DEVELOPMENT AND OPTIMIZATION OF A HIGHLY EFFECTIVE AND LOW ENERGY INTENSIVE ELECTRO-DISINFECTION SYSTEM FOR BALLAST WATER TREATMENT

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Abstract

Biological invasions through ships' ballast water create threats to the environment and to the human health and thus, need to treat prior to the discharge. In this study, an innovative electro-disinfection reactor system is developed and optimized for disinfection of *E. coli* in ballast water to achieve the International Maritime Organization's (IMO) guideline, 250 CFU/100ml. Optimized hydraulic retention time (HRT) and current to achieve the guideline are 30 s and 0.3 A respectively. The energy consumption is 0.004 kWh/m^3. Electrochemically produced chlorine is found to be the major disinfectant agent in the system. Electro-disinfection is effective and low energy intensive, thus possesses the ability to improve and use as a technology for ballast water treatment.

Keywords: Ballast water treatment, Chlorine, E. coli, Electro-disinfection, optimization.

1. Introduction

Ballast water is an essential component for the stability of the vessels during the voyage. Ballast water is taken in from the source port when the ship does not carry cargo and subsequently deballast at the destination port when it taken the cargo in. A wide variety of marine organisms can transport from one place to another through ship's ballast water and create environmental, economical and health crisis around the world. The only ballast water management technology practicing so far is the ballast water exchange at mid ocean. This process can either be sequential or flow through dilution (Endresen et al., 2004). Ballast water exchange is not efficient enough in removing the living organisms and not safe enough to the ship and to the crew (http://web.mit.edu/seagrant). Therefore, the need of a safe, efficient and cost effective alternative treatment technology is increasing. Heating technology using the waste heat from engine (Rigby et al., 1999; Thornton et al., 2004), Ultraviolet irradiation combined with pretreatment (Nilsen et al., 2001), ozonation (Herwig et al., 2006) and chemical biocides (Gregg et al., 2007) are some other technologies which have been researched for ballast water treatment. The abovementioned technologies have limitations such as reactivation of organisms, high cost, chemical storage, toxicity and low efficiency in disinfection.

Compared to the above disinfection technologies, electro-disinfection possesses the advantages such as no storage of chemicals and low foot print. In this technology, solution to be disinfected is passed through a reactor equipped with electrodes while applying direct or alternative current to the electrodes. Electro-disinfection has been found to be effective in killing wide variety of organisms in wastewater (Stoner et al., 1982; Patermarakis et al., 1990; Sarkka et al., 2008). Inactivation of living organisms can be due to chlorination (Stoner et al., 1982), lethal oxidants (Patermarakis et al., 1990) or electric shock (Matsunaga et al., 2000). When the wastewater is mixed with seawater, the salinity increases and the electro-disinfection technology becomes more reliable with lower energy consumption (Li et al., 2002). Therefore, it is speculated that the electro-disinfection can be effectively incorporated to the purpose of ballast water treatment. Purpose of this study is to develop an electro-disinfection reactor which can fulfill the IMO guideline D-2 for living organisms in discharging ballast water. In the present discussion, bench scale electro-disinfection reactor has developed and optimized to achieve the IMO guideline for *E. coli* in discharging ballast water. Besides, the major disinfectant agent has investigated.

2. Experimental

Seawater was collected and artificially contaminated with *E. coli* (ATCC 10798) such a way that the initial *E. coli* concentration of the seawater solution is around 10^6 CFU/100 ml. The resulted seawater solution was used as the simulated ballast water in the experiments. The electrochemical disinfection reactor system mainly consisted of the designed reactor, a DC power supply (TDK-Lambda, Japan/Israel), a peristaltic pump (Cole Parmer Instrument Co., USA) and a container to fill seawater with an overhead stirrer. Volume of the disinfection reactor was 1.2 L and contained relatively inert metal electrodes. Experimental design for the optimization of designed reactor for disinfection of *E. coli* was done by statistical software, Minitab 15 (Minitab Inc., USA). Central composite design was selected, according to the number of factors to be handled. Range of HRT and current to be applied were selected as 15-45 s and 0.1-0.5 A respectively. The design resulted in 13 different combinations of applied current and HRT. Seawater solution and the experimental setup which are explained above were used in experiments. For each experiment, two samples were collected after the system became stable for chlorine analysis and detection of *E. coli*.

Na_3PO_4 was selected as the chloride free electrolyte. Concentration of the salt was adjusted such a way that the final conductivity of the Na_3PO_4 electrolyte was similar to the conductivity of seawater. Solution pH was adjusted using H_2SO_4 to reach the pH of seawater. This electrolyte was contaminated with cultured *E. coli* and the concentration of *E. coli* was set to 10^6 CFU/100ml. The experimental setup explained above was used for the experiments. Optimized HRT was used and the investigation was carried out at different energy inputs by varying the applied current. The experiments were repeated under the similar conditions using seawater as the electrolyte.

3. Results and discussion

3.1. System Optimization

Optimization was done based on the final *E. coli* concentration. The IMO guideline for *E. coli* in discharging ballast water, 250 CFU/100 ml, was chosen as the target to be achieved. Optimized HRT and current were found to be 30 s and 0.3 A respectively. To achieve the above results, energy consumption at the electro-disinfector was as low as 0.004 kWh/m^3 (see Fig. 1 (a) & (b)). Further, it was found that the developed electro-disinfection system is capable of achieving 4 log inactivation of *E. coli* which in-turn fulfill the IMO guideline at total residual chlorine concentration of 1 mg/L.

