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Biofouling Assessment in Ocean Thermal Energy Conversion (OTEC) Power Plant Facility - A Case Study Conducted in UPM-UTM OTEC Centre in Port Dickson, Negri Sembilan

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Abstract

Ocean Thermal Energy Conversion (OTEC) is renewable source of energy that harnesses potential energy of sea water at difference sea water temperature. In an example of a closed-loop OTEC system, the hot surface sea water is used to vaporized refrigerant in a separate system, where the vaporized refrigerant is channelled to the turbine for power generation before it is cooled down to liquid form with the cold deep sea water. Apart from its advantage as a base-load source of renewable energy, OTEC could be exploited for various other industries which potentially generate various economic activities for surrounding communities. However, operating this system that utilises sea water as its main fluid may increase potential biofouling in pipelines and processing equipment due to unwanted growth and accumulation of microorganisms which may affect the overall performance in OTEC system by reducing efficiency of heat exchanger, hindering optimum flow inside pipelines or in a worst-case condition causing severe blockage and damage to the processing equipment. There are numbers of reported biofouling assessment techniqes in OTEC but these methods are time-consuming and adopt destructive method in analysing biofouling sample, thus losing important information especially on biofouling deposition mechanism. A new biofouling detection system which adopts non-destructive, continuous and robust in rigorous field application is required for overcoming this problem. Therefore, this research aims to determine a suitable biofouling detection system particularly under OTEC power plant conditions. By taking UPM-UTM OTEC Centre as an actual case, the proposed activity starts with field biofouling assessment by collecting seawater sample from potential site, along with other important parameters. The sample is later used to mimic biofouling growth and deposition under controlled-environmental laboratory setup, followed by suitable application of analytical instruments for assessing biofouling growth profile and its deposition under different substrates and conditions.

Key words : OTEC, marine biofouling, cultivation techniques, non-invasive assessment

1. Introduction

Ocean Thermal Energy Conversion (OTEC) is one of renewable sources of energy that utilises thermal gradient of the sea water at different sea level by pumping warm water supply from sea surface to generate vapour that run a turbine, while concurrently the cold water supply from deep sea water is used to cool down the outlet steam from the turbine for re-condensation (Pelc & Fujita, 2002). Based on this concept, optimum OTEC system could be achieved at minimum sea temperature gradient of 20oC within the sea depth of 1000 m (Syamsuddin et al., 2015).

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Apart from its capability as a continuous and base-load renewable energy generation (Mitigation, 2011), it is estimated that OTEC has capability for producing energy up to 3 TW (Nihous, 2007), where this number is estimated could meet twice of electricity demand worldwide. Unlike other sources of renewable energy such as solar and wind energy, the applicability of OTEC could be diversified to other industries such as deep sea water (DSW) and desalinated water generation, air conditioning system, aquaculture industries, hydrogen gas production, mineral extraction (i.e. lithium) from sea water and for cosmetic and high-grade food production (Kobayashi et al., 2001). In an example of closed-loop OTEC system, refrigerants such as ammonia and R-134a is used as working fluid in the closed-loop cycle through cooling and heating stage (Pelc & Fujita, 2002). This is done when warm sea water obtained at the sea water surface is channelled to an evaporator to vaporize the working fluid, converting it to from liquid to high-pressure vapor flow where it is later used to run a gas turbine for power generation. The stream coming out from the turbine is then cold down by a condenser using cold deep-sea water intake, where the condensed working fluid is pumped and circulated back into the evaporator. The efficiency for about 3-5% could be achieved in an optimum OTEC system (Uehara & Ikegami, 1990). However, this efficiency could reduce for about 1-2% as a result of fouling that could take place inside the heat exchangers (evaporator or condenser) (Berger & Berger, 1986).

