

A study on the effect of pulsed power ultrasound waves on marine biofouling

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Ultrasonic technique is one of the promising non-invasive technologies to control biofilm formation on the marine substratum. A prototype ultrasonic system was designed and developed to control biofouling in the marine environment. The Ultrasonic technique was utilized to control the biofilm formation on copper test coupons suspended in a continuous seawater flow through system. The colonization of microorganisms promotes settlement of higher order organisms; therefore, deactivation of microorganisms is likely to affect the fouling density. Ultrasonic sound waves at 25 kHz with an electric drive power of 500 watts were used to control aquatic biofouling and growth in an open seawater circulation experimental setup. The ultrasonic waves create microscopic cavitations which damages the outer cell structure of microorganisms destroying them and preventing them from growing around the ultrasound exposure areas. The experiments were conducted continuously over a period of 21 days and were repeated several times to ensure reliability. A reduction in the microorganism activation was observed on the ultrasound exposed area besides preventing damages to the structure of the test coupon. Based on the encouraging results, a low cost prototype ultrasonic digital system controlled by pre-programmed microchips was custom built and the same is being planned for further studies in the frequency range 20 – 40 kHz.

[**Keywords:** Pulse power, Ultrasonic waves, cavitation, Biofouling control]

Introduction

Marine biofouling is a natural process occurring in the ocean as soon as any structure is submerged or moored underwater and it was found as a limiting factor for achieving economic ocean resources exploration and climate prediction. Climate change prediction is a challenging and complex task because of biofouling over the sensors and system deployed in the open ocean and that affects the quality of signal measurements and interfere with the performance of various systems. Biofouling control is a very complex process and must be studied simultaneously in two approaches such as the improvement of knowledge of biofouling kinetics and the development of prevention strategies. These two methods should be correlated to get efficient biofouling control solution¹. Direct Current and voltage application to the structure deployed in the marine environment is one of the methods of biofouling control but continuous release of heavy metals creates environmental issues². In the coastal regions, the biofouling rate, especially biofilm formation, is too high because of high biological input, nutrition and pollution. Biofouling control in the coastal area is a challenging and complicated task³. Biofouling and biofilm

formations are universal problems that increase fuel consumption and system maintenance costs. The approximate cost of biofouling maintenance to the US Navy is 260 million dollars per annum⁴. The use of TBT (Tributyltin) based toxic biofouling control paint was completely banned internationally from 1 January 2008 onwards⁵. Multiple field studies related to biofilm and biofouling control has to be examined and integrated to get a better solution for marine biofouling control⁶. The ultra-sonication technique is a promising environmental friendly, non-chemical marine biofouling control method but this method is highly efficient only if it is applied from initial stage onwards. Optimized system will provide an economic and efficient solution to the marine biofouling control⁷. The main objective of this study was to determine the effectiveness of the ultrasonication system in real time to control biofilm formation in the test coupons deployed in a seawater tank. The custom made designs would help to develop a novel cost effective ultrasonification system to prevent biofilm formation in marine Instruments, Nuclear power plants and marine sensors. Integration of suitable power transducers to the ultrasonic power amplifier system is required for maximum energy transfer to cover the large

control area and to achieve maximum biofilm control. Optimization of pulse power transfer mode may be useful for effective utilization of power transfer to the load.

Materials and Methods

To investigate the ultrasonic technique in real time operation for the control of biofilm, a functional model was established at the sea front laboratory of the National Institute of Ocean

Technology (NIOT) located at Neelankarai, Chennai. The real time system consisted of ultrasonic frequency signal generation module (Function generator), power amplifier module; Impedance matched piezoelectric ultrasonic frequency transducer, test coupons, tanks, continuous water circulation pumping system, seawater intake pumping system, and 1 ton Fiber Reinforced Plastics (FRP) tank as shown in the Figure 1.

