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Effects of temperature on wastewater treatment in an affordable microbial fuel cell-adsorption hybrid system

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ABSTRACT

A cost effective single-chamber microbial fuel cell (MFC) integrated with adsorption system was tested under different operating temperatures to observe pH profiles, organics, solids, nutrients, color and turbidity removal and power density generation. The optimum operating temperature range was found to be ~25–35 °C with majority of the removals achieved at ~35 °C. Maximum power density recorded was 74 ± 6 mW/m^3 with coulombic efficiency (CE) of 10.65 ± 0.5% when operated at 35 °C. Present studies had successfully demonstrated the effectiveness of a hybrid system in removing various types of pollutants in POME at optimum temperature and able to fulfill the stringent effluent discharge limit. Chemical oxygen demand (COD), total solids (TS) and turbidity removals increase linearly with temperatures with removal efficiency of 0.5889% C^{-1}, 1.0754% C^{-1} and 0.7761% C^{-1}, respectively. The temperature coefficient (Q_{10}) is found to be 1.06, 1.45 and 1.09, respectively. Besides, MFC-adsorption hybrid system had demonstrated superior stability over a wide range of operating temperatures in terms of COD removal as compared to the non-integrated MFC system.

1. Introduction

Microbial fuel cells (MFCs) are bioelectrochemical devices that utilize bacteria as a biocatalyst to oxidize the organic matters present in the wastewater to produce bioenergy [1–3]. MFCs have the ability to remove various types of pollutants present in the wastewater [4,5]. They are renowned for their great capability for direct bio-energy generation from various biodegradable compounds, ranging from pure compounds to complex substrates in the wastewater [6]. There were many studies done on the typical standalone two-chambered MFC because such design is very easily constructed and typically suitable for lab scale studies. Nevertheless, standalone treatment system has limitation such as less wastewater treatment efficiency as compared to the MFC hybrid system [7]. Much studies had demonstrated the ability of hybrid MFCs in removing various types of pollutants present in the wastewater such as chemical oxygen demand (COD) [8–10], phosphorus [11], dye [12,13], suspended solids (SS) [10], total nitrogen (TN) [14], ammonia nitrogen (NH_3—N) [15,16], and so on. Majority of the effective pollutants removal were done by integrating MFC with other unit operation or processes. Recently, it has been reported that greater bio-energy generation and wastewater treatment can be accomplished when MFC is hybridized with unit operations or processes such as adsorption [17], membrane bioreactor [10], sequencing batch reactor [18], membrane, aeration system [19], anaerobic digester [20], aerobic system [15], biofermentor [21], anaerobic fluidized bed [22], wetland [23], anaerobic fluidized membrane reactor [24] and anaerobic sludge blanket [25]. MFC could also possibly be combined with other process such as nitritation-anammox where the research had been greatly developing in order to remove wastewater which content high level of nitrogen content [26,27].

Now, among many influencing parameters, temperature is one of the important factors which can affect the power generation as well as the water treatment performance. The definite temperature may affect the bacterial kinetics and also the types of bacteria that reside in the anodic biofilms in the wastewater fed systems [28]. Thus, while bacterial growth rate and respiration can be affected by the changes in temperature, the community development and structure can also be crucial [29].

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Nomenclature

ACFF	Activated carbon fiber felt
AFMBR	Anaerobic fluidized bed membrane bioreactor
APHA	American public health association
BOD	Biochemical oxygen demand
C_a	Total coulombs by calculated by integrating current over time
CE	Coulombic efficiency
COD	Chemical oxygen demand
C_t	Concentration of the solution at any time
D_1	Design of Behera et al. (2011)
DOE	Department of environment Malaysia
ECG	Electrocardiogram
GAC	Granular activated carbon
GFB	Graphite fiber brush
I	Current (A)
I-BAF	Immobilized biological aerated filter
MFC	Microbial fuel cell
MBR	Membrane bioreactor
$NH4^+$	Ammonium ion
NH_3—N	Ammonia nitrogen
P	Power density (mW/m^3)
PEM	Proton exchange membrane
POME	Palm oil mill effluent
Pt	Platinum
Q_{10}	Temperature coefficient
R_1	Rate at temperature 1
R_2	Rate at temperature 2
SS	Suspended solids
T_1	Temperature 1
T_2	Temperature 2
TN	Total nitrogen
TMBR	Tubular membrane bioreactor
TOC	Total organic carbon
TSS	Total suspended solids
TVS	Total volatile solids
V	Voltage (V)
ν	Liquid volume (L)

Thus far, not much research has been done on the air- cathode MFC with ceramic pot as the substitute to proton exchange membrane (PEM) except Ghadge & Ghangrekar [30] and Chatterjee and Ghangrekar et al. [31]. The reactor setups for both studies were done on standalone MFC and recently, only one had come to the effort of integrating MFC with adsorption hybrid system with ceramic pot as the PEM [32]. Besides, the effects of temperature in MFC hybrid system has never been understood especially when activated carbon is applied in the design because the performance of both MFC and adsorption system are sensitive to operating temperatures.

