–50 μm size), *Escherichia coli (E. coli)* and the *Enterococcus* group were selected. In order to fulfill the biological water quality criteria of the IMO G8 guidelines, the mixture of indigenous organisms and the cultured surrogate species in laboratory (> 50 μm: *Artemia salina* and *Brachionus rotundiformis* (Rotifer), 10–50 μm: *Amphidinium carterae*, *Scrippsiella trochoidea* and/or *Tetraselemis spp.*) were added into the test water. The disinfection efficacy of this ballast water treatment system on marine organisms (10–50 μm or >50 μm) was evaluated by three kinds of measurement using a light microscope, an epifluorescence microscope and a

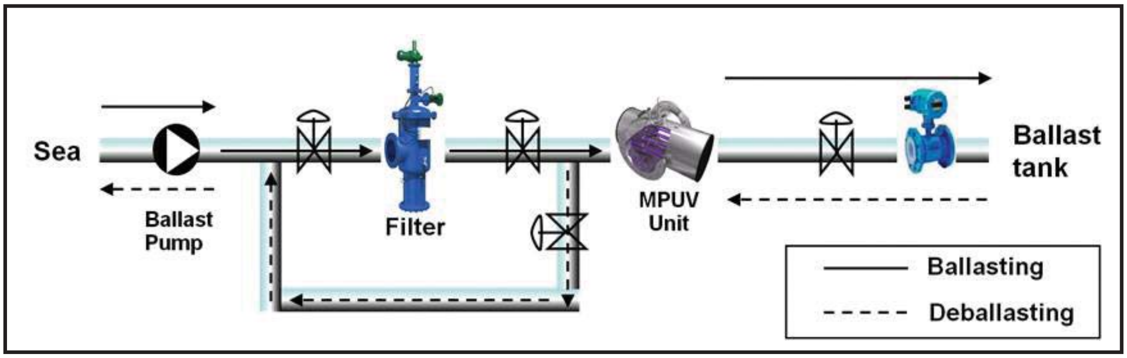

Figure 1. *MPUV ballast water treatment system (GloEn-Patrol™)*

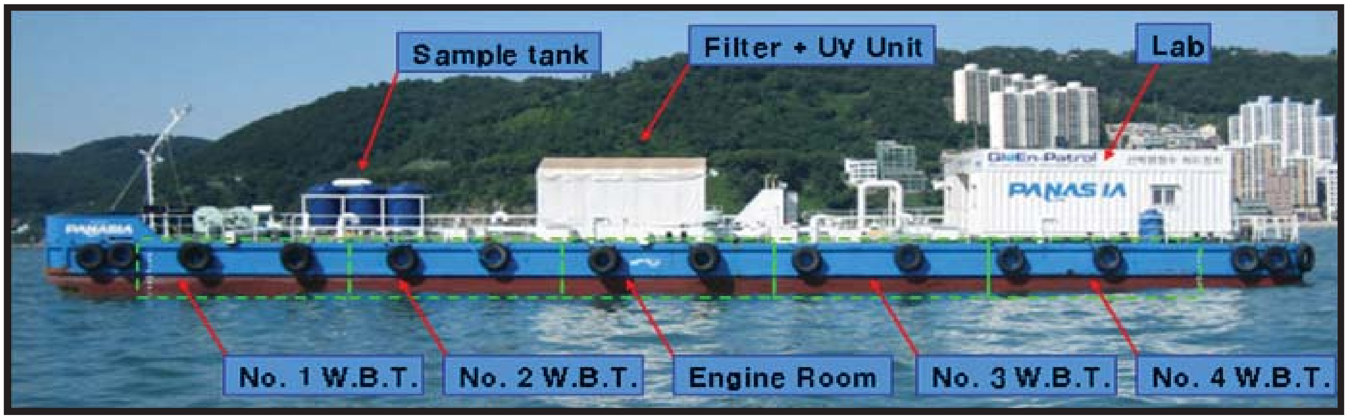

Figure 2. *Land-based test facility*

fluorometer. For *Escherichia coli (E. coli)* and Enterococcus, 10–40 mL of the sample was filtered on a 0.2 μm membrane filter, and then the filters were incubated on the *E. coli* and coliform count agar plate or intestinal *Enterococci* agar plate for 24 h or 48 h at 35 °C.

