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A comparative study for electricity generation and wastewater treatment from palm oil mill effluent by microbial fuel cell using different sizes of electrodes

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Abstract— The growth in the worldwide of energy demand every year and the over consumption of non renewable sources of energy has led to the identification and use of renewable and cost effective sources of energy. In this context, palm oil mill effluent, which contains high levels of degradable organic materials, has gained importance as a source of electricity generation using a microbial fuel cell (MFC). Two microbial fuel cells were produced, one made up of larger electrodes and the second of comparatively smaller electrodes; for the generation of electricity and wastewater treatment using palm oil mill effluent (POME). A comparative study showed that MFC with larger electrodes had greater efficiency for electricity production, resulted maximum 0.721 V and wastewater treatment, and resulted maximum chemical oxygen demand (COD) removal of 81%, biochemical oxygen demand (BOD) removal of 72 % and total organic carbon (TOC) of 82%. On the other hand, MFC with smaller electrodes showed less effective results compared to the former MFC.

Index Terms— Microbial fuel cell (MFC), wastewater treatment, Palm oil mill effluent (POME).

I. INTRODUCTION

Microbial fuel cells provide new opportunities for sustainable production of energy from biodegradable, reduced compounds [1]. Microbial fuel cells are treating wastewater with an enhanced power output. A MFC converts energy, available in a bio-convertible substrate, directly into electricity [2]. It can be achieved when bacteria switch from the natural electron acceptor, such as oxygen or nitrate, to an insoluble acceptor, such as the MFC anode [3]. This transfer can occur either via membrane –associated components, or soluble electron shuttles. Electrons then flow through a resistor to a cathode, at which the electron acceptor is reduced. In contrast to anaerobic digestion, a MFC generates electrical current and off-gas containing mainly carbon dioxide [4, 5].

Palm oil mill effluent (POME) is an organic waste material produced at the palm oil mills. During the production of 1-ton crude palm oil, more than 2.5 tons of POME is produced [6]. POME is composed of solids (mainly organic), residual oil, high concentrations of organic nitrogen, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Typically, COD and BOD in the POME are in the range of 15000-100000 mg/l and 10250-43750 mg/l respectively [7]. POME has adverse environmental impacts including land and aquatic contamination and loss of biodiversity [8]. Palm fruit is the major source of lipase producing microorganisms. Studies have shown that for organisms to degrade palm oil, it must have to produce lipase. The microorganisms possessing lipases are generally able to degrade and mineralize POME and thus help significantly in its treatment. Biodegradation of oily wastes is the cheapest and surest means of managing POME to prevent the attendant environmental impacts. Furthermore, the microbial fuel cells (MFCs) have emerged as promising technology for the treatment of wastewaters [9]. They enable the recovery of energy out of the wastewater, while limiting both the energy input and the excess sludge production [10]. The wastewater treatment efficiency of MFC with POME evaluated by comparing before and after treatment values of wastewater parameters like chemical oxygen demand (COD) removal efficiency, biochemical oxygen demand (BOD) removal efficiency, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), ammonical nitrogen and nitrate nitrogen [11-15].

II. MATERIALS AND METHODS

A. Sample collection and characterization

The sludge was obtained from anaerobic digester pond at Sai Ulu Langat Palm Oil mill in Dengkil, Malaysia. It was cultivated in the Modified Wolfe's Medium [8] containing (g/l): glucose 1.0; $NaH_2PO_4.H_2O$ 2.76; Na_2HPO_4 4.26; NH_4Cl 0.31 and KCl 0.13, 10 ml Wolfe's vitamin solution. The cultivation was carried out in 2000 ml Duran bottle with 1000 ml sludge together from the collection site. The sludge mixture was purged with nitrogen gas to remove oxygen to keep the anodic chamber anaerobic [16]. The mixture continuously stirred with magnetic stirrer to keep the culture active. The stock culture was fed with modified Wolfe's medium in room temperature ranging from 28-30^{0}C, for at least 2 times to obtain a stable culture communities and controlled COD level in the sludge. Subsequently, the culture was harvested by dewatering the sludge and transfer into the chamber for the start up of MFC's experiment.

