On-line biofouling control in the plate heat exchanger system through osmotic shock

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Cost effective control of biofouling is a challenging task in the hazardous environment, especially in the nuclear power plants and desalination plants. Biofouling control of plate heat exchangers was investigated extensively using osmotic shock and the effectiveness of the method was evaluated using microbiological data. Microbiological analysis were carried out in the inlet and outlet sea water and compared before and after the osmotic shock. Prevention of scale deposits in the plate heat exchanger system can benefit particularly nuclear power plants and desalination plants and avoid unexpected production shut-downs resulting in substantial improvement to power production in nuclear power plants. The water quality data showed significant fouling control and improvement in the plate heat exchanger operation. The plate heat exchanger system was examined for two different duration (5 and 10 days) and two different temperature regime in order to test system efficiency and to prevent the biofilm formation. A detailed analysis of the entire treatment process was correlated with the microbiological observation and functioning of the system.

Keywords: On-line monitoring, biofouling control, PHE

Introduction

Biofouling refers to the undesirable accumulation of a biotic deposit on surface. It is observed in many surfaces ranging from ship hulls, oil, automobile, steel, and paper production, food, beverage industries and plate heat exchanger. Plate heat exchanger has a wide range of application in many industries like power stations, desalination plants and milk and dairy industry. It is very important to arrest the biofouling at the stage of induction and growth of microorganism and to analyze the presence of microbial load in plate heat exchangers. Fouling problems cannot be avoided in many heat exchanger operations, and it is necessary to introduce defensive measures to minimize fouling and the cost of cleaning. Deposits accumulating in the small channels of a compact heat exchanger affect both heat transfer and fluid flow. Fouling deposits constricting passages in a compact heat exchanger are likely to increase the pressure drop and therefore reduce the flow rate. Reduced flow rate may be a process constraint; it reduces efficiency and increases the associated energy use and running costs as well as maintenance costs. Chlorination for biofouling control in marine industries, nuclear power plant cooling water system and in other fields was initiated way back in 1924. Even after nine decades, chlorine remains the most widely used biocide for biofouling control because of non-availability of alternate cost effective promising biofouling control technology. Chlorine dosage is an important factor to reduce the environmental problems and effective biofouling control in plate heat exchanger system. Optimization of the chlorine dosage was achieved by conducting sequence of experiments in the floating real time Ocean Thermal Energy Conversion (OTEC) power plant plate heat exchanger system. The chlorine gas and sodium hypochlorite for antifouling treatments has been banned in the Venice lagoon and the industries were instructed to identify novel methods to control the biofouling without using dangerous chemicals. Prevention of biofouling in the plate heat exchangers will reduce the operational cost; improve the system life time and the performance of the plate heat exchanger. Real time biofouling monitoring in the PHE is too difficult a task because it requires often dismantling of the PHE and also affects the system operation time and cost. The main objective of this study was to...
determine the effectiveness of the osmotic shock method in the real time biofilm formation control in the plate heat exchanger system; development and optimization of novel cost effective biofilm prevention method for plate heat exchangers using online monitoring system in marine applications.

**Materials and methods**

The experimental setup consisted of plate heat exchanger, data logger, resistance temperature detector (RTD), thermostat, personal computer (PC) and sea water pumping system. To investigate the thermal osmotic shock technique in real time operation for the control of biofilm formation, a functional model was established (Fig.1) at the sea front laboratory of the National Institute of Ocean Technology (NIOT) located at Neelangarai, Chennai.

A stainless steel plate heat exchanger system was used to transfer heat between two liquids. A cross flow plate heat exchanger system was selected to evaluate the proposed non-chemical method for the on-line real time biofouling control. In a plate heat exchanger, plates are arranged in such a way that it forms channels of hot and cold liquid alternately. Due to corrugations in the plate high turbulent flow increases the heat transfer rate.

A picologger on-line data recorder system was used for the real time plate heat exchanger temperature monitoring. This system consists of twelve analog channels which were configured and calibrated to record the real time temperature data. Pico data logger system can be connected directly to USB port in the computer and does not require separate power supply for system operation. Powerful and user friendly picolog software (software name: picolog, software version: picolog for windows 3.1x) was used for sensor calibration, offset correction and real time data recording in the computer. The sampling rate of the data logger system was around 1 MS / sample and the resolution was 12 bits. Four RTD sensors (model : PT – 100) were fixed on the plate heat exchanger inlet and outlet ports and suitable analog circuits were also designed and implemented for real time temperature recording. The resolution of temperature sensor was 0.01°C. In order to minimize the effects of the lead resistances in the RTD sensors, a three-wire configuration was used.