RESULTS AND DISCUSSION

Biological efficacy test

The biological efficacy tests were performed at two different sites with more than 10 PSU difference in salinity for 5 days. After the MPUV treatment, the treated water and control water (i.e., non-treated water) were stored in a tank for 5 days, following which the numbers of viable organisms or microorganisms were counted.

The initial concentrations of the organisms for the group larger than 50 μm and for the group between 10 and 50 μm in size were 1.8 (± 0.9) x 10^5 inds/m^3 and 1.9 (±0.9) x 10^3 inds/mL, respectively, while the concentrations of *E. coli* and *Enterococcus* were 5 x 10^4 and 4 x 10^2 CFU/100 mL in the test seawater (see **Fig. 3**). After 5 days, 57–98% of organisms in the control water (non-treated water) were killed, while in the treated water most of organisms and microorganisms were inactivated to more than 99.99% of inactivation efficacy. Similarly, in the brackish water (see **Fig. 4**), high inactivation efficacies of more than 99.99% were observed for all tested organisms or microorganisms after the MPUV treatment.

Formation of chemical oxidants and potential by-products

As shown in **Table 1**, •OH and TRO were not detected in either the untreated or the treated water samples, which implies that the MPUV ballast water treatment system does not produce any secondary stable oxidants. As regards H_2O_2, a trace level (18–48 μg/L in seawater) of residual H_2O_2 was detected in the treated water samples after the MPUV treatment. However, knowing that the concentration level was in the μg/L range and that H_2O_2 could be produced naturally by many living organisms, either within the organism itself or in the surround medium (*Anders et al., 1970*), therefore the concentration of H_2O_2 formed during the MPUV treatment is not considered to be problematic in the marine aquatic environment.

Bromate (BrO_3^-) and nitrate (NO_3^-) which are known as toxic inorganic by-products, were not detected in any samples. In the seawater tests, halogenated organic by-products, such as THMs, HAAs, TCE, and PCE, were not detected in either the untreated or treated water samples. In the brackish water, however, low levels of HAAs were detected in both the untreated water (0.6–26.5 μg/L) and in the treated water (0.74–26.5 μg/L). These results arose from the contamination of the raw water with trace levels of HAAs, but were not formed as a result of the treatment.