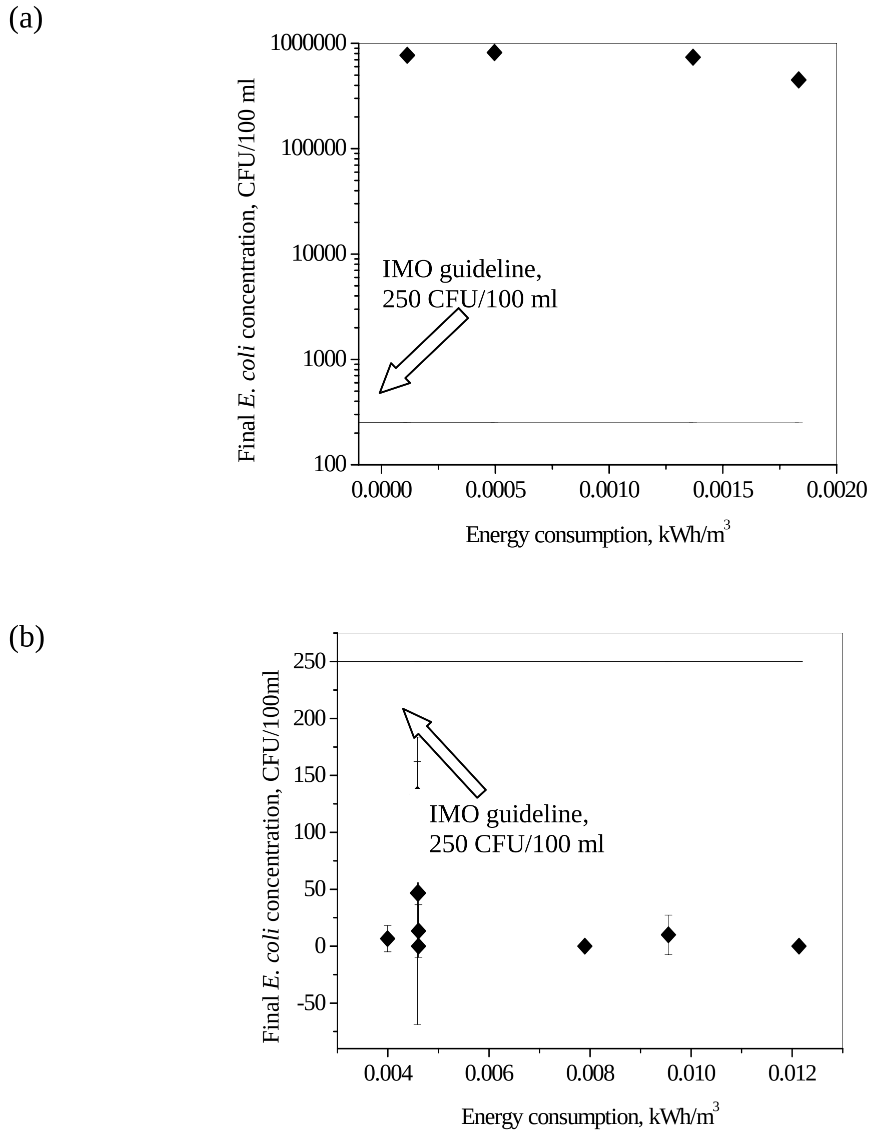

Fig. 1: Comparison of Final *E. coli* concentration with IMO guideline vs. energy consumption. (a) Energy consumptions < 0.004 kWh/m^3.(b). Energy consumption > 0.004 kWh/m^3.

3.2. Effect of chloride ion

Electro-disinfection process can produce several disinfectant agents such as chlorine, ozone and free radicals. Further, there is a possibility of disinfection due to the direct electric shock (Patermarakis et al., 1990; Matsunaga et al., 2000). In this study, the electrolyte is rich in chloride ion which can oxidize to chlorine at the anode. In order to investigate the effect of chlorine and the collective impact of other possible disinfectants, Na_3PO_4 was used as the electrolyte. It was found that the disinfection efficiency when use Na_3PO_4 as the electrolyte is far behind that of the seawater electrolyte. For example, at an energy consumption of 0.004 kWh/m^3, (the value of interest in the present system) disinfection efficiency of the system with Na_3PO_4 was only 22.9% while for the similar energy consumption, disinfection efficiency of the system with seawater was 99.99%. Therefore, it is anticipated that the major disinfection agent of the present system is chlorine, while the contribution of the other mechanisms is about 20%.

4. Conclusions

Electro-disinfection reactor was designed and optimized for disinfection of *E. coli* in seawater and the possibility of using the system in ballast water treatment was evaluated. Ability to meet the IMO regulation for *E. coli* in discharging ballast water was used as the major criterion of optimization. Optimized HRT and the current of the reactor were found to be 30 s and 0.3 A respectively. Specific energy consumption to achieve the optimized reactor performance was 0.004 kWh/m^3. The total residual chlorine concentration at the above conditions was 1 mg/L and the disinfection efficiency was 99.99%. Electrochemically produced chlorine was found to be the major disinfectant agent while the other disinfection mechanisms contributed to about 20% of the inactivation.

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