Table 1Characteristics of POME

Parameters	Concentration (mg/l)
BOD	23000-50000
COD	50000-85000
Ph	4.0-5.0
Total carbohydrates	15000-18000
Total nitrogen	750-850
Ammonium nitrogen	20-30
Phosphorus	12-18
Oil	1800-2200
Total solids (TS)	28000-40000
Volatile suspended solids	8000-11000
Alkalinity	90-140
Total phosphorous	85-110
Total organic carbon	10000-15000

All values are in mg/l except pH.

C. Configuration of mfc

In the study, two MFCs were used for the comparative evaluation of electricity generation and wastewater treatment. The first MFC larger sizes of electrodes used, while in the second MFC comparatively smaller electrodes are taken. The dimensions of larger electrodes and smaller electrodes were 50mm x 130mm x 10mm and 50mm x 80mm x10mm respectively. The electrode material used was graphite and employed for both anode and cathode chambers. In both MFCs, same size of electrodes used. Electrodes installed at the opposite ends of each other at 7.3 cm apart. The electrode at cathode coated with 0.5 mg cm^{-2} 50% Pt/C catalyst to increase the reduction of oxygen. The culture medium in anodic chamber, Modified Wolfe Medium, plays a key role as an anodic electrolyte. The cathodes chamber filled with only 50 mM PBS (in g/l), was continuously air sparged by aquarium pump. Proton exchange membrane (Nafion 117) used as connector between anode and cathode containers.

D. Electrical parameters and measurements

The potential of both the MFCs of different electrodes measured with a digital multimeter connected to the line between the anode and cathode in open and closed circuit configuration. When the load was replaced with a high resistor of 82 kilo ohm, current drawn was minimized. The corresponding voltage across the resistor terminals was recorded with time and the electrical outputs were estimated.

E. Water quality analysis

The chemical oxygen demand (COD) of POME and the input and output from the microbial fuel cell was determined using closed reflux method [17]. The characteristic of POME such as Biochemical Oxygen Demand (BOD) and Total Organic Carbon (TOC), pH, Nitrogen, Phosphorous, Total phosphorous, Oil, Alkalinity, Ammonical nitrogen were monitored according to standard method (APHA, 1998). The data analyzed by using Statistical Package for the Social Sciences (SPSS) software with one-way variance analysis (ANOVA).

III. RESULTS AND DISCUSSION

A. Voltage production

The performance of POME to produce voltage for both MFCs measured through multimeter. MFC with large electrode produced higher voltage as compared to the MFC with small electrode. POME produced maximum voltage at large electrode and at small electrode, 0.721V and 0.460V respectively, as shown in Figure 1. Substrate is one of the most important biological factors affecting electricity generation [18]. The efficiency of voltage relates with the ability of microorganisms to oxidize the substrate and transfer electrons to the anode electrode [19].

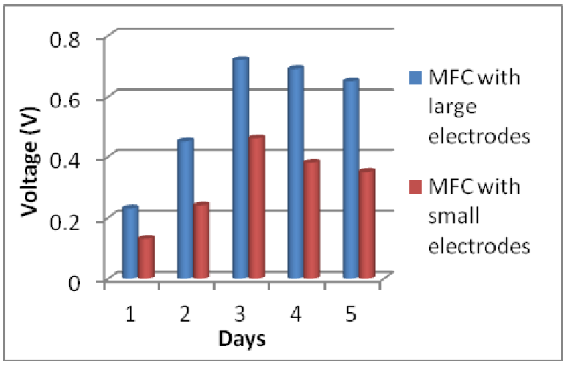

Fig.1 Voltage Production

B. BOD removal and treatment

BOD removal from POME was examined by using both the MFCs,. The maximum percentage of BOD removal for MFC with larger electrodes was 72 %, meanwhile, the maximum percentage of BOD removal for MFC with smaller electrodes was 65 %, presented in figure 2.