The Tamson Low temperature Circulator (TLC-2) was used for both heating and cooling operation. The temperature rating of the TLC-2 is from -20°C to 100°C. Accurate temperature regulation was achieved by using a microprocessor controlled proportional integral and derivative (PID) system also enabling an “auto tune” and controller tuning function (Fig.1 & 12) for optimum setting of the temperature regulation.

The sea water intake system was set up in order to evaluate the biofouling on the plate heat exchanger system. The flow rate of sea water in the plate heat exchanger was fixed at 10 L / min for the entire experiment. The thermostat was filled with fresh water and connected to PHE for biofouling on-line monitoring experiments. The thermostat temperature was maintained around 15°C for low temperature experiment and 44°C for high temperature experiment. The water in the thermostat circulates with the help of its pump and it is a closed loop system. Hence, the hot water from the thermostat flows to the hot water inlet of the plate heat exchanger set-up, through its outlet valve. Osmotic shock was applied to the PHE by using fresh water circulation based on the change of temperature (Δt) value and its performance for various temperature shocks applied to the system for effective system operation. Finally the fresh water was collected and mixed well to make the uniform suspension of debris or biomass. The initial and final turbidity of fresh water was measured using water quality measurement system (make: Hydrolab, model: Quanta).
The samples were collected on every 7th day up to 78 days for high temperature experiment and on every 4th day up to 40 days for low temperature experiment. The microbial load was analyzed for all the collected sea water samples to identify the influence of temperature on microorganisms. The spread plate technique was used to estimate the total viability count of microorganisms. Different culture media like Zobell marine agar, heterotrophic plate count (HPC) agar and pseudomonas agar were used for the bacterial enumeration in triplicate.

Results and discussion

Control of biofouling in PHE experiment was conducted using osmotic shock technique. Physical and biological methods were employed to understand the control of fouling in plate heat exchanger. The osmotic shock given to the fouled organisms present in the PHE was attained by using fresh water circulation. In PHE two types of thermostatic environments such as high and low temperatures were maintained by the temperature control unit. It was observed that after the shock treatment, the outlet water in the PHE was turbid than the inlet fresh water. It is clearly evidenced that due to the osmotic shock the fouled organisms in the PHE got detached (Fig.8 and 9).

High temperature experiment

Once in 10 days the shock was given in PHE system, on-line data result shows that after the shock treatment, heat transfer efficiency Δt was maintained very well (Fig.10). The PHE inlet sea water temperature range was varies according to the climate from 27°C to 31°C. The PHE outlet sea water temperature was varied from 38°C to
Fig. 2. Culturable marine bacteria of sea water for high temperature experiment

Fig. 3. Culturable heterotrophic bacteria of sea water for high temperature experiment
Fig. 4. Culturable Pseudomonas bacteria of sea water for high temperature experiment

Fig. 5. Culturable marine bacteria of sea water for low temperature experiment
Fig. 6. Culturable heterotrophic bacteria of sea water for low temperature experiment

Fig. 7. Culturable Pseudomonas bacteria of sea water for low temperature experiment
Fig. 8. Fresh water turbidity level during and after the osmotic shock for high temperature experiment

Fig. 9. Fresh water turbidity level during and after the osmotic shock for low temperature experiment
42°C. The total viable count in zobell marine agar was ranged from $4.08 \times 10^4 - 9.96 \times 10^4$ and $3.1 \times 10^3 - 1.15 \times 10^5$ cells/ml in the PHE sea water inlet and outlet respectively (Fig.2). Total viable count of microorganisms in pseudomonas agar was ranged from $3.7 \times 10^3 - 1.16 \times 10^4$ and $1.6 \times 10^3 - 3.2 \times 10^4$ cells/ml in the PHE sea water inlet and outlet respectively (Fig.4). $1.99 \times 10^4 - 5.61 \times 10^4$ and $1.4 \times 10^3 - 4.3 \times 10^3$ cells/ml were observed in heterotrophic plate count agar in the PHE sea water inlet and outlet respectively (Fig.3). More than 70% of bacteria were eliminated which might be the effect of controlled environment created by the temperature control unit.