When considering a system that uses water as a main processing fluid, the untreated and raw water usage contains various physical-chemical properties which directly affects a system that is in contact with water. One of such examples is on fouling where it could occur as a result of deposition of matters that could disrupt optimum flow of water in a processing system. This fouling problems could be contributed by various factors, whether scaling or crystalline fouling, organic fouling due to the deposition of organic matter, particle and colloidal fouling as a result of silt or clay deposition or microorganism fouling (Al-Juboori & Yusaf, 2012). Over period of time, the deposition of fouling along pipeline wall and other parts of exposed surface such as joints, fittings, valves and rotating equipment (rotors, compressors and turbines) may hinder optimum flow of water and reduces functionality of the equipment where eventually if it is not controlled, it could lead to major loss of time and function. In relation to biofouling, each biofouling assessment is explicit with respect to the physio-chemical properties of water source as well as complex and detailed engineering specifications, which consequently affects the overall process performance (Mitchell & Benson, 1980). For example, the presence of thin biofilm of 25-50 micrometer could reduce the performance of OTEC by 50% (Berger & Berger, 1986). Apart from that, large deposition of macrofouling may potentially restricting water pipeline, increasing additional weight to a floating OTEC facility and in worst condition, might cause serious damage to the processing facilities (Flemming et al., 2009).

The concern in biofouling study in OTEC is comparative to the interest and advancement of OTEC over period of years with most of reports on the assessment of biofouling in OTEC facility have been initiated since late 1970s to mid-1980s (Berger & Berger, 1986; Fetkovich et al., 1977; Mitchell & Benson, 1980). Several biofouling assessment techniques proposed in this report were based on the nature of biofouling that growth and deposited on a concerned surface inside OTEC facilities. For example, the direct-contact shell-and-tube heat exchangers used in the study adopted the heat transfer monitoring (HTM) device for determining the thickness of micro fouling that is appeared as a thin layer of biofilm on the surface of heat exchanger (Berger & Berger, 1986; Mitchell & Benson, 1980). The thickness of biofilm is estimated by measuring rate of heat transfer, considering heat transfer resistance as a result of thin biofilm on the surface of heat exchanger. Apart from this physical assessment, few biological and biochemical assessments were reported using extracted sample of biofouling. A set of coupons attached to the surface of heat exchanger were subjected to accumulated biofouling deposition over period of time. The accumulated sample on the coupons was extracted by scrapping manually by cutting out a section of heat exchanger tube (Berger & Berger, 1986) or using a special tool to scrap any deposit on the surface of heat exchanger (Nebot et al., 2010). The sample was later subjected to either visual inspection or by biochemical assessment. In this case, scanning electron microscopy (SEM) was used to provide qualitative assessment of biofouling growth on the contact surface with water, providing crucial information on the type of organisms or materials involved, rough estimation of biofilm thickness and the nature of its growth (Mitchell & Benson, 1980). In addition, several laboratory biochemical assessments were carried out, for example adenosine triphosphate (ATP), total organic compound (TOC), carbohydrate analyses and chlorophyll contents (Berger & Berger, 1986).

The establishment of these methods indicates their applicability for assessing biofouling in OTEC system. The usage of coupon-stripped method in an actual OTEC facility provides realistic evaluation of biofouling, thus providing effective measures for its preventive approach. For instance, the TOC method is still considered as the most important method today for analyzing potential biofouling due to the fact that the biodegradable content is proportional to the biofouling growth (Flemming, 2011). However, these techniques are lack in term of their feasibility aspect when strategizing suitable biofouling controlling measures in correspond to the severity of biofouling as they only allows for long-term biofouling observation assessment, which in reality biofouling deposits may change over period of time with spatial deposition profile on surfaces (Farhat et al., 2015). In addition, the destructive substratum extraction procedures provide discrepancy particularly for a progressive biofouling deposition over period of time (Nivens et al., 1995), limiting biofouling controlling measures only for a short-term basis. A flexible and effective biofouling monitoring method is required for overcoming this limitation, with focus on several qualities of non-invasive and non-destructive detection technique, with its feasibility to be implemented in field as well as on-line biofouling detection system.

