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# Microbial disinfection of seawater using hydrodynamic cavitation

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ABSTRACT

Hydrodynamic cavitation has been effectively proven to be an efficient advanced oxidation process on an industrial scale. The utility of hydrodynamic cavitation for microbial disinfection of seawater has been reported in this work. Seawater is used as cooling water in refineries and nuclear power plants or as ballast water in the shipping industry. Various norms and regulations of the International Maritime Organization (IMO) make it compulsory for ship owners to treat the ballasting seawater before discharging it into the sea. Also, if the seawater is not properly treated, it causes biofouling which affects the performance of cooling tower and other heat transfer equipments. It has been observed through our study that, hydrodynamic cavitation can be effectively used for microbial disinfection of seawater. Effectiveness of different types of cavitating devices for the extent of disinfection was studied. It was conclusively proved that, slit type of geometry consumes 40% less energy compared to cylindrical geometry for similar extent of seawater disinfection. A combination of the conventional treatments of water disinfection such as chlorination and thermal treatment with hydrodynamic cavitation was found to increase the overall rate of disinfection significantly. Rate of reaction almost doubles when 5 ppm hypochlorite was used as disinfectant with the combination of cavitation compared to when only 5 ppm of hypochlorite was used. Similarly the rate of disinfection increases 2.5 times at 50 °C in combination with cavitation compared to when, only 50 °C was maintained and disinfection was carried out.



## 1. Introduction

For the past 30 years there has been a remarkable growth in the reported work on an efficient treatment and water purification technique by all categories of users. The categories include municipal, industrial, institutional, medical, commercial and residential. The increasingly broad range of the reported techniques for improving water quality has motivated the water treatment industry to refine existing techniques, combine different methods and explore new emerging water purification technologies. Similarly, seawater disinfection is equally important due to its applications in shipping industry and refineries.

Ships use ballast water to provide stability and maneuverability during a voyage. Water is taken on at one port when the cargo is unloaded and usually discharged at another port when the ship receives a cargo. The local microorganisms, ranging in size (from viruses to large fish) living in the surrounding water or sediments, are taken on board with ballast water. There is a potential danger for the introduction of non-native organisms – called *bioinvaders*, alien species, nonindigenous species or exotic species – into the port of discharge. In order to avoid this problem; IMO has made it compulsory to all shipping companies to treat the water before discharging it into the sea again [1]. Unfortunately no single ballast water management technique has been able to remove all types of organisms from ballast tanks. A combination of different methods may prove to be more effective than one method alone, however little research has been conducted into this possibility. It is difficult to implement treatments because the ship owners are understandably reluctant to install technology that is expensive, unreliable or time consuming. When evaluating ballast water treatment options a number of general factors must be considered. The factors include cost, the effectiveness of the method, the footprint and the possible external risks, which the treatment may pose to human health and the environment during its enforcements. The monetary cost of a treatment method includes the cost of the equipment, the crew needed to operate the treatment equipment, the cost of the disinfectant chemicals and the time needed for the treatment. Many treatment methods require the ships be retrofitted with the necessary equipment or in new ships these equipments included as an integral part in their design. Both of these options may be quite expensive. The ship's crew members have many tasks to perform on a ship, thus, the crew that is needed to operate this additional treatment task may decrease the number

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**Nomenclature**

| | | | |
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| $N$ | viable microbial count at time $t$ (CFU/ml) | $k$ | rate constant for disinfection ($min^{-1}$) |
| $N_0$ | viable microbial count at the beginning of the experiment (CFU/ml) | $P_h$ | pump discharge pressure (Pa) |
| $E$ | hydraulic energy input (J) | $Q$ | volumetric flow rate ($m^3$/min) |
| $E'$ | hydraulic energy input per unit volume (J/$m^3$) | $t$ | time (min) |
| | | $V$ | volume of seawater ($m^3$) |

of crew members that are available for other essential ship operations. If a treatment method slows down the journey of a vessel or causes excess fuel consumption the voyage will be more expensive and uneconomical. Any adapted treatment method should also provide easy means for port authorities to monitor its operations and effectiveness. As many treatment methods work on the basis of killing the organisms in ballast water, the method itself may pose a risk to human health or to the environment if the treatment is not properly carried out in the ballast tanks. These risks and costs need to be evaluated and compared to the risk of introducing alien species in a port.