A recent study has been done by integrating MFC with adsorption system and such system has demonstrated great pollutants removal in the palm oil mill effluent (POME) such as COD, biochemical oxygen demand (BOD), total organic carbon (TOC), TN, NH_3—N, total solids (TS), total suspended solids (TSS), total volatile solids (TVS), turbidity and color [32]. Till now, the study of such system was only done at operating temperature of $25 \pm 1\,^{\circ}C$. The effect of other operating temperature for such system has not been studied in terms of wastewater treatment and bio-energy generation.

MFCs can produce energy from various substrates and reported in literature. However, to the best knowledge of the authors, the studies of the effect of temperatures had only been done on these few sources which includes beer brewery wastewater [33], domestic wastewater [34–36], sanitary wastewater [37], barley processing wastewater [38] and synthetic wastewater [39,40]. Municipal water treatment experiments which were done previously at low temperatures (5–15 °C) could also be used as a source of high potential MFC operation for electricity generation [41]. At present, none has come to understand the effects of temperature with palm oil mill effluent (POME) as a substrate to MFC which is known as the major contributor of the pollution loads in the rivers in countries such as Malaysia and Indonesia. POME is very rich in terms of organic matters and existing treatment method such as ponding system requires long retention time and ineffective to meet the wastewater quality standard. Since POME has very high organic matters content, therefore it can be used as a source of fuel to the MFC for bioenergy generation.

The aim of this work was to treat the palm oil mill effluent and at the same time to take the advantage from the treatment by integrating the MFC with adsorption system to generate bioenergy. Thus, the effects of temperatures in terms of power generation, pH profiles, organics, solids, nutrients, color and turbidity removal in the MFC- adsorption hybrid system were carried out systematically and presented in the present study.

2. Experimental

2.1. MFC construction

The single chamber air-cathode MFC-adsorption hybrid system with the separator fabricated from ceramic material were constructed and described in Ref. [32]. The schematic diagram of the MFC-adsorption hybrid system and the membrane electrode assembly are as shown in Fig. 1. Anode compartment consists of graphite fiber brush (GFB) (Mill-Rose Co., USA) that served as current collector and employing commercial granular activated carbon (GAC). Prior to experiment, the GFB was soaked in pure acetone overnight and heat-treated at 450 °C, and washed three times with distilled water. GAC was cleaned with distilled water several times and oven dried to remove ashes and other impurities before they were used. A specific surface area of $1000\,m^2\,g^{-1}$ (Nantong Ruibang Activated Carbon Filter Material Co. Ltd, China) activated carbon fiber felt (ACFF) was selected as the cathodes materials, which were wrapped around the ceramic pot (7 mm thick) which acted as the medium for proton exchange. Electrocardiogram (ECG) gel was applied evenly between ceramic pot and ACFF in order to increase hydration and contact area. A copper rod was selected as the circuit connector in the cathode compartment. The reactor working volume for this setup was 5.65 L.

2.2. Experimental design and operation

The MFC-adsorption hybrid system was inoculated with POME from nearby palm oil mill at Felcra Jaya, Kota Samarahan where the POME samples was taken from the second anaerobic pond and the same source was used as the substrate to the MFCs without any additions of nutrient and buffer solution for the anode chamber. Wastewater sample was kept in a cold room at 3 °C prior to use. The characteristic of the POME collected was analyzed and tested (Table 1).

The MFC-adsorption hybrid systems were inoculated at $25 \pm 1\,^{\circ}C$, where $50\,\Omega$ of external resistance was installed in between the anode and the cathode segment. The systems were operated at various temperature (15 °C, 20 °C, 30 °C, 35 °C, 40 °C and 55 °C) once steady voltage was achieved and the performance were compared to the previous study which was done at operating temperature of 25 °C [32]. The performance of the MFCs at