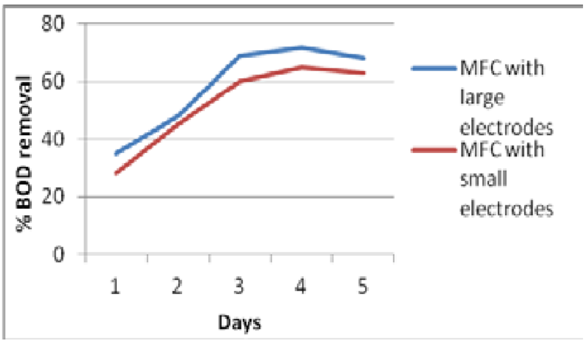

Fig. 2 % of BOD removal

C. COD removal and treatment

The efficiency of both MFCs for the removal of chemical oxygen demand evaluated by comparing the values before and after the treatment of POME. The MFC with comparatively larger electrodes shows maximum COD removal 81 %, than MFC with smaller electrodes, 70%, as shown in figure 3.

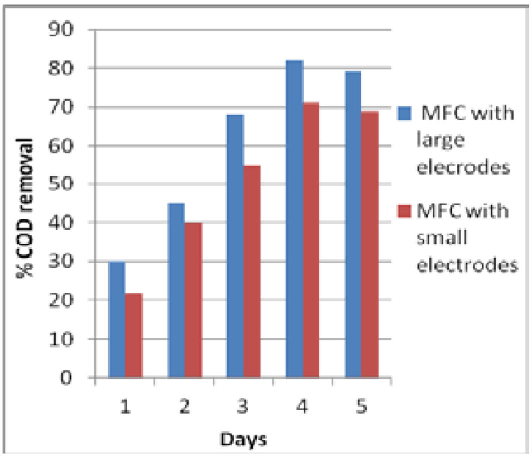

Fig. 3 % of COD removal.

D. TOC removal and treatment

Total organic carbon of the substrate (POME) was evaluated before and after the experiment. The TOC concentration in POME was 11330 mg/l before the experiment, which decreased to 1953 mg/l after the experiment in MFC with larger electrodes, resulted 82% removal of TOC. On the other hand, in the MFC with smaller electrodes, initial TOC concentration decreased to 3245 mg/l, resulted 71% removal of TOC from the POME, as can be depicted in figure 4.

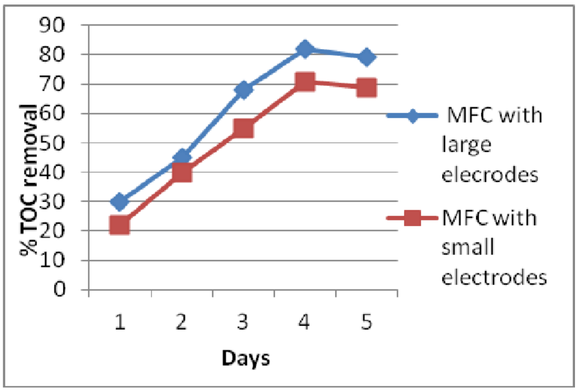

Fig.4 % of TOC removal

IV. CONCLUSION

At the end of the study, it could be concluded that MFC is the promising technology for the generation of renewable energy and wastewater treatment. In a typical MFC, size of the electrodes plays a pivotal role in its efficiency. The results proved MFC with electrodes of larger surface area performed better as compared to the MFC having electrodes of smaller surface area. MFC with large electrodes showed maximum voltage production (0.721), BOD removal (72%), COD removal (81%) and TOC removal (82%) than MFC with smaller electrodes, which showed maximum voltage production (0.460), BOD removal (65%), COD removal (70%) and TOC removal (71%). The microbial fuel cell being a promising resource for the future has to be furthered investigation for improvements in its performance and capability to handle wastewater with higher organic loads. Electrolyte concentrations and resistance, electrode materials and surface area, operating temperatures and oxygen reaction kinetics are the key areas for further investigations.

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