

Electricity generation from palm oil tree empty fruit bunch (EFB) using dual chamber microbial fuel cell (MFC)

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Abstract. : Microbial fuel cell (MFC) has been discovered and utilized in laboratory scale for electricity production based on microbial degradation of organic compound. However, various source of fuel has been tested and recently complex biomass such as lignocellulose biomass has been focused on. In the present research, oil palm tree empty fruit bunch (EFB) has been tested for power production using dual chamber MFC and power generation analysis has been conducted to address the performance of MFC. In addition, two microorganisms (electric harvesting microbe and cellulose degrading microbe) were used in the MFC operation. The analysis include voltage produced, calculated current and power. The first section in your paper

1. Introduction

The world today is looking for alternatives to compensate for higher demands of fossil fuel. This is due to global use of fossil fuels (coal, oil, and natural gas) increased by 1.3 percent in 2002, to 8,034 million tons of oil equivalent, according to preliminary estimates based on government and industry sources. In addition, coal, natural gas and oil accounted for 87 percent of the world's primary energy consumption based on data published in the World Watch Institute, 2013. Thus, the drive for new discoveries on renewable energy is high and is also a necessity for future generation. Renewable energy is generally defined as energy that comes from resources which are naturally refill on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. One of most focus on in recent years is microbial fuel cell (MFC). MFC is introduced due to its sustainability and environmental friendly despite being useful to use waste to gain benefits (Franks and Nevins, 2010).

Basically, MFC converts chemical energy to electrical energy by using catalytic reaction of microorganisms in a biochemical reactor. MFC may use many types of substrates mainly any form of biodegradable organic matters such as glucose, sucrose, xylose and complex matters such as polymeric starch. A typical MFC for producing electricity consists of anodic chamber and cathodic chamber which, is separated by a proton exchange membrane (PEM). In the presence of microbes in the anaerobic anodic chamber, protons and electrons are produced by oxidation of organic substrate. The protons generated are transfer to the cathodic chamber through the PEM and subsequently combined with oxygen to form water.

In terms of substrates, MFC has been used to facilitate the conversion of simple sugar such as glucose or more complex substrates such as corn stover to electricity in laboratory scale (Logan, 2006). Lignocellulosic biomass poses a great example of natural sources for bioenergy and its abundance creates opportunity for more challenging acquisition of MFC application. Meanwhile,



Malaysia shares its richness of oil palm trees, which accumulated more than 80% (total include Indonesia) of the world oil palm tree. At the same time, the intense palm oil productions produce more than a quarter per planted land of waste or biomass from the oil palm tree. Empty fruit bunch (EFB) is one of the by-product or considered as scheduled waste.

In this study, the use of dual chamber MFC to generate electricity was studied and the MFC system ability to extract power from EFB as fuel source was observed. However, it was later demonstrated that the degradation of lignocellulose from EFB is influenced by different concentration of substrates. Complex sugar needs pre-treatment steps to be degraded into simple sugar. Hence, degradation of lignocellulose to simple sugar will generate more power compare to complex lignocellulose form.

2. Materials and Methods

2.1 Preparation of pre-treated EFB

Beforehand, dry EFB was collected from local oil palm tree plantation (Bangi, Malaysia) and stored in drying condition (approximately 50 °C) prior to use. The dried EFB was crushed and manually sieved to collect particle size between 250 to 400 mm sizes. Next, the crushed EFB was soaked in distilled water in a water bath at 80 °C. After water filtration, the EFB was then subjected to alkaline pre-treatment by addition of 2.5 M of sodium hydroxide and autoclaved for 15 min at 121 °C. The mixture was then subjected to another filtration process to separate the solid pre-treated EFB from alkaline solution and subsequently mixed with sodium hypochlorite solution (6-14 % active chlorine) for bleaching process. After the delignification process or the pH of the filtrate became approximately 3 (pre-treated EFB became almost white in color), the EFB fiber produced was washed several times with running tap water until the pH of EFB fiber became 7.0. After pre-treatment, the EFB fiber was used directly for MFC operation.