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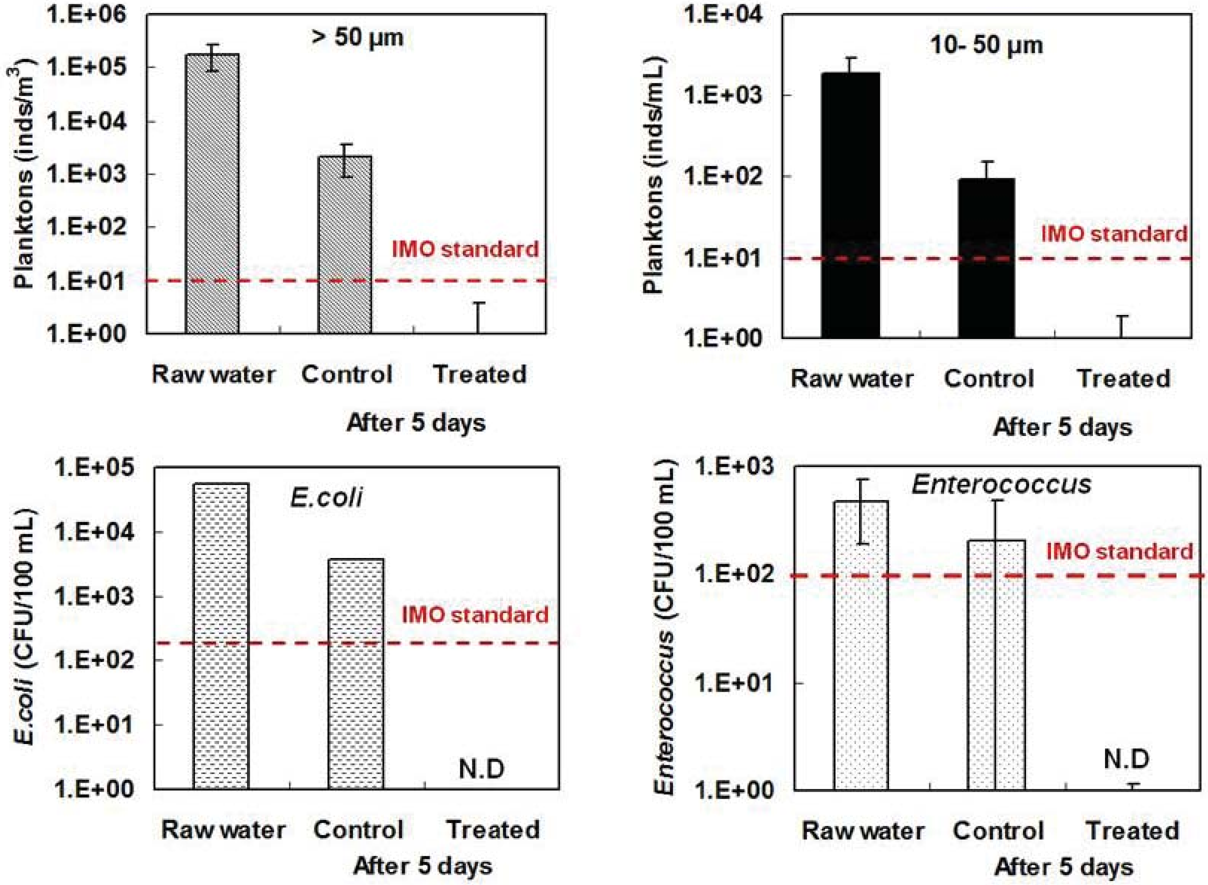