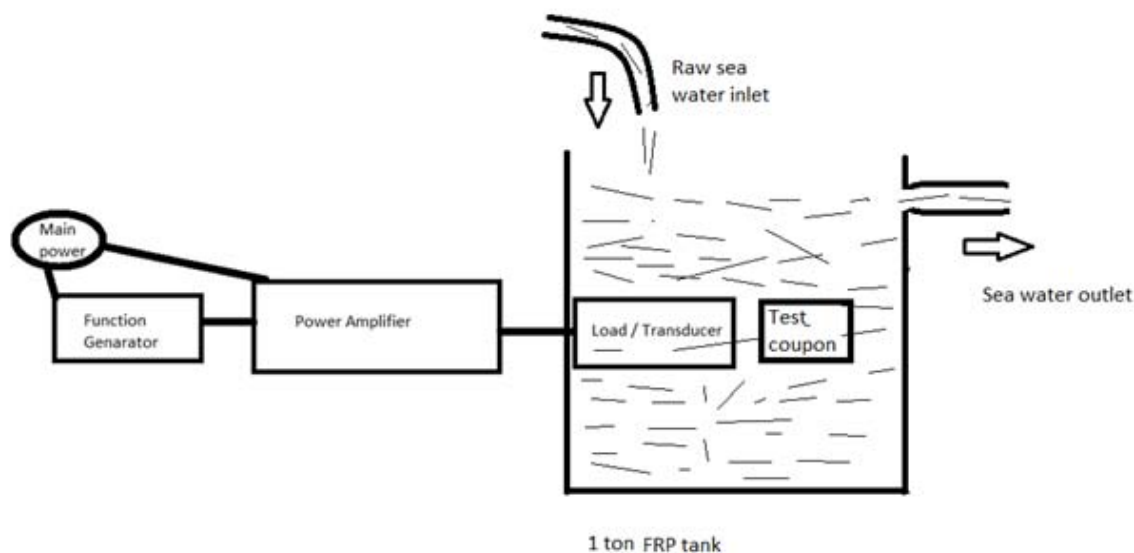


Fig. 1 - Schematic block diagram of pulsed power ultrasonic system setup for biofouling control

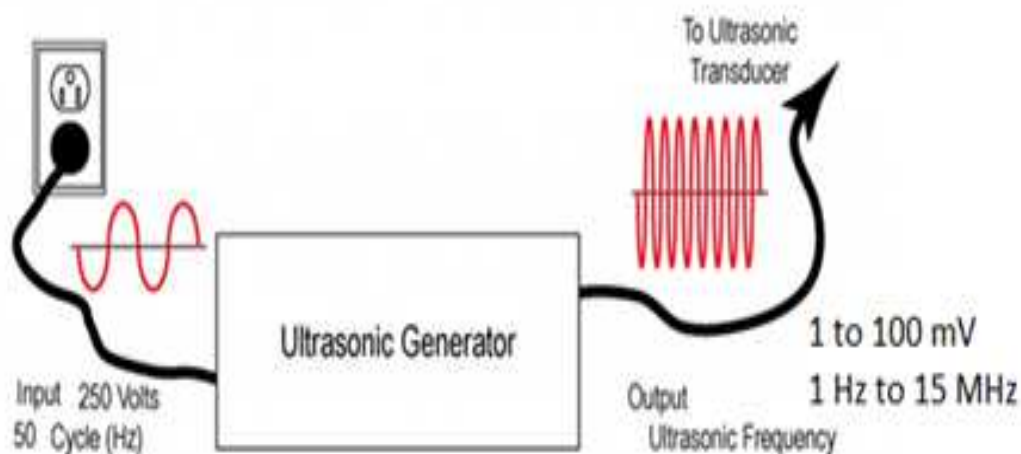


Fig. 2 - Real time signal generator system

In the real time experiment HP (Hewlett Packard, HP 33120A) function generator system was used to generate the signals. A signal frequency of 25 kHz, sinusoidal wave form shape

of 100mV was selected in the experiment. A signal generator generates voltage wave forms at a desire repetition rates. An ideal signal generator can simply be modeled as a voltage source. A

practical signal generator is modeled as an ideal signal generator and was connected in series to the source resistance. The terminal voltage $v(t)$ was the output of the signal generator and depended on the terminal current and resistance.