2.2 Inocula preparation

Bacillus E1 and *Clostridium Cellulolyticum* were used in this study and readily stored in the -80 °C as glycerol stock. Prior to use, both microorganisms were grown in Luria-Betani broth supplemented with 1.0 % (w/v) carboxymethyl cellulose (CMC) to enhance growth of both microbes. Approximately 100 mL of LB broth with optical density of 2.0 at 600 nm for each microbes was used for the MFC operation. Meanwhile, the cells were harvested through centrifugation at 5,000 rpm for 20 min and pellet was dissolved in 15 mL of potassium phosphate buffer, pH 7.0 each prior to use in MFC.

2.3 Nafion 117 pre-treatment

Nafion 117, a proton exchange membrane was used to separate the anodic and cathodic chambers. The membrane was subjected to pre-treatment procedure in order to get rid of any impurities through boiling at 80°C for one hour in distilled water, one and half hour in 3.0 % hydrogen peroxide, H₂O₂, one hour in distilled water, one and half hour in 0.5 M of sulfuric acid, H₂SO₄, and finally one hour wash with distilled water (M. Rahimnejad et al., 2011).

2.4 MFC set-up and operation

The dual chamber of MFC for the present study consists of two chambers which contain microbes, pre-treated EFB and 0.1 M potassium phosphate buffer in the anodic compartment, while in the cathodic side, potassium permanganate and the same buffer was added. Both compartments was connected with two carbon electrodes which was connected with copper wire as connector to complete the electrical circuit of the fuel cell. The electrode was placed on opposite sides in each chamber and separated by Nafion 117 as depicted in figure 1.

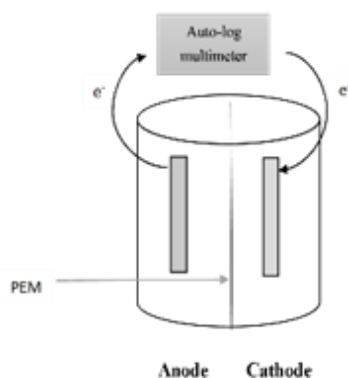


Figure 1. A schematic representation of dual chamber MFC used.

Specifically, 244 mL of 0.1 M potassium phosphate buffer solution, pH 7.0 and 6 mL of mixed microbe inoculum (15% from total volume 250 mL) were added in anodic chamber. In addition, pretreated EFB fiber was added as source of fuel. Both of the solutions were stirred in order to mix properly. While 7.902 g of potassium permanganate (electron acceptor) was diluted in 1.0 L of 0.1 M phosphate buffer solution and 250 mL of the solution was used as catholytes in cathodic chamber.

The auto-log multimeter was connected to the external circuit to obtain voltage or potential differences between the anode and cathode. The voltage data was recorded every 1½ hours until maximum voltage was reached and the readings were stable. It took about three days to achieve maximum value of open circuit voltage (OCV). Next, the resistor was connected to obtain voltage which designated as closed-circuit voltage (CCV). The voltage data was recorded every five minutes for one hour and was repeated twice using different resistance value. All MFC trials were operated at room temperature. Meanwhile, all CCV values were then calculated to obtain both power and current using Ohm's Law formulae ($V=IR$ and $P=V^2/R$ or $P=I^2R$; V = voltage in volts, R = resistant value in Ohm, and I = current in amperes)

3. Results and discussion

3.1 Open Circuit Voltage profile

Open Circuit Voltage (OCV) which is considered as a measurement of voltage in the MFC after some time without any current going through the system. Thermodynamically, the OCV value can be interpreted as the cell electron motive force (E_{mf}) value which does not taking account on the losses due to potential resistance presents in the system (Logan et al., 2006) and fully working MFC cannot achieved the E_{mf} value due to the potential losses posed within the MFC system. These include internal electrolyte which contains soluble ions, the randomized activity presents during degradation of substrates and biochemical conversion that may produces several ions that will be attracted to electrode (anode). From the results, maximum achievable OCV was averaged from maximum OCV values of 1.5, 3.5 and 5.5 g/L pre-treated EFB, and the calculated value was 0.647 ± 0.03 (V). It was reported that theoretical value of achievable E_{mf} through glucose oxidation is 1.1 V and only half of the value was achieved from the overall OCV. It is unknown whether the complexity of the substrate or EFB is the main factor of the low value, and there is possibilities of internal hindrance such as competition of substrates between microorganisms or the removal of contaminants produced in the biomass degradation (Juang, 2012).