The PHE on-line $\Delta t$ value on the first day was around $10.79^\circ C$ and it was slightly oscillating up and down based on the microbial load in the PHE inlet sea water, $\Delta t$ started decreasing on the
seventh day onwards and on the 10th day it was around 10°C. Osmotic shock was applied on 10th day because of low Δt and after the treatment there was an increase in Δt value and it reached up to 11°C on 11th day. A steady Δt value was observed for the period of four days from 11th to 14th day and then again there was a decrease in Δt value from the 15th day onwards and it was around 9.48°C on the 20th day. Osmotic shock was applied again on the 20th day to increase the Δt value in the PHE system. There was a significant improvement in Δt value after the second treatment and the osmotic shock treatment pattern was followed for every 10 days up to the 80th day during the experiment. On-line temperature data logging system provides the details of biofilm formation scenario in the PHE system (Fig. 10).

Low Temperature experiment

In the low temperature experiment, the microbial growth in Zobell marine agar ranged from 5.16 × 10^4 to 9.19 × 10^4 and 4.37 × 10^3 to 7.95 × 10^3 cells / ml in the PHE sea water inlet and outlet respectively (Fig. 5). Total viable count of microorganisms in pseudomonas agar was 5.6 × 10^4 to 1 × 10^5 and 4.9 × 10^2 to 7.6 × 10^3 cells / ml in the PHE sea water inlet and outlet respectively (Fig. 7). 3.35 × 10^4 to 5.21 × 10^5 and 2.74 × 10^4 to 4.82 × 10^4 cells / ml were observed in heterotrophic plate count agar in the PHE sea water inlet and outlet respectively (Fig. 6).

The PHE on-line Δt value on the first day for the low temperature experiment was around 10.23°C. The Δt value started decreasing from the second day onwards and on the 5th day it was around at 8.99°C the reason might be the formation of biofilm inside the PHE system. Osmotic shock was applied on the 5th day because of low Δt value and then the Δt value reached 9.83°C after the treatment. A steady decrease was observed in Δt value from 8th day onwards and it was around 9.02°C on the 10th day. Osmotic shock was applied again on the 10th day to increase the Δt value in the PHE system. Osmotic shock treatment pattern was followed for every 5 days up to 40 days during the experiment. There was a major reduction in Δt value on 35th day and the Δt value was around 6.77°C. After the attempt of the 7th osmotic shock, the maximum Δt was around 7.59°C which indicated that there was a decline in PHE performance (Fig. 11) in the low temperature experiment. Compared with high temperature experiment there was more decrease in Δt value in the low temperature experiment (Fig. 10 and 11). There was a drastic decrease of microbial load in the outlet sea water sample than the inlet sea water sample in the high temperature experiment. In contrast, the microbial load decreased slightly in the outlet sea water sample than the inlet sea water for the low temperature experiment. Continuous presence of high microbial load in low temperature experiment may be leading to high biofilm formation, which in turn causing low Δt values.

The mechanism of biofilm formation is attachment and detachment of the microorganisms. Hence the microbial flora may vary based on the season. Many physical forces play a role on the detachment of biofilm. Three major and important physical forces playing a role on detachment of biofilm were erosion or shearing, sloughing, and abrasion. Similarly here osmotic shock technique was employed to remove the biofilm on the plate heat exchanger. The plate heat exchanger was made up of stainless steel material; generally the aspect of biofilm and biofouling studies has been documented on different type of materials like polyolefins, stainless steel, galvanized iron and high density poly ethylene (HDPE). Very few research evidences are available for biofouling control on plate heat exchanger. The maximum turbidity value of 24 and 14 NTU was observed in the fresh water of low temperature and high temperature experiments after the osmotic shock treatment. After the treatment the turbidity reduced more than 90%. It was also reported that the cooling water tower system needs to be cleaned using biocides on the tenth day when the fouling rate is high. One of the important factors produced by the biofilm forming bacteria is slime, which is a polysaccharide that provides the protection against chemical and mechanical damages to the bacterial cell. Glycocalyx is a polysaccharide that provides the protection against chemical and mechanical damages to the bacterial cell. There are few research reports available on the microbiological approach of biofilm formation control in the PHE. In the present work the osmotic shock treatment was given in ten days for high temperature experiments and in five days for low temperature experiment for the removal of fouled organisms based on the online monitoring of heat transfer efficiency of biofilm formation in the PHE.

Conclusion

Online data logging system provides continuous measurements, immediate results and quantitative feedback of PHE system performance. The system permits in-situ, real-
time biofouling monitoring and provides an evaluation of non-chemical treatment performance on biofilm. Online biofouling monitoring systems provide a historical record of biofilm levels and can provide an alert when ∆T exceeds from a baseline control. Both on-line real time biofouling monitoring system and osmotic shock technique provides reliable and effective solution to the biofilm formation by removal of biofouling and enhancing the performance of the PHE system.

![Figure 12. Controller tuning results](Image)

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