Apart from the biofouling assessment techniques, method for simulating biofouling growth and deposition in laboratory assessment is another aspect that need to be considered. While field biofouling assessment provides realistic biofouling growth and profile, this method is tedious and time-consuming, thus setting up simulated environment for is essential for continuous and convenient assessment of biofouling growth and deposition. However, this effort considered to be challenging, taking into accounts various realistic environment factors to imitate biofouling growth and deposition such as the presence of nutrient, physical and chemical characteristic of sea water sample, and also presence of other seawater biological species (either flora or fauna) (Stewart, 2012). Under engineering perspective, numerous studies have discussed biofouling laboratory setup using a known species that are cultured under controlled environment (Bryers & Characklis, 1981; Videla & Characklis, 1992), but it is almost impossible to culture most marine microbial species (Rinke et al., 2013) under actual microbial growth medium (i.e. seawater). Even with the success of cultivating microbial species under laboratory setup, the microbial species may not realistically represent overall species as it cover only 1% of overall species. Nonetheless, several improved, in-situ cultivation techniques for marine microbial growth have been reported such as diffusion chamber technique (Kaeberlein et al., 2002), ichip technique (Nichols et al., 2010), I-tips technique (Jung et al., 2014) and others, which indicating prospect in conducting this analysis under laboratory setup.

2. Research Objectives and Scope of Study

Potential biofouling deposition might give adverse effect towards OTEC power plant facility as a result of large usage of seawater intake as its main processing fluid. However, most of reported techniques adopt destructive method in extracting biofouling sample and require long period of time for each assessment, thus losing important information especially for the biofouling deposition mechanism. A non-destructive and continuous method which could be adopted in actual field condition is needed for solving this problem. Therefore, this research activity aims to identify potential biofouling in OTEC system, specifically at UPM-UTM OTEC Centre, Port Dickson, Negri Sembilan and to conduct laboratoy assessment for biofouling using suitable analytical instruments. UPM-UTM OTEC Centre is a pioneering and the first OTEC facility in the world that serves as a laboratory-scale hybrid OTEC (H-OTEC) system which has potential for generating up to 3 kW of electricity as well as concurrent desalinated water (DSW) production using the same facility.

The scope of study for this research activity covers two major parts, the first part is to assess potential biofouling growth and deposition by conducting field assessment evaluation at coastal area near to UPM-UTM OTEC Centre, Negri Sembilan, Malaysia as well as to simulate biofouling growth under laboratory setup. The information obtained from this assessment activity allows preliminary evaluation of biological and physical-chemical profiles of potential biofouling that may be present on the subjected surface (or substrate). The second part of this study covers on methods for detecting biofouling, both through direct assessment on the subjected substrates (in-situ assessment) as well as external assessment from collected biofouling sample (ex-situ assessment). This assessment provides physical and/or quantitative analysis of biofouling growth which is then compared to the results obtained from the first activity.

3. Research Methodology

The overall research activity covers three major activities, covering on biofouling assessment activities on field as well as in laboratory work and biofouling detection using several laboratory analytical instruments. The summary of these proposed activities are presented in a flow chart, presented in Figure 1.