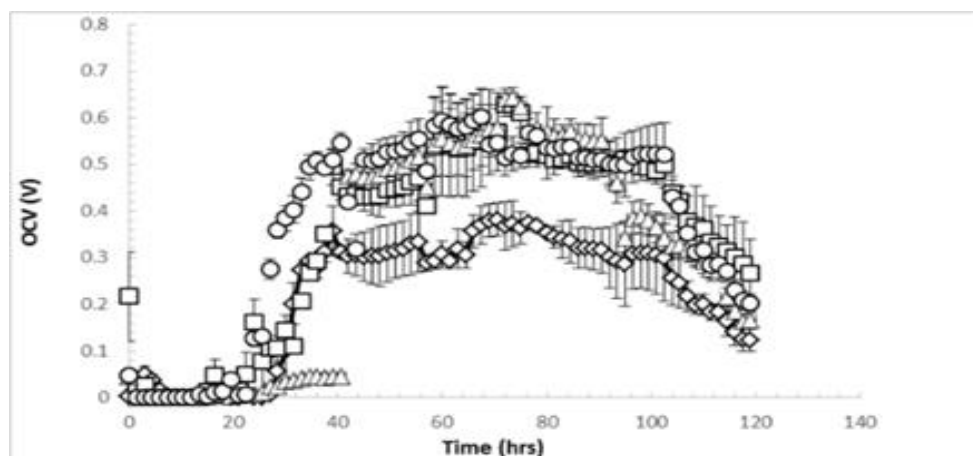


Figure 2. OCV profile for different concentration of pre-treated EFB. The symbols indicate the concentration of pre-treated EFB normalized with the volume of the anodic compartment which was 250 mL ; ‘ \diamond ’ represents 7.5 g/mL, ‘ \square ’ was 5.5 g/mL, ‘ Δ ’ was 3.5 g/mL, and ‘ \circ ’ was 1.5 g/mL of pre-treated EFB added.

3.2 Closed-circuit evaluation

The real evaluation of an MFC or general fuel cell, is by testing the system over several resistance value. Figure 3 shows the resistance test using varied resistant value and each voltage obtained was converted to power and current. After the maximum OCV of mixed culture was achieved as shown in Figure 3 (a), the different resistance (5 mins for each interval) was applied to the system in order to obtain power density and current density. By changing the resistance, a new voltage will be obtained and hence a new power density at that resistance as shown in Figure 3 (a). The figure shows that the ‘power overshoot’ phenomenon occur at the early stage of applying resistance. The power decrease quickly to 0.011W from 0.016W. However, the calculated power was stable by giving 0.012W when applied resistance of 30000 Ω to 70000 Ω . It was reported that ‘power overshoot’ is probably due to anode potentials changes which related to the unstable electrical activity occurs within microbial biofilm formed on the anodic electrode gradually over the time of operation (Zhu et al., 2013). However, the phenomenon is still in the process of understanding.