Different methods, physical and/or chemical can be used for treating the ballast water. Each method has its advantages as well as disadvantages. The physical methods include methods such as, filtration and use of hydro-cyclone [2–4]. In filtration, screens or strainers are used as filter media. In hydro-cyclones, high velocity centrifugal rotation of water is used to separate the particles/organisms. Both these methods can filter larger organisms and sediments from the seawater very effectively, but cannot filter out smaller target microorganisms. Also, filter screens need periodic backwashing and also a larger surface area for the higher filtration rates. Hydro-cyclones are less effective than filters in terms of their removal efficiency. Filtration can be used in combination with the other disinfection technologies as they are very effective in removing the larger organisms. The chemical methods for disinfection includes, use of chlorination, electrochlorination, ozonation and hydrogen peroxide [5–8]. In chlorination, chlorine gas is dosed in water which destroy cell walls of the organisms which leads to their death. Chlorine gas is inexpensive, but is extremely corrosive, even at residual level. Instead of chlorine gas, sodium hypochlorite can be used as a source of chlorine and can be injected into ballast water stream. The problem with chlorination is the high doses of chlorine requirement when other organic contaminants are present. It is dangerous in terms of handling and safety precautions needs to be taken. Also, the organic matter in the seawater forms toxic halogenated organic compounds during chlorination, which needs to be separated and disposed off safely. In electro-chlorination, electrolytic decomposition of seawater to $^{-}OCl$ and HOCl (hypo-chlorous acid) takes place and the acid acts as a disinfecting agent. The only advantage of this method is that, it does not require any additional chemical storage and use. But this method is ineffective against cysts and form harmful disinfection by-products (DBP's). Also, separate installation of electrochemical cells can increase the initial capital cost investment. In ozonation, ozone gas is passed through the stream of seawater. Ozone is very powerful but unstable oxidizing agent which can effectively kill microorganisms along with spores when used as a disinfecting agent. Ozone chemistry in seawater differs from that in fresh water because of the presence of bromide ions [1,9]. It has been reported that the bromine in seawater gets converted to hypobromide ion and hypobromous acid, which leads to the formation of bromoform, which is a toxic by-product and possible carcinogen produced by reaction with organic matter. This bromine ion hindrance leads to the requirement of higher concentration of ozone and longer contact times. Hydrogen peroxide ($H_2O_2$) can be also be used as a disinfectant for seawater. Hydrogen peroxide is an uncharged molecule that passes easily through cell membranes by diffusion. Inside the cells, reactive and destructive hydroxyl radicals are liberated by $H_2O_2$. The oxidizing properties, the rapid degradation, the environmentally friendly degradation products (water and oxygen), and the fact that it can be produced electrochemically make $H_2O_2$ a promising disinfectant for onboard treatment of ballast water.

Several authors have reported the use of advanced oxidation processes such as microwave irradiation, UV radiation, fenton oxidation for ballast water treatment [10–13]. Although these techniques are effective in removing the seawater microorganisms, the major problems are associated with the scale up and maintenance of such processes on board a ship. Installation and operating costs of such systems is another major issue which has not been addressed yet satisfactorily.

In this work we have tried to use the technique of hydrodynamic cavitation for microbial disinfection of seawater. Hydrodynamic cavitation has been effectively proved to be an efficient technique in terms of energy consumed and cost of operation for the disinfection of bore well water and industrial effluents [14,15]. Shivram et al. [16] have carried out the seawater disinfection using cavitation produced by vortex diode and have proved its effectiveness in killing of various types of zooplanktons present in the seawater.

The physical and chemical effect of hydrodynamic cavitation includes creation of high temperature and pressure shock waves and generation of highly reactive hydroxyl radicals [17]. Shock waves could also possibly cleavage the molecular bonds. The free radicals thus generated can oxidize organic pollutants, and extreme temperatures (hot spots) can also pyrolyse the molecules if they are in the vicinity of the collapsing cavity [18]. However these processes are most likely of less importance in the case of disinfection by hydrodynamic cavitation, because of the larger sizes of the microorganisms [19] which need to be targeted. In addition to the generation of strong oxidizing agents, cavitation bubble collapse also results in the generation of shock waves, high shear regions, high temperature and pressure pulses. Such adverse/extreme local environmental conditions may result in the mechanical rupture of the cell walls, loss of intracellular materials which eventually results in cell death. Which of these diverse mechanism is responsible for the actual disinfection and to what extent, is very difficult to predict. It has been assumed that the combination of all these collapse conditions contribute at least partially to the disinfection of microorganisms in the case of hydrodynamic cavitation. It is very difficult to predict the exact mechanism of disinfection in the case of cavitation based disinfection/disruption operations. Several authors have tried to predict the mechanism of disinfection/disruption using cavitation. Balasundaram and Harrison [20] have carried out the disruption of *Escherichia coli* using orifice plate for the purpose of preferentially releasing the intracellular proteins from organisms. They have proposed a stage wise disruption of cells for the protein release for multiple passes through orifice plate. In the first stage, the outer membrane is perforated allowing the loss of periplasmic proteins. In the second