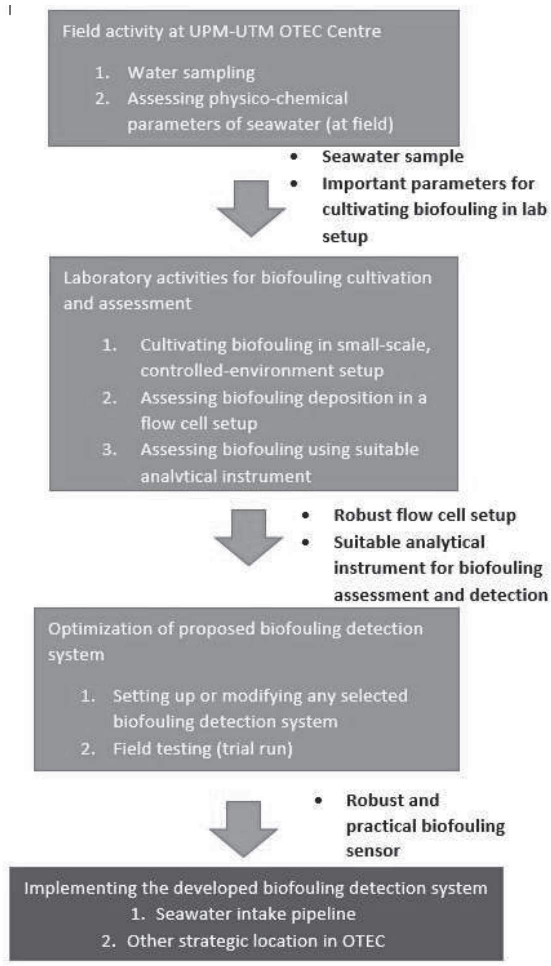

Fig. 1 Flow chart for proposed research activities

The first activity which is the field study allows realistic assessment of potential biofouling particularly in physico-chemical parameters which support biofouling growth and deposition. However, for practical and continuous monitoring setup, it is adequate to represent actual biofouling setup by obtaining sea water sample before the sample is cultivated under controlled-environment laboratory setup using the sea water sample. This requires suitable sea water sampling at near location near to UPM-UTM OTEC Centre, with focus on to the intake and outlet sea water pipeline for the newly-developed OTEC facility. In addition, measurement of physico-chemical properties of the seawater sample is needed as it provides important information for the growth and deposition of biofouling. For example, parameters such as pH, salinity, gradient seawater temperature at different sea water depth, the availability of nutrients, sea water tide and flow and other parameters are some of crucial parameters that need to be considered.

After acquiring seawater sample and important parameters, the cultivation of biofouling is conducted under laboratory scale in UiTM facility. The objective is to grow biofouling, as close as possible, to real environment of the system. One of proposed setups is by imitating biofouling growth inside a small seawater tank, presented as in Figure 2.

This setup serves as a basis for identifying biological as well as physical-chemical profiles of biofouling growth before a small or medium-scale flow cell is developed. Unlike the setup presented in Figure 2, the flow cell simulates biofouling growth and deposition under continuous flow inside a small channel, which indirectly serves as a setup for biofouling assessment using suitable laboratory analytical instruments.

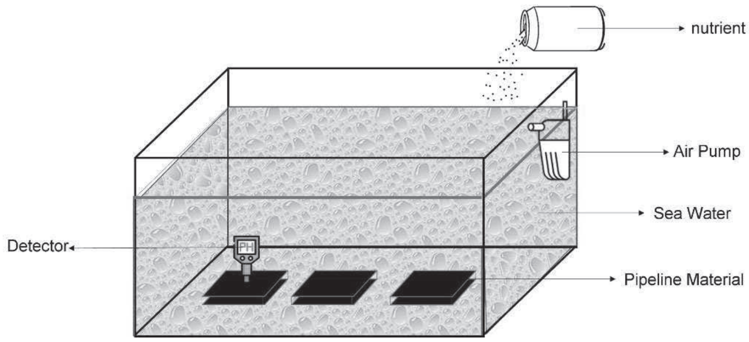

Fig. 2 Schematic diagram of biofouling laboratory setup using a small seawater tank

Considering option for non-destructive assessment, analytical instruments such as optical microscope or spectroscopic instruments (i.e. Fourier Transform Infrared or Raman Spectroscopy) could be used by observing biofouling from collected biofouling samples or direct observation at the biofouling laboratory setup. After identifying appropriate analytical instruments, other options such as chemical detectors could be used for biofouling detection. The comparison between previous analytical instruments results and the chemical detector system allows adequate calibration and additional measurement for conforming the biofouling detection. In addition, appropriate modification to the current analytical techniques might be considered for suiting up actual measurement condition to the setup of analytical instruments. After completing this stage, the proposed analytical instrument could be potentially used in field by conducting its applicability and practical implementation under rough environment condition. If it turns to be successful, the biofouling detection system could be then implemented in strategic location near or in seawater intake pipeline system at UPM-UTM OTEC Centre.

8. Expected results and outcomes

Upon completion of this research activity, a comprehensive report which evaluate any potential biofouling growth and deposition in UPM-UTM OTEC Centre is available as a guideline for the laboratory operator in mitigating biofouling within their facility. Options which include non-destructive and practical biofouling detection systems or sensor which have been analysed and tested in this research activity provide a practical and effective technique to analyse biofouling growth and deposition, either in laboratory setup or in operating OTEC setup.

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