The signal generated from the HP signal generator was connected to a power amplifier system for signal power amplification. In the real time experiment, Instrument Inc. make class AB type (Model: M2) power amplifier was used for signal power amplification to eliminate the inherent non-linearity of Class B designs and to avoid heat-generation and wasteful inefficiencies of the Class A design. Total distortion of the system is less than 2% only. Each Output PWB (Printed Wiring Board) drives an individual output transformer, which is located on the board to minimize wiring inductance. The small size of this transformer and second breakdown considerations of the output transistors limit the low frequency response to 10 kHz. Each amplifier board was rated at 100 VA continuously or 250 VA in tone bursts up to 1 second duration and 10% duty cycle. The high frequency response with resistive or inductive loads can be varied up to 500 kHz. The amplifier is user friendly variable without any overload to the amplifier. 25 kHz frequency rated 100 mV input voltage was supplied to the pulse power amplifier system and the output of the power amplifier was around 3.4 A, 147 V, 499.8 watts pulse power ultrasonic signal. The pulsed mode power was connected to a custom built piezoelectric transducer (reactive Load) using a BNC connector.

The 25 kHz frequency rated piezoelectric acoustic transducer was fitted inside the continuous flow-through tank system. The transducer was connected to pulsed power ultrasonic transducer module using rated BNC connector cables. A Tonpilz piezoelectric transducer converted the electrical input signals to corresponding acoustic signals using electro-acoustic technique. When a piezoelectric material is subjected to stress or force, it generates an electrical potential or voltage proportional to the magnitude of the force. This type of transducer makes an ideal converter of mechanical energy or

force into electric potential and vice versa. These transducers are simple, reliable, and very robust, and hence find wide use in marine research and acoustic signal analysis. The seawater intake system was set up in order to assess the intensity of biofouling on copper coupons. One set of coupons was kept in a FRP tank without ultrasonic treatment. In the second FRP tank, another set of coupons was exposed to pulsed powered ultrasonic wave. The flow rate of seawater was fixed 1 L / sec during experiment.

Results

The experiment was carried out using pulsed power ultrasonic signal, the power and frequency applied to the test coupon was around 500 watts (147 Volts, 3.4 Amps) and 25 kHz, respectively. Copper metal coupon, admeasuring 9×15 cm, was used for the experiment. The pulsed power biofouling protection area of the test coupon was around 50 % and is observed in the exposed copper coupon (Fig. 3). In the active ultrasound exposed area fouling was not observed and such 100% biofouling protection in the active ultrasound exposed area is not reported elsewhere till date using ultrasonic environmental friendly technique. This study indicated a significant marine biofouling control in the test coupons. The experiment was carried out over a period of 21 days using coastal nutrient rich raw seawater from off-Chennai, India. To confirm the results, the tests were conducted three times and in all the experiments similar results were obtained. Visual observation of test coupons and control coupon confirms the control of marine biofouling with the effect of pulsed power ultrasonic signal. During the standardization of the experiment we observed power loss in the load section owing to transducer impedance mismatching with pulse power amplifier module. To avoid the power losses we developed 100 % impedance matched power amplifier and transducer module.