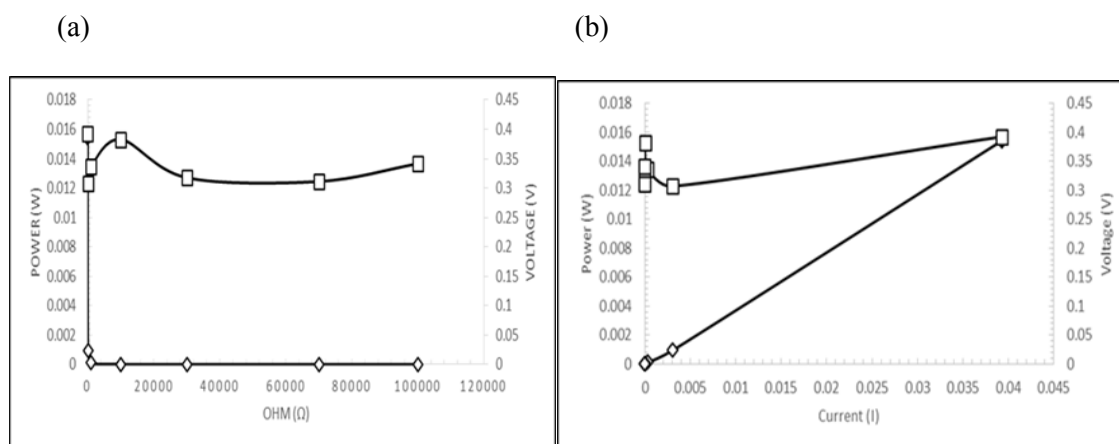


Figure 3. Power and voltage profile. (a) Power (P) and voltage (V) obtained vs resistant value applied in closed-circuit operation. (b) Power (P) and voltage (V) curve against calculated current (I) from measured voltage (V). ‘ \square ’ indicates power and ‘ \diamond ’ indicates voltage respectively.

3.3 EFB vs other lignocellulosic biomass

Based on Table 1, previously we have shown that from the same pre-treated EFB, we can extract approximately 0.002 W of power value using a different MFC design which was a single chamber with air-cathode. In the present evaluation, using the dual chamber MFC, we were able to obtain 10-fold of the single chamber MFC and in fact 100-fold higher compared to recent reported MFCs (Krisnaraj et al., 2015; Ma et al., 2015; Mahmood et al., 2015). However, since our system was conducted in a batch-mode, a total comparison with the fed batch system is quite unfair. In addition, the operating MFCs were different in terms of designs and electricigens used, which makes comparison even more difficult. On the contrary, all MFCs show promising impact on the future energy development.

3.4 EFB to Electricity

Based on the conversion of EFB to power in this study, from 1.375 g or 5.5 g/L of pre-treated EFB, maximum power of 0.016 W can be obtained which if calculated shows a value of 0.0012 W per 1 g of substrate. If the power that can be generated from 1 kilotonnes of EFB is estimated, approximately 1.16 kW of power can be extracted, which is enough to power most electrical appliances. Meanwhile, at present only few MFCs have been proven to be able to produce significant amount of power using wastewater in pilot scale which produced power in the range of 0.4 to 51 W/m³ (Tota-Maharaj and Paul, 2015; Wu et al., 2016; Jiang et al., 2010). The present MFC conducted is very promising to be scaled-up for pilot plant based system. However, the difficulties of sustaining the power produced in prolong period and considering cost efficiency of pre-treating the EFB will indeed have impacts in scaling-up or commercialization purpose.

Table 1. List of different types of lignocellulosic biomass used for MFC application.

Type of lignocellulose biomass	Type of MFC used	Mode of operation	Max power (W)	References
Rice straw	V-shaped MFC	Fed Batch	1.1×10^{-4} W ^a (112 mW/m ³)	Ma et al., 2015
Sugar cane bagasse	Three chamber MFC	Fed Batch	1.3×10^{-4} W ^a (8.78 W/m ³)	Krisnaraj et al., 2015
Corn cob	Same as above	Fed Batch	1.0×10^{-4} W ^a (6.73 W/m ³)	Same as above
Empty fruit bunch	Single chamber MFC	Batch	1.9×10^{-3} W ^a (0.678 W/m ²)	Mahmood et al., 2015
Empty fruit bunch	Dual chamber MFC	Batch	1.6×10^{-2} W	This report

^a indicates calculated power based on the reported value and volume of the anodic chambers used.

4. Conclusion

It was observed that complex substrates such as lignocellulosic biomass is possible to be utilized for power production in MFC system. However, the impact of sustainability and cost efficiency of the MFC system, in addition of the occurrence of power overshoot over high current observed in the MFC operation pose a great challenge to overcome.

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