Figure 3. *Biological efficacy: Seawater*

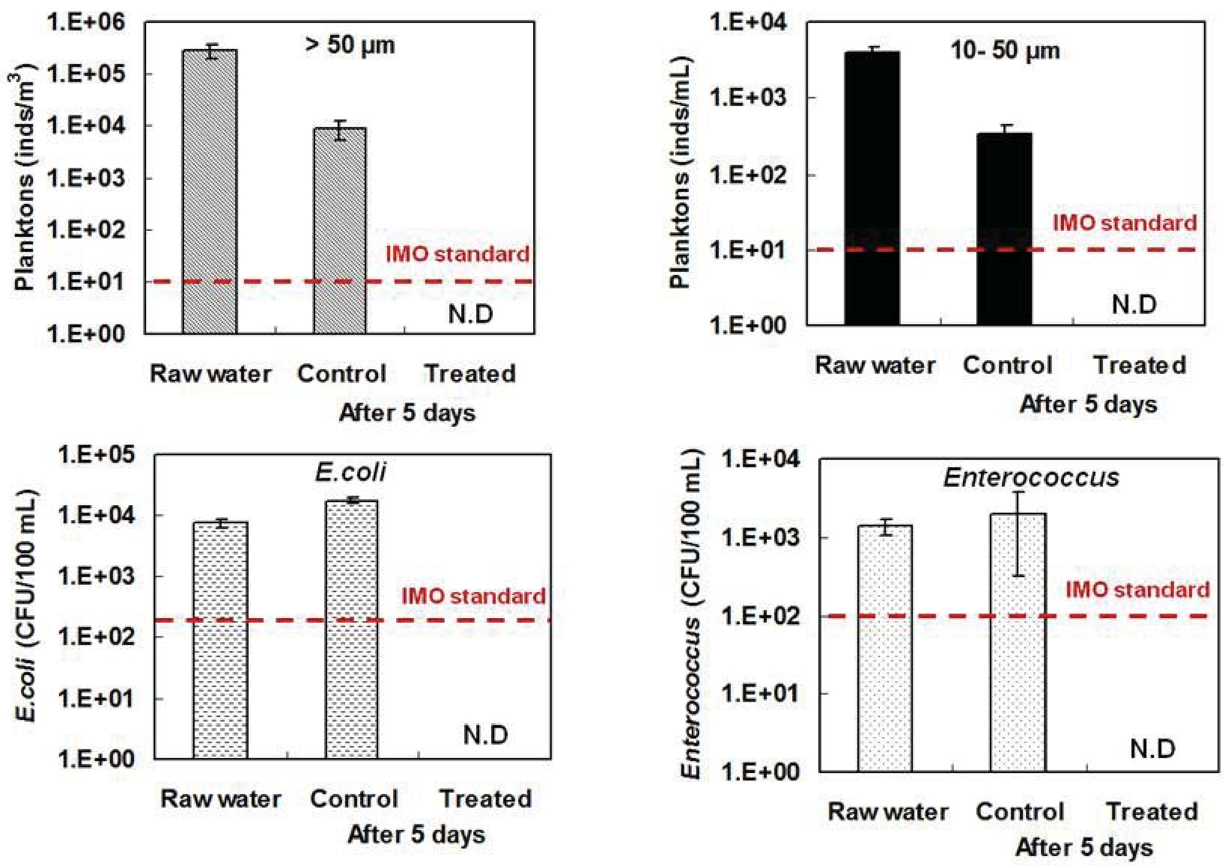

Figure 4. *Biological efficacy: Brackish water*

Table 1. *Formation of chemical oxidants and potential by-products (Seawater)*

Test period		Day 0		Day 3	Day 5	
Procedure		Ballasting		Storage (3 days)	Deballasting (after 5 days storage)	
Parameter	Unit	Untreated water	Treated water	Treated water	Untreated water	Treated water
•OH	μM	ND	ND	ND	ND	ND
TRO[a]	mg/L	ND	ND	ND	ND	ND
H_2O_2	μg/L	ND	48	ND	ND	18
BrO_3^-	μg/L	ND	ND	ND	ND	ND
NO_3^-	mg/L as N	ND	ND	ND	ND	ND
THMs[b]	μg/L	ND	ND	ND	ND	ND
HAAs[c]	μg/L	ND	ND	ND	ND	ND
TCE	μg/L	ND	ND	ND	ND	ND
PCE	μg/L	ND	ND	ND	ND	ND

a. TRO: Total Residual Oxidants, chlorine ($HOCl/OCl^-$), bromine ($HOBr/OBr^-$), mg/L as Cl_2.
b. Chloroform, Bromodic *a* hloromethane, Dibromochloromethane, Bromoform
c. Dibromoacetic acid, dichloroacetic acid, monobromoacetic acid, trichloroacetic acid.

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CONCLUSIONS

The biological efficiency and formation of potential harmful by-products after the MPUV ballast water treatment were investigated for ballast water with various salinities. In the biological efficacy tests, indigenous species (>50 μm and 10–50 μm) and surrogate microorganisms (*E. coli* and the Enterococci group) were tested. The results showed clearly that the organisms and microorganisms tested could be inactivated by the MPUV treatment showing more than 99.99% inactivation efficacy in both water matrices, and the biological efficacy successfully met the standard of International Maritime Organization (IMO). In addition, there were no residual oxidants in the treated water, except for H_2O_2 (18–48 μg/L), and no harmful by-products were formed by the MPUV treatment in this system. In summary, the MPUV system is a clean and effective technology that can safely treat ballast water and does not affect the marine aquatic environment.

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