Discussion

The frequency range and test coupon material were selected with a careful review of previous reports and analysis. In an earlier report

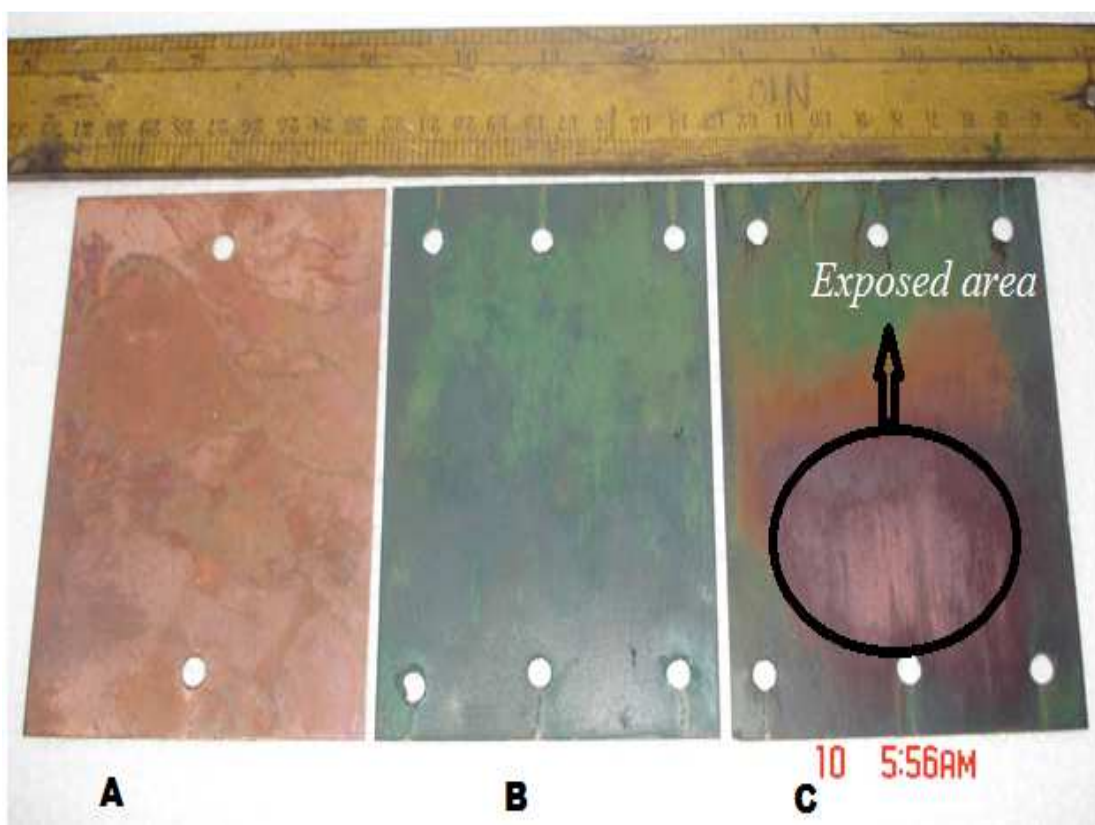


Fig. 3. Shows the effects of ultrasonication on the unexposed coupon (A), control coupon without ultrasonication (B) and experimental coupon subjected to 25kHz(C).

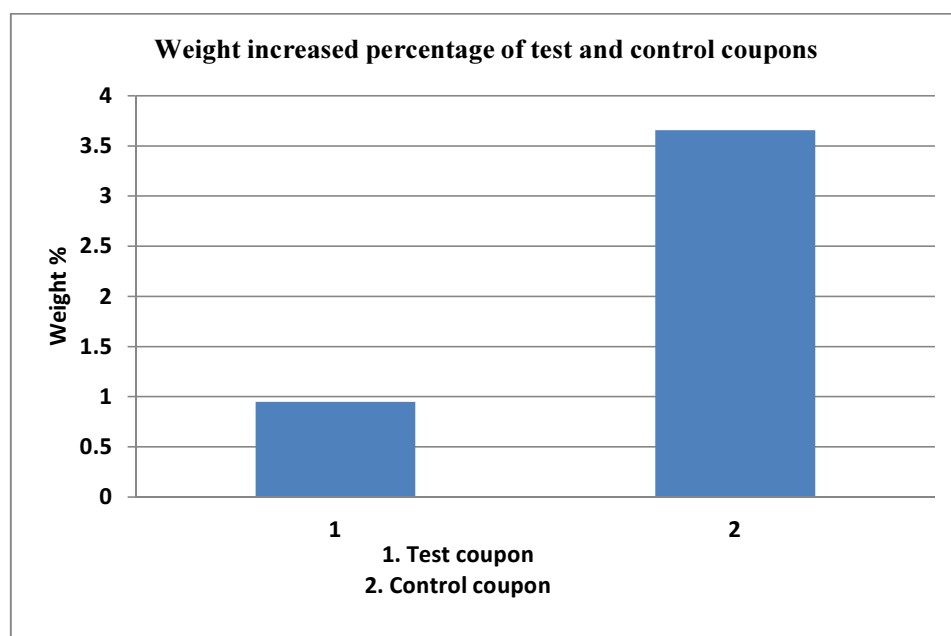


Fig. 4 - Shows the percentage weight increased in the test and control coupons.

it was reported that the frequency ranges from 35 kHz to 100 kHz did not induce higher cavitation but in the lower frequency range the cavitation rate was very high⁸. Ultrasonic

treatment for biofouling control gives better results compared to chemical based treatment methods because the chemical methods releases environmentally hazardous materials and

molecules to the ocean. In contrast, low intensity ultrasound will not cause any cumulative effect after treatment and this makes ultrasonic treatment technique as an environmental friendly technique⁹. It processes several benefits over chemical-based or biocide strategies. Chlorination for biofouling control was initiated way back in 1924 and chlorine remains the most widely used biocide for biofouling control because of non-availability of cost effective promising biofouling control technology. Ultrasound could be applied in a discontinuous pulsed fashion, as has been described for electric fields to save energy and to distribute energy in efficient way¹⁰. Cavitation induced by ultrasound has been used to control the viability of several organisms, including bacteria and algae growing on solid substrates. Cavitation is followed by implosion, which generates high liquid shear forces. High intensity ultrasound could develop higher levels of cavitation, which can be used to control biofouling¹¹. The interesting result of the experiment is to increase the active ultrasonic exposure area. Since, this is a lab scale prototype experiment; we have used small transducer for this study. Only a particular area of the coupon was exposed for the treatment, the exposed area (Active area) is marked in the picture (refer Fig.3). It is very clear there was no fouling in the exposed area, evident even to the naked eye. The experiment was conducted thrice and all that time the results were almost same. Fouling organisms were scraped from the control and treated coupons and observed under the microscope and the fouling status for both control and test coupons were confirmed.

The weight of both test and control coupons were measured before and after the experiments for analysis. It was observed from the results that the weight increased by 0.9479% in the test coupon (weight before experiment: 133.970 mg, weight after the experiment: 135.240 mg), while in the control coupon the weight increased by 3.658 % (weight before the experiment: 134.210 mg, weight after the experiment: 139.120 mg). The results revealed that there is a significant fouling control in the test coupon compared with control coupon. To achieve the high active load area multiple transducers using single power amplifier interface module was developed and the testing is under progress.

Conclusion

Based on this study, pulsed ultrasound might be a promising technique for marine fouling prevention and is likely to be site specific

with respect to the frequency of operation. Chemical methods are being banned in some cases because of environmental issues. To make promising environmental friendly non-chemical treatment for biofouling control further investigations are needed. Pulse mode ultrasonication is found to be a promising technology if the system economics and operational costs can be optimized. The results revealed that ultrasound can completely control the biofilm formation in the marine structures. Undoubtedly, a thorough assessment of the effect of ultrasound on the marine environment would be prudent before its widespread application. With an optimized engineering design, its implementation will ideally prevent biofilm formation from the basic stage while limiting the impact of ultrasound to the